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Edited by

N. VAN DER SCHRAAF

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PREFACE

Last year the Netherlands Geodetic Commission decided to mark its hundreth anniversary, 20th February, 1979, with some kind of celebration. In the hundred years of its existence the Commission has not sought much publicity for its work. It is true that the publications and annual reports of the Commission, issued at home and abroad, put its work on record, but the vital role of the Commission in advancing geodesy in The Netherlands and encouraging international cooperation in geodesy was, and still is, too little known by many geodesists. Consequently, the centenary of the Commission provided a welcome opportunity to make its work better known.

The celebration itself had a dual character, firstly, a one-day symposium and secondly, the publication of a memorial volume. The themes chosen for the symposium, held 15th March 1979 were, geodesy in its relation to geophysics, astronomy and satellite geodesy, and the mathematical developments associated with these topics. Besides the addresses and lectures delivered during the symposium, the memorial volume contains a detailed account of the work carried out by the Commission, or under its auspices, during the last hundred years. In addition, the volume contains articles in which personal and ex-officio members give their views on certain scientific aspects of geodesy and its application by the various government geodetic services. Related scientific fields are also discussed.

I would like to take this opportunity to thank all those who contributed to the success of the symposium or submitted articles for the memorial volume. In particular, mention should be made of the assistant-secretary of the Commission, Mr. N. VAN DER SCHRAAF who, in a comprehensive article, has recorded the history of the Commission and, as editor of the memorial volume, spared neither time nor pains to present this publication in its present form. The valuable help of Mr. J. CARR (Langport, Somerset, U.K.) in revising the English idiom is gratefully acknowledged.

Finally, many thanks are due to the firm W. D. MEINEMA for the fine craftmanship they showed in printing the memorial volume.

G. J. BRUINS

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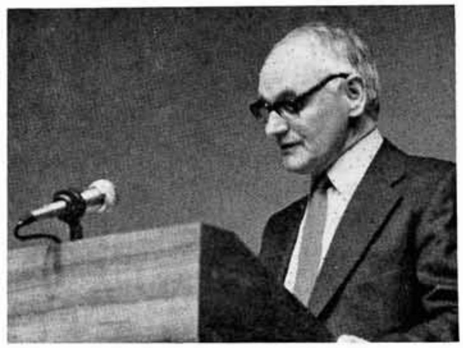
PART I

CENTENARY CELEBRATION ON 15TH MARCH 1979



1 OPENINGSWOORD VAN DE VOORZITTER VAN DE COMMISSIE, Prof. ir. G. J. BRUINS
Opening address by the President of the Commission,

Dames en Heren,
Hartelijk welkom op deze bijeenkomst ter herdenking van het 100-jarig bestaan van de Rijkscommissie voor Geodesie. Unaniem hebben de leden van de Commissie gemeend, dat aan dit feit enige ruchtbaarheid mocht worden gegeven, niet alleen in eigen kring maar ook daarbuiten. Het verheugt me op deze bijeenkomst te kunnen begroeten:

- de vertegenwoordiger van de Minister van Onderwijs en Wetenschappen Mr. GOEDHART, Hoofd van de Directie Ruimteonderzoek, technologie en oceanografie.
- de vertegenwoordiger van de Minister van Defensie de Schout bij Nacht KREFFER, chef der Hydrografie.
- de voorzitter en waarnemend voorzitter van het College van Bestuur van de Technische Hogeschool, de heren DE HART en SCHWARZ, wier gastvrijheid we vandaag zeer op prijs stellen.
- U, Professor ROELOFS, oud-secretaris en oud-voorzitter van onze Commissie gedurende een lange reeks van jaren. Ook een hartelijk welkom tot de andere leden van onze Commissie.

Welkom ook aan professor VAN DE HULST, voorzitter van de Nederlandse Commissie van Geofysica en Ruimteonderzoek van de Koninklijke Academie van Wetenschappen; aan Ir. PRINS, voorzitter van de Nederlandse Commissie voor Zeeonderzoek van de Koninklijke Academie; aan de heer KORDES, voorzitter van de Bestuurlijke Overleg Commissie Overheids-Automatisering.

De voorzitters van de Nederlandse Vereniging voor Geodesie, Professor BOGAERTS, van de Nederlandse Vereniging voor Fotogrammetrie, Dr. LIGTERINK, van de Nederlandse Vereniging voor Kartografie, de heer PIKET, van de Stichting Nederlands Genootschap voor Landmeetkunde, de heer HOOS en van het Landmeetkundig Gezelschap "Snellius" de heer VERSLUYS, heten we eveneens van harte welkom.

A special word of welcome to our guests from abroad. To the President of the International Association of Geodesy, Professor Kukkamäki, to the General-Secretary of this organization, Monsieur Louis, to the Presidents of the Geodetic Commissions of Germany, Professor Heupel, of Switzerland, Professor Schürer and of Denmark Dr. Kejlsø. And last but not least to Professor Melchior from Brussels, to Professor Bjerhammer from Stockholm and to Dr. Aardoom from our own country, who have kindly consented to lecture today. We are honoured that you all have accepted our invitation and will take part in the celebration.

The Commission felt that for this memorable day a theme should be chosen that would place geodesy in a broader scope of science, namely geophysics, astronomy and mathematics. Due to the continuous increase in the accuracy of measurements, geodesy is becoming more and more dependent on investigation in those fields of science. On the other hand it seems that geodesy sooner or later can contribute to the solution of geophysical and especially of geodynamical problems.

Professor Melchior and Professor Bjerhammer are internationally so well known as geophysical and mathematical specialists that our only hesitation in asking them to give a lecture was that we would take too much of their time.

The Commission also felt that attention should be given to the special field of satellite geodesy, which has developed so enormously during the last twenty years and has for example already contributed much in obtaining a better knowledge of the gravity field of the earth. Through the work of Dr. Aardoom and his group the technique of observing satellites by means of lasers has been brought to a high level in this country. For this reason we have asked Dr. Aardoom to tell us something about the characteristics of this field of research.

Before starting on this essential part of our meeting, I should like to say a few words about the history, the present task and the structure of our Commission, especially for those of you who are not acquainted with the Commission or with geodesy. This subject involves the Dutch so particularly that I must ask our foreign visitors to excuse me for adressing our Dutch guests in their own language for the next few minutes.

De geschiedenis van de Commissie bestaat in grote trekken uit twee delen. De eerste halve eeuw, van 1879 tot 1930 had zij niet alleen een wetenschappelijke en adviserende taak, maar ook – en vooral – een uitvoerende taak op het gebied van waterpassing en triangulatie.

De *primaire waterpassing*, in 1878 van haar leiding beroofd door het overlijden van Dr. COHEN STUART (van 1864 tot zijn overlijden hoogleraar-directeur van de Polytechnische School), kwam dadelijk bij de oprichting van de Commissie onder haar directe leiding te staan. Ook werd zij belast met het toezicht op de primaire driehoeksmeting, in 1866 door Dr. STAMKART begonnen en in 1881 bij zijn overlijden bijna voltooid. De *waterpassing*, de zgn. eerste nauwkeurigheidswaterpassing werd in 1886 beëindigd. De verdere werkzaamheden, nodig voor de bijhouding van de waterpassing werden daarna overgedragen aan de Directie Algemene Dienst van de Rijkswaterstaat. De *driehoeksmeting* van Stamkart – aan een kritisch onderzoek onderworpen door de Commissie – werd in 1885 afgekeurd en in 1886 gaf de Regering toestemming voor het uitvoeren van een nieuwe primaire en – later ook – van een secundaire driehoeksmeting in eigen beheer. Vierenveertig jaar later, in 1930, had de Commissie geheel aan haar opdracht voldaan. Gedurende deze tijd had de Commissie vele civiel-ingenieurs, Delftse studenten en terreinhulpen in dienst. De verdere zorg voor het vaste-punten-net van naar ik meen 7000 punten werd overgedragen aan de Dienst van het Kadaster, toentertijd ressorterende onder het Ministerie van Financiën.

De primaire driehoeksmeting moest, om aan haar wetenschappelijk doel – de bepaling van de vorm en de afmetingen van de aarde – te kunnen voldoen nog worden aangevuld met astronomische lengte-, breedte- en azimutbepalingen. Deze metingen werden ook in het einde der vorige eeuw verricht, door of onder het wakend oog van Leidse en Utrechtse astronomen, die vanaf het oprichten van de Commissie hierin zitting hadden.

Toen dan in 1930 ook het tweede grote project, de driehoeksmeting, was voltooid, leek het erop alsof de Commissie in een zeker vacuüm zou vallen, ware het niet, dat juist aan het einde der 20er jaren en vooral in de 30er jaren de ogen van de internationale geodetische wereld waren gericht op het zwaartekrachtsonderzoek op zee van VENING MEINESZ, dat hij onder de auspiciën van de Commissie uitvoerde. Dit onderzoek, eveneens gericht op de vormbepaling van de aarde, had ook een sterk geofysische inslag.

In diezelfde tijd vond in de Commissie intern beraad plaats over haar taak en doelstelling nu de grote projecten, de primaire en de secundaire driehoeksmeting, waren voltooid. Vooral de leden SCHERMERHORN, TIENSTRA en VENING MEINESZ waren hierbij betrokken. De Commissie (en met haar ook de Regering) vond dat zij niet meer beantwoordde aan de stand van zaken. Haar naam, nog steeds Rijkscommissie voor Graadmeting (lees: driehoeksmeting) en Waterpassing zeker niet en de oorspronkelijke taakstelling evenmin. Men voelde evenwel behoefte aan een orgaan dat de wetenschappelijke taak der Commissie voortzette en tevens coördinerend zou optreden ten opzichte van de verschillende takken van Rijksdienst op geodetisch gebied. Bij het K.B. van 5 oktober 1937 werd de Rijkscommissie voor Graadmeting en Waterpassing omgedoopt in Rijkscommissie voor Geodesie met als taak de behandeling van de vraagstukken van wetenschappelijke en praktische aard op geodetisch gebied. De uit deze taak voortvloeiende werkzaamheden konden zo nodig onder haar leiding worden uitgevoerd. Tevens diende de Commissie, desgevraagd, advies te geven aan takken van Rijksdienst. En vervolgens had zij zich, zo nodig, te vertegenwoordigen in de bijeenkomsten of bij de werkzaamheden van wetenschappelijke organisaties op geodetisch of aanverwant gebied.

De samenstelling van de Commissie werd op deze taak afgestemd. Vertegenwoordigers uit het wetenschapsgebied der geodesie, maar ook uit dat der astronomie en der geofysica werden als persoonlijke leden benoemd. Daarnaast had de Commissie ambtshalve leden, hoofden of directeuren van ambtelijke diensten nl. de Algemene (thans Meetkundige) Dienst der Rijkswaterstaat, het Kadaster, de Hydrografische en Topografische Dienst en de toen nog bestaande Triangulatiedienst der Artillerie. Later heeft ook de hoofddirecteur van het K.N.M.I. als ambtshalve lid in de Commissie zitting genomen.

De tweede wereldoorlog heeft spoedig daarop de werkzaamheden van de Commissie voor een groot deel lam gelegd, maar in 1946 reeds werden door de leden nieuwe wetenschappelijke projecten geëntameerd b.v. door TIENSTRA: de opname van het Nederlandse primaire driehoeksnet in de gezamenlijke hervereffening van de Europese driehoeksnetten, door ROELOFS: de introductie van Laplace punten in het Nederlandse primaire driehoeksnet ter versteviging hiervan. Door VENING MEINESZ werd het zwaartekrachtsonderzoek ter zee weer op gang gebracht. Zo zou ik kunnen doorgaan met op te noemen welke initiatieven op geodetisch gebied in de loop van de daarop volgende jaren tot heden toe door de persoonlijke en de ambtshalve leden zijn aangedragen en gerealiseerd. Enkele voorbeelden mag ik misschien nog noemen:

1. De omrekening van de coördinaten van de driehoeksmeting van stereografische projectie naar de wereldomvattende Universele Transversale Mercatorprojectie.
2. De aanleg van een ijkbasis voor lengtemeting in de Loenermark, volgens het interferentieprincipe Väisälä en gemeten door onze Finse collega's KUKKAMÄKI en HONKASALO.
3. De meting van een basis op de afsluitdijk ter versteviging van het noordelijk deel van het primaire driehoeksnet in het kader van het Europese driehoeksnet.

4. De aanleg van verschillende ijkbases voor het ijken van zwaartekrachtsmeters.
5. De deelname aan een tweede hervereffening van het Europese driehoeksnet, van het Europese waterpasnet, van een Europees zwaartekrachtsnet.
6. De krachtige voortzetting van het zwaartekrachtsonderzoek ter zee en te land.
7. Evenzo op geodetisch-astronomisch gebied o.a. de astronomische lengte- en breedtebepalingen van vrijwel alle primaire punten van het Nederlandse driehoeksnet.
8. Vraagstukken betreffende bodembewegingen in Nederland en betreffende het gemiddeld zeeniveau.

Al deze onderzoekingen en werkzaamheden konden slechts tot stand komen door een goede samenwerking van alle leden, zowel persoonlijke als ambtshalve. De dank van de Commissie gaat uit naar de geodetische diensten die dikwijls personeel en instrumenten inzetten om de plannen te realiseren. Ook naar de Afdeling der Geodesie van de Technische Hogeschool en naar het Laboratorium voor Geodetische Rekentechniek waar vele geavanceerde en statistische methoden betreffende precisie en betrouwbaarheid van geodetische metingen werden geïntroduceerd. Ook dankt de Commissie de Koninklijke Marine en in het bijzonder de Hydrografische Dienst, die steeds doorgaat haar personeel en haar opnemingsvaartuigen in te zetten ten behoeve van geodetisch onderzoek.

Veel van deze onderzoekingen en werkzaamheden worden verricht in subcommissies en werkgroepen, als bijvoorbeeld de:
- subcommissie Triangulatie
- subcommissie Bodembeweging
- subcommissie Zwaartekrachtonderzoek
- subcommissie Mariene Geodesie
- werkgroep Plaatsbepaling
- werkgroep Doppler-satellietwaarnemingen.

Op één belangrijk aspect van de werkzaamheden van de Commissie wil ik nog gaarne ingaan. Naast genoemde geodetische onderwerpen, welke alle in meer of mindere mate een mathematisch-fysische en instrumentele achtergrond hebben komen sinds een 10-tal jaren ook vraagstukken van een geheel ander karakter in de Rijkscommissie naar voren. De toenemende intensivering van het grondgebruik door overheid en particulieren vereist uniform kaartmateriaal en onderling overeenstemmende kaartgegevens. En daar blijkt in Nederland nog maar al te veel aan te ontbreken. Als gevolg van vele discussies en een rapport over dit onderwerp, waarbij ook de Rijkscommissie nauw betrokken was, is in 1975 een Koninklijk Besluit verschenen tot invoering van een Grootschalige Basiskaart en tot instelling van een Centrale Karteeringsraad. Thans worden in verschillende delen van Nederland door de Dienst van het Kadaster en de Openbare Registers uitgebreid proeven genomen met de vervaardiging van deze kaart. Maar de maatschappij vraagt om een nog uitgebreidere en meer algemene informatie met betrekking tot vastgoed. Hoe aan deze algemene vraag te voldoen wordt thans bestudeerd door de door de Rijkscommissie ingestelde werkgroep „Uniformering van de codering, classificering, nauwkeurigheidsaanduiding en generalisering van geodetische gegevens met betrekking tot vastgoedsystemen", ingesteld in 1974. Inmiddels heeft deze werkgroep een studie-opdracht van de Bestuurlijke Overlegcommissie voor Overheids-Automatisering (de B.O.C.O.) aanvaard. De Rijkscommissie stelt dit contact zeer op prijs.

Over een ander vraagstuk eveneens van grote maatschappelijke betekenis zal eveneens een studie worden gemaakt nl. om te komen tot instelling van een orgaan of autoriteit aan wie de totstandkoming van een meetkundige grondslag en de bewaking van de positiebepaling op het continentale plat van de Noordzee kan worden toevertrouwd. Een soort Noordzee-kadaster dus. Overleg over deze materie in de Rijkscommissie heeft geleid tot de instelling van een stuurgroep met vertegenwoordigers van de Ministeries van Defensie, Verkeer en Waterstaat, Volkshuisvesting en Ruimtelijke Ordening en Economische Zaken.

Centenary celebration, 15th March 1979

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2 ADDRESS BY THE PRESIDENT OF THE INTERNATIONAL ASSOCIATION OF GEODESY, PROF. DR. T. J. KUKKAMÄKI

Mr. President, Members of the Rijkscommissie voor Geodesie, Ladies and Gentlemen,
We are all happy to have the opportunity to participate in the 100th anniversary of the Geodetic Commission of The Netherlands. In saying a few words on behalf of the International Association of Geodesy I will not go back to the time before the birth of this Association, and must therefore not mention your famous geodesist, the originator of triangulation, SNEL VAN ROYEN. But I have a very good reason to mention another Dutch scientist, the director of the Leiden Observatory, VAN DE SANDE BAKHUYZEN, who served as the Secretary General of the International Association of Geodesy from 1900 to the end of 1916. As we all know, the secretary of an organization is usually more important than the president, especially when a secretary remains in office for a relatively long period, as was the case with BAKHUYZEN. In addition, the period BAKHUYZEN served the IAG was exceptionally important, and even dramatic. It included the 50-year Congress in Hamburg, where numerous important decisions were made, the years of the First World War, and finally the expiration of the governmental convention of the International Association of Geodesy. It was due to VAN DE SANDE BAKHUYZEN's efforts that international geodetic activity continued as well as possible under wartime conditions. In addition, he was the main organizer of the Reduced Geodetic Association of the Neutral Nations, which kept international geodetic activities alive in the interim. This association was mainly concerned with the polar motion service, before the International Union of Geodesy and Geophysics was established in 1919 and its associations were organized.

In this present period of the 120-year existence of the IAG, a Dutch scientist again played a leading role in a dramatic phase, during the fateful years of the Second World War. The famous gravimetrist F. A. VENING MEINESZ presided over the IAG from 1933 over the whole war time up to 1948. We thus see how the great members of a small nation have taken care of affairs while big nations have fought against each other.

I will not use too many minutes of this important, solemn day to list the other geodesists from The Netherlands who have in many ways promoted international geodetic work by serving in different organs of the IAG. I only express the deep gratitude of the IAG to the Rijkscommissie voor Geodesie and to the geodesists of The Netherlands for their valuable and important contribution during the one hundred years of the Rijkscommissie's existence.

Our dear President permitted me to say some words on behalf of the Geodeettinen laitos, the Finnish Geodetic Institute. This is a special pleasure as the Rijkscommissie and the Geodeettinen laitos have worked in close cooperation for many years. The first and most important form of cooperation was the friendship and collaboration between VENING MEINESZ and HEISKANEN. Then I may recall the baseline measurement carried out by HONKASALO and myself at Loenermark, where we then learned, at least, to pronounce the name of your airport, Schiphol.

In addition, there is a form of cooperation which we in Finland appreciate very much. For 17 years one student from Delft every year has worked at our institute for his training abroad. Our scientists have only pleasant memories of these energetic and friendly representatives of your university and your fine country. I will not mention all of them. But of course, we especially remember the first one, PUTMAN, who has a daughter with a Finnish name, HELMI, which means pearl. Then later we almost got a shock when Mr. HENDRIK SCHOK came to our institute on our fiftieth anniversary. We are somewhat disappointed to notice that none of your boys has married a Finnish girl. For instance VAN ANGELEN brought his bride from as far as Surinam and held his wedding in Helsinki. All these young fellows have brought our two institutions very close together and we are thankful for this.

The Board of the Geodeettinen laitos has written the following letter to the Rijkscommissie.

The Geodeettinen laitos in Finland would like to offer its congratulations to the Rijkscommissie voor Geodesie on the occasion of its 100th anniversary in recognition of the important work it has carried out. We are grateful for the cooperation we have received from the Rijkscommissie and from individual Dutch geodesists.

3 Lecture by P. MELCHIOR *)
INTERRELATIONSHIP BETWEEN GEODESY, GEOPHYSICS AND ASTRONOMY

Geodesy is one of the oldest sciences and its techniques are amongst the oldest in the history of science. Already two centuries before Christ, ERATHOSTENES put into practice the first geodetic principles. Then, for several centuries the Arabs kept this science alive until the great era of navigation discoveries gave also strong impact to earth sciences. But the role of Dutch scientists was important, as the very start of geodesy as a modern science is due to a Dutchman SNELLIUS (WILLEBRORD SNEL VAN ROYEN) who in 1615 established the principle of triangulation and measured in this way an arc of 1°11'5 between Bergen op Zoom and Alkmaar including a base measured in the vicinity of Leiden. Also the mechanical theory of the pendulum by CHRISTIAN HUYGENS had a considerable influence by introducing the first precise timekeepers which allowed the development of fundamental astronomy and geodesy.

From that time geodesy has attracted the sagacity of genial scientists like GAUSS, BESSEL, MAUPERTUIS, CLAIRAUT and LAPLACE, not only because of the beauty of the difficult mathematical problems it raised, but also because of the imaginative experimental procedures it suggested. The history of geodesy is thus extremely rich and it would be indeed a great temptation to describe it at length today when we are celebrating the centennial anniversary of the Geodetic Commission of The Netherlands. However, I have thought that it would be more appropriate to look into the future rather than in the past, considering indeed the dynamism of the Dutch Commission which is so well prepared to add new successes to its long distinguished history in geodesy. It is during the second part of this century that the extraordinary development in all the earth sciences has given to geodesy its real place.

Geodesy, the science devoted to the description of the figure and size of the planet earth and to the determination of coordinates of any point on its surface in a precisely and carefully defined system of reference could not be reasonably developed without any reference to the other earth sciences. It is indeed by the exchange of new ideas and new discoveries made in the different fields that the recent impressive progress has been accomplished. The extraordinary technological developments of the last twenty years are offering the geodesists powerful means to solve simultaneously problems of major economic importance and problems of major geophysical interest. In this respect one has never to forget that when the precision of measurements is increased to such a level as now, the mathematical support which is necessary for the interpretation must also be developed with extreme rigour.

One has to be well aware that the precision now required for practical tasks like the deter-

*) Observatoire Royal de Belgique, Brussels.

mination of boundaries of oil exploration areas at sea and relocation of marine oil rigs can not be achieved unless the basic problem of the frame of reference and the time-scale are solved with the highest precision.

Another problem of major concern, the prediction of earthquakes, requires the measurement of relative changes of position in seismic areas and relative motions of tectonic plates with a precision of 1 cm/year. This again, beyond the evident requirements for the net precision of the measuring instruments, raises the problem of the frame of reference as most essential. It is clear that as long as we were not asked to give this information with a precision better than, let us say 50 metres, there was no great problem in satisfying the conditions. Nevertheless a number of elementary astronomical operations are necessary to define the directions of the axis while the position of the origin remains uncertain unless artificial satellites are observed. This basic preliminary operation is the first contact of geodesy with fundamental astronomy. Both fields were developed together and it is difficult to trace a firm demarcation between them.

This is the evident reason why every geodetic organization always attracted the most distinguished astronomers. I would nominate here amongst the most famous, members of the Rijkscommissie voor Geodesie: KAPTEYN, DE SITTER, OORT who was also a prestigious president of the International Astronomical Union.

As soon as the precision needed is better than 30 metres serious problems arise in the correct definition of the axes in their positioning. This system of axes must also be defined in such a way that the equations describing the motion of artificial satellites with respect to it will be as simple as possible. Moreover these equations contain derivatives with respect to the time which is supposed to be everywhere available and uniform. All our observations will be referred to this system of axes and with respect to a supposed uniform time-scale. Again this should raise no special difficulties if the earth were a perfectly rigid body turning with constant speed around its principal axis of inertia. The complicated structure of our planet with gaseous atmosphere, its oceans, its drifting tectonic plates and slowly convecting mantle, its convecting fluid core, makes these ideal conditions completely illusory.

We must accept the idea that neither the axis of inertia, nor the axis of rotation are fixed within a permanently deforming planet and that the rotational speed itself cannot be constant and consequently can not be used as a timekeeper. Because the laws of the motions in the atmosphere and oceans as well as within the liquid core or the mantle are yet poorly known we are unable to prepare an ephemeris which should allow us to predict the axis' wandering and the rotation speed fluctuations.

This is the reason why, at the very beginning of the development of modern geodesy, not long after the foundation of the International Geodetic Association, one of the first world enterprises of this association was to establish in 1890 the International Latitude Service which was organized for monitoring the motions of the pole of rotation at the surface of the earth. This was a first geodetic step towards geophysics and the problems of the earth's interior. It is exceptional that such a programme which was envisaged initially for a limited period of time has been continued until now, that is for 80 years, in the same observatories with the same programme. It is astonishing that despite the world political convulsions it did not suffer any interruption. The danger had however been very serious during the First World War and it must be remembered today that the continuity, which is now considered as without price, was ensured thanks to the tenacity and energy of the at that time secretary of the International Geodetic Association (1900–1916) and president of the Netherlands Geodetic Commission, Professor H. G. VAN DE SANDE BAKHUYZEN who became indeed the secretary of the so-called Reduced Geodetic Association among Neutral Nations from 1916.

The polar motion phenomenon has raised very considerable interest amongst theoretical seismologists and the existence of a series as long as 80 years, thanks to the initiative of the IAG, has allowed them to derive very important conclusions concerning the rheology of the earth's interior. Since the very beginning of these investigations there was indeed a great concern about the role of a fluid core on the lengthening of the famous Euler period of 305 days to the observed 435 days. The development of our knowledge of the core structure has been considerable during the last ten years but some features are still uncertain like its possible density stratification or are still practically unknown like its viscosity (we just know that it is problably very low).

It is not clear where the polar motion energy is dissipated – the oceans, the mantle or the core are possible sinks – but the source of excitation is as obscure. The role of the atmosphere or of the seismic activity is a matter of great concern for astronomers, geodesists and geophysicists. Here, most probably lies one of the keys for understanding major processes inside our planet.

According to the computations of DAHLEN the result of the big Chile earthquake of 1960 is an excitation specified by a magnitude of 0″010 with azimuth 110°E while the Alaska earthquake (1964) produced an excitation magnitude of 0″005 only with azimuth 193°E, surely a too low level of excitation to maintain the free motion of the pole.

The most recent analysis of the polar motion by WILSON and HAUBRICH (1976) has indicated a period of 435.2 sidereal days for this free motion (called Chandler motion) with an uncertainty of ± 5.2 days at 90 per cent confidence level. The Chandler period as derived from seismological earth models by M. L. SMITH (1977) is 403.6 sidereal days to which an oceanic contribution of 27.6 days (according to DAHLEN) must be added which gives 431 days. The agreement with the observed period is good. This theoretical investigation shows that the fluid outer core essentially abstains from rigid rotation with the mantle during the Chandler wobble which means that at this frequency pressure coupling is relatively inefficient. Another result of the theoretical investigations is that the Chandler period does not depend strongly on the details of density stratification of the outer core and would therefore appear to be of limited utility as a gross earth inverse datum (D. L. SMITH).

But it is important to note that there is a narrow range of frequencies in which core-mantle pressure coupling efficiently connects the core rotation to the mantle rotation by the nearly resonant excitation of the fluid core's tilt-over mode. This range of frequencies falls inside the diurnal part of the earth tide spectrum.

However, other physical processes have not been taken into account yet: viscosity of the core, non-elliptical topography of the core-mantle interface, dynamo action within the core.

The present state of precision of the observations of the polar motion, of the nutations and of the earth tides shows that the analysis of these phenomena could provide us with new possible tools to investigate these properties but that the precision of measurements must still be improved to provide new constraints helping to define these aspects of the core constitution. Fortunately we can already say that the high precision instruments needed already exist: the laser ranging devices, the astronomic radio interferometry (Very Long

Base Interferometry – VLBI or Connected Element Interferometry – CEI) and the cryoscopic supraconducting gravimeter.

For about ten years the tracking of navigation satellites based upon the measurement of the Doppler shift of radioelectric frequencies has made possible a considerable improvement in the determination of the polar motion but it does not appear as the definitive solution. We may guess that this solution will be provided by laser ranging and very long base interferometry using extragalactic radio sources of unlimited lifetimes, and referring in this way to the most nearly inertial frame of reference presently known. The equipment needed and the analysis of the immense flow of data are evidently very expensive and it is not yet clear how the investment can be made to organize world nets of observing stations and computing centres. The National Ocean Survey of the US National Oceanic and Atmospheric Administration has begun a project, designated POLARIS (Polar motion Analysis by Radio Interferometric Surveying), to establish and operate a three station network of permanent VLBI observatories to monitor polar motion and UT1. The system should be capable of determining coordinates of the pole to better than 10 cm over an averaging period of 8 hours. Very fortunately such techniques are also now introduced in Europe e.g. at Kootwijk Observatory for the laser ranging and Dwingeloo for the VLBI.

The coupling mechanism between core and mantle is evidently the key of the problem of the earth rotation anomalies. Three mechanisms of coupling are proposed: inertial and topographic, viscous, electromagnetic. The only information we have at present concerning the inertial and topographic couplings are all of geodetic origin. It is clear that if the core mantle boundary was perfectly spherical and the core material inviscid, no movement could be transmitted from the mantle to the core and vice versa. The two media could rotate independently. However the Clairaut theory, which is the fundamental theory in dynamical geodesy, allows us to calculate, by numerical integration, the ellipticities of the equipotential surfaces inside the earth on condition that the outside surface flattening as well as the density distribution are known. One finds in this way a flattening 1/400 for the core-mantle interface but this rests on the hypothesis that the earth is in hydrostatic equilibrium – which is not strictly true. Such a flattening corresponds to a difference of 9 kilometres between the equatorial and polar radius of the core, a difference which the seismological techniques have not been able to measure. Thus the only available information at the present time is of geodetic nature. Evidently if a fluid is contained inside an elliptical cavity the motion of the mantle may be transmitted to it by pressure effects.

It is moreover evident that this fluid which is a mixture of iron and some lighter element (probably sulphur) at or near its eutectic point, exhibits some viscosity and we should thus consider the existence of a boundary layer. In this layer there is a strong velocity gradient which allows the adjustment of the internal fluid flow to the movement of the lower mantle elastic boundary. *Dissipation* takes place inside this boundary layer, the thickness of which is proportional to the square root of the viscosity while *resonance* may happen when the oscillations of the boundary have a period very near to the period of free oscillations of the fluid in its container.

The possibility of resonance has been suspected indeed since the time of the discovery of the polar motion and a number of beautiful mathematical analyses were constructed by HOUGH, SLUDSKY and POINCARÉ. The problem was considered again under the impulse given by JEFFREYS and numerous papers by many distinguished authors have been published since the Geophysical Year which lead to the conclusion that this effect is indeed observable in the form of perturbations of the amplitudes of some earth-tide waves having their period close to the resonance period (23 hours 56 minutes) and of the amplitudes of the associated astronomical nutations.

The theoretical models calculated by MOLODENSKII, which were reconfirmed by the calculations of MANSINHA, PO YU SHEN and M. L. SMITH are in very good agreement with the earth tide observations conducted with gravimeters, horizontal pendulums and extensometers and with recent NASA VLBI observations related to the nutations.

The problem still pending concerns one of the tidal waves, unfortunately of very small amplitude (wave ψ_1) associated with the annual astronomical nutation, which, because it is extremely near to the resonance frequency could give direct information about the viscosity if observed with more precise instruments. We may hope that the cryoscopic supraconducting gravimeter on one side (earth tides) and the VLBI on the other side (nutations) will give us this possibility.

Another major information about the core mantle interface can be derived from physical geodesy. It is to VENING MEINESZ that gravimetry owes the most of its power as a geodetic technique for investigating the internal structure of the earth. The extraordinary development of spatial geodesy during the last twenty years has permitted one to derive from the perturbations of the satellite orbits a rather detailed description of the earth's gravity field in the form of a development in Legendre spherical polynomials. This model of the equipotential surface of the earth called the Standard Earth contains at present more than 500 terms, from the order 2 to the order 30 or more.

The gravity field evidently reflects the internal density structure of the earth and it may reasonably be suspected that the terms of lower order ($n = 3, 4$) have their origin in very deep density lateral heterogeneities at the level of the core-mantle boundary while the terms of order 5 to 8 may be explained by lateral density heterogeneities of the transition zones at 400 km and 670 km depth. According to these lines BOTT has shown that a temperature difference of only 4.5 °C at the depth of 400 km should displace the crystallographic transition level by 1 km and would produce in this way an anomaly of 11 milligals. HIDE has calculated that corrugations of the core mantle boundary of one to two kilometres height could explain the spherical harmonics of order 3 and 4.

It is clear that such corrugations, if they exist, should play a considerable role in the core mantle topographic coupling as well as in the region of hydrodynamical flow inside the core and therefore in electromagnetic coupling. The correlations between irregularities of the rotation speed of the earth and the magnetic field are highly suggestive in this respect.

I would like now to return briefly to the problem of earthquake prediction – which is presently of enormous interest because of its human involvements and because political authorities are now very sensitive to this problem. I would like to show how geodesy will play a major role in the detection of the so-called precursors of big seismic events.

A typical seismic phenomenon, being the result of a mechanical stress which, in many cases, has been at work for a very long time, is preceded by deformations that are slow in the beginning, then accelerate or even take on quite another aspect in the last moments just before the earthquake itself. A number of geophysical signs resulting from such deformations have been identified and now serve as so many "primary precursors" to the accomplishment of an earthquake prediction, i.e. the determination of the date, site, magnitude and probability of an expected earthquake. Geodetic-type measurements cover a fairly wide range of techniques and seem to be well-suited to identify the most reliable precursors:

1. Uplifts of the earth's crust, as demonstrated by brief and repeated levellings as well as (along sea-coasts, of course) non-tidal sea level variations measured by tide gauges.
2. Progressive and reversible tilts of the ground, as evidenced by recording tiltmeters and confirmed by levellings. Hence the precursor signal is not so much the amplitude of the progressive tilt as the change in azimuth occurring some time before the earthquake. Publications concerning this "indicator" have been very numerous.
3. Deformation of geodetic triangulation networks. Such deformations can now be detected fairly quickly by repeated measurements of the length of the sides of the triangles. These measurements (which should be called trilateration rather than triangulation) are made by means of electronic distance-measuring instruments (tellurometers, geodimeters). Permanent monitoring of these deformations can also be ensured by the use of horizontal or vertical extensometers (invar wires and rods, quartz tubes, laser interferometers).
4. Local variations of gravity, which could be observed with the best traditional gravimeters, or better, by means of newly-developed, portable instruments (vertical throw or free fall) giving absolute measurements.

I feel that it would have been an impossible challenge for me to try to present some really original ideas here to such a distinguished assembly of scientists. Nevertheless I would try to show you some still unpublished results just obtained which surely are of modest impact on the present. But, considering the very rapid permanent improvements of technology, I am confident that they will be of some use before long.

Amongst the crucial phenomena in the tectonic processes are thus the possible secular or sudden uplifts of the crust. At first sight it does not seem too difficult to monitor vertical movements by repeating field gravity measurements providing that they will be of a very high precision. Sudden changes of gravity reaching 100 microgals or even more have been reported after some strong earthquake. Our main interest should be, however, for precursors because they could evidently offer a valuable tool for the prediction of earthquakes. In the case of precursory phenomena we can not expect large changes but possibly a small fraction of these. Therefore the measurements have to be precise to a few microgals, let us say even to 10 microgals, which is feasible with the most modern instruments equipped with electronic output. Supposing that this precision has been achieved during a given gravity profile, the reduction of the measurements must include an exact correction for the tidal variations which can reach 200 microgals (the amplitude is the greatest in equatorial and tropical regions) or more with periods near to 8, 12, 24 hours, 15 days, etc.

There is no problem actually to produce the correction for the global solid earth tide to a precision of one microgal by using a sufficiently good earth-tide model and taking into account the hydrodynamical effects of the liquid core. However, we are less sure by far about the interaction effect of the oceanic tides upon the earth tide, which are acting by their direct attraction on the instrument itself and by their loading effect upon the crust which is additionally deformed by it. A procedure allowing the calculation of these effects has been developed by FARRELL by using Green functions but it rests evidently upon the precise knowledge of the distribution of the tides in the open oceans and seas all around the world.

Something like eight maps describing the tidal oscillations of the water masses in the world oceans have been constructed by different authors by numerical integration of the famous Laplace tidal equations but their solutions diverge considerably from each other because of the introduction of different boundary conditions, friction laws or simply grid interval (1°, 4° or even 6°). The results of such computations presently diverge by so much that they are simply useless. Therefore we had no alternative but to check the computed effects by making direct measurements of the tidal loading with very precise and very carefully calibrated gravimeters. The success of this technique has been such that some authors have suggested solving the inverse problem, that is the improvement of oceanic tidal maps by applying to them as constraints the value of the loading vector observed with gravimeters or tiltmeters on the continents. It is already clear that amongst the existing maps one (the Parke map) is satisfactory for the European gravity net while another one (Hendershott map) is more satisfactory for Australia and the South Pacific.

What is surely remarkable is that all the obtained loading vectors (defined as the difference between the observed tide and the computed solid earth tide) are of the same order of magnitude over very large areas and that this magnitude fits very well with the loading computed from the oceanic tidal maps. The discrepancies with oceanic maps is in general in the phases. We give here as examples two samples of such results obtained for the main tidal wave M_2 (period 12 hours 23 minutes) which concern two very widely separated areas: Western Europe where the amplitudes are around 3 microgals and East Australia – New Zealand – South Pacific where the amplitudes reach 10 microgals.

Table I M_2 tidal load vector

	observed		calculated	
station	B	β	L	λ
Cambridge	2.45	68	2.93	60
Brugge	2.65	70	2.14	69
Bruxelles	2.01	64	2.09	63
Witteveen	1.90	41	1.48	57
Walferdange	1.84	56	1.95	61
Strasbourg	1.37	50	1.78	60
Paris	2.73	60	2.83	66
Clermont F.	3.22	58	2.72	71
Grasse	2.02	58	1.97	66
Bordeaux	5.79	74	4.08	80
Porto	5.10	110	7.26	110
Bonn	1.52	57	1.74	59
Hannover	1.28	51	1.31	57
Frankfurt	1.09	52	1.63	58
Chur	1.83	52	1.64	58
Torino	1.60	37	1.87	64
Graz	1.98	25	1.20	47
Pecny	1.06	32	1.16	48
Obninsk	0.95	−7	0.43	−3
Bergen	1.61	−133	1.30	−134
Trondheim	5.00	206	3.24	206
Bodoe	3.69	179	2.92	179
Helsinki	0.41	30	0.45	55
Sodankyla	0.47	105	0.65	106

Table II M_2 tidal load vector

	station	observed		calculated	
		B	β	L	λ
Java	Bandung	6.63	−17	5.51	− 3
Celebes	Ujung Pandang	4.69	−26	3.12	10
	Manado	6.47	− 2	5.63	8
N. Guinea	Jaya Pura	5.57	−17	5.82	−15
Papua	Port Moresby	4.93	− 6	3.55	− 8
Australia	Darwin	3.55	24	3.03	3
	Charters T.	4.02	−57	3.27	−11
	Armidale	3.62	−51	5.85	−43
	Canberra	3.42	−43	5.54	−43
Tasmania	Hobart	3.96	−65	3.12	−42
N. Zealand (S)	Lauder	1.68	−62	2.29	−88
N. Zealand (N)	Hamilton	8.28	−42	9.63	−59
N. Caledonia	Noumea	13.06	−36	8.91	−27
Fiji	Suva	11.66	− 5	11.03	−22
Samoa	Apia	14.42	−27	7.80	−22

Note to tables I and II
The "observed vector" (B, amplitude; β, phase) is obtained by subtracting from the observed tidal component a "theoretical" component calculated for a model earth composed by an elastic mantle and a liquid core (Molodensky model).

The "calculated vector" (L: amplitude; λ: phase) is obtained by the Farrell method on the basis of the Parke cotidal map for the European stations but on the basis of the Hendershott map for the Pacific area.

In these tables B and L are given in microgals, β and λ in degrees, the minus sign corresponding to a lag.

Reference: P. Melchior, M. Moens, B. Ducarme, M. van Ruymbeke- Tidal loading along a profile Europe – South Asia – Australia – South Pacific. In: Physics of the Earth and Planetary Interiors, 1979 (in press).

The coherency of the phases for such small vectors gives an impressive idea of the performances of the gravimeters (Geodynamics and LaCoste-Romberg). It should be mentioned that, at this level of precision, the barometric loading effect has also to be taken into account in gravity measurements.

I have reviewed only briefly some of the problems linking geodesy to astronomy and to geophysics but I hope this is sufficient to indicate new lines for further progress. Geodesy is a planetary science, this means that it is by essence multinational and that no country, even if very big in size and power can alone solve the scientific problems of the planet. Geodesy has a multidisciplinary impact. Indeed it could never be separated from fundamental astronomy and navigation. As an example the geodetic theories and techniques are now applied to determine the shape and gravity field of the moon and planets. The most recent developments have opened new multidisciplinary areas with seismology and with oceanography.

By the end of this year the International Union of Geodesy and Geophysics will have to decide upon the implementation of a new programme which should be a follow-up of the geodynamics programme. This new project, prepared in common with the International Union of the Geological Sciences, has an important geodetic segment referring precisely to problems like those of the frame of reference, very precise positioning and distance measurements for controlling tectonic movements, gravity survey control of uplift, tidal loading, etc. It is not unreasonable to hope that geodesists will succeed in giving a correct answer to these questions before the end of this century. This is surely what I wish all of you today.

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4 Lecture by L. AARDOOM*
SELECTED TOPICS IN SATELLITE GEODYNAMICS

Abstract

The development of ground-based satellite laser ranging has been instrumental in the evolution of satellite geodesy to satellite geodynamics. To contribute to the detection and monitoring of lithospheric plate mobility for earthquake research is one of the technique's potentialities. An outline is given of the kinematic phenomenon of lithospheric plate motion in relation to geodetic strategies of measuring it. Earth-orientation is indicated as a related topic both as regards its measurement by satellite laser ranging and its interpretation. Relative station positioning and earth-orientation are important components of a joint satellite geodynamic contribution to the study of lithospheric plate mobility.

1 Introduction

The impressive improvement of kinematic measurement precision in artificial satellite techniques over the past decade or so, contributed to the evolution of satellite geodesy to satellite geodynamics. Geodynamics in general is understood to be the science concerning the dynamic behaviour of the earth-moon system. We will restrict ourselves here to the earth as a gravitating deformable body, including however the hydrosphere and part of the atmosphere. Geodynamic phenomena are monitored by a variety of means. Of the geodetic means we will consider only the space techniques and out of these only the artificial satellite techniques (see Fig. 1). A break-down of current or potential artificial satellite techniques is given in Fig. 2; only earth-to-satellite laser ranging will be further elaborated here, however.

The most striking development of this technique is the improvement of its precision of measurement over the years since 1965 (see Fig. 3). A single shot-ranging standard deviation of about 10 cm is presently (1979) attainable; 3 cm is expected in the early eighties. The 3 cm level is critical in two respects: firstly, this level is technically feasible, although a further substantial progress is somewhat doubtful in a foreseeable future; secondly, this level is required for monitoring some important geodynamic features, e.g. crustal deformation.

We will restrict ourselves here to the kinematics of motions, refraining from a discussion of their causes and of their physical interpretation. The following is a decomposition by solid-earth mobility:

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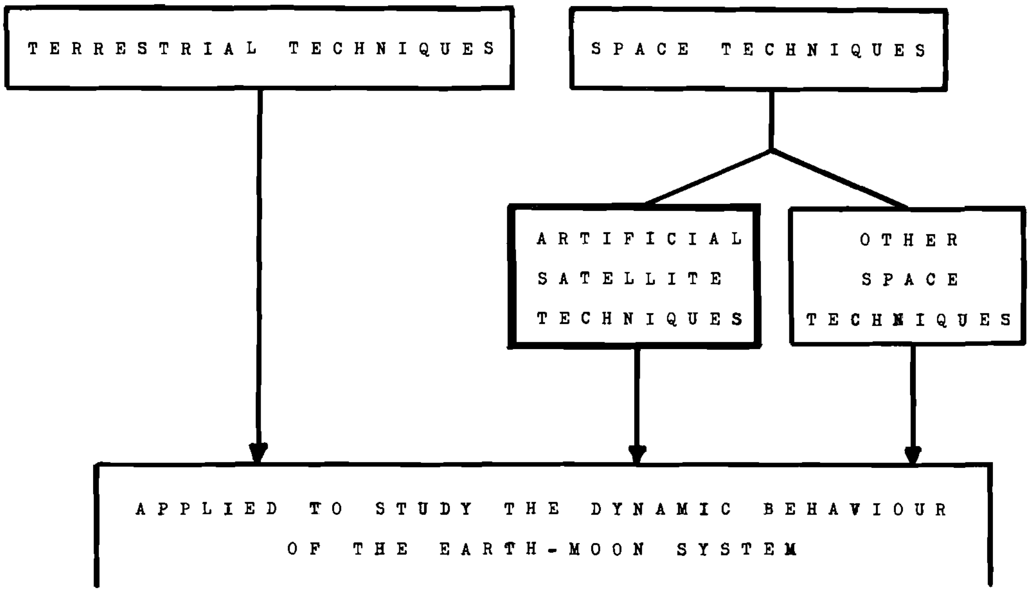

Fig. 1. Geodetic techniques for geodynamics.

ARTIFICIAL SATELLITE TECHNIQUES

EARTH to SATELLITE	-PHOTOGRAMMETRIC GONIOMETRY -RADIO-DOPPLER RANGE-RATING *LASER RANGING -RADIO RANGE-DIFFERENCING
SATELLITE to SATELLITE	-RADIO-DOPPLER RANGE AND RANGE-RATING -LASER RANGING
SATELLITE to EARTH	-RADAR ALTIMETRY -LASER RANGING

Fig. 2. Break-down of artificial satellite techniques with emphasis on ground-based laser ranging.

- orbital motion of earth's mass centre (geocentre);
- orientation of geocentric "earth-fixed" frame of reference;
- motion of lithospheric plates relative to "earth-fixed" frame of reference;
- deformation of lithospheric plates;
- tidal deformation of the earth;
- effects of non-tidal loading and unloading;
- seismicity.

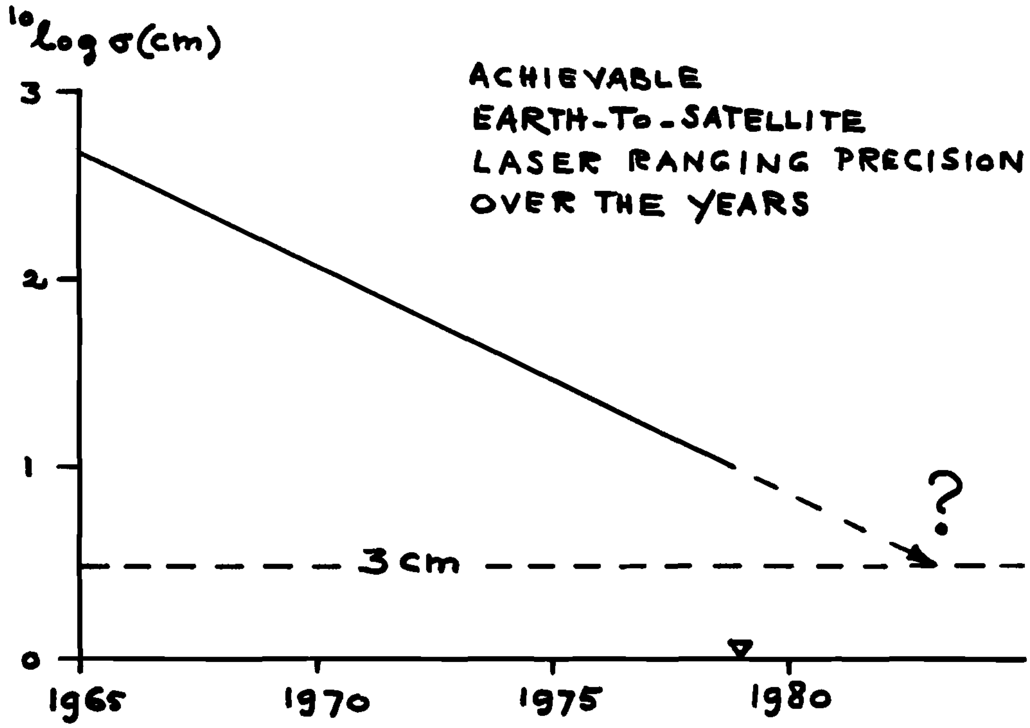

Fig. 3. Achievable ground-based laser ranging precision over the years.
σ (cm) is single-shot standard deviation of ranging in centimetres.

2 Lithospheric plate motion as selected primary topic

As geodynamic topic we select the motion and deformation of lithospheric plates as primary subject. A closely-related subject is the orientation of a geocentric "earth-fixed" frame of reference. This latter subject pertains to the rotation of the earth and will be reverted to later (see section 5). The selected primary subject is timely and enjoys current scientific, political and social interest because these crustal motions are likely to have signatures which may be distinct earthquake precursors and thus eventually be useful for predicting major earthquakes [1]. Contemporary topics in lithospheric plate mobility are:
- the exact delimitation of plates;
- the (non)-rigidity of plates;
- its relation to seismicity;

- the variability of creep rate, both in space and in time;
- the prevailing plate-driving mechanics.

Fig. 4 depicts the impact of space techniques on the selected primary subject. We will now further focus on "station positioning" and later mention "earth orientation".

Some kinematic features of lithospheric plate mobility can be classified according to:

Reference:
- relative motion of plates;
- motion of plates relative to crust-fixed reference frame;
- motion of plates relative to mantle;

Extension:
- global interplate motion;
- intraplate deformation;
- relative motion near plate boundaries;

Dimensionality:
- horizontal motion;
- vertical motion.

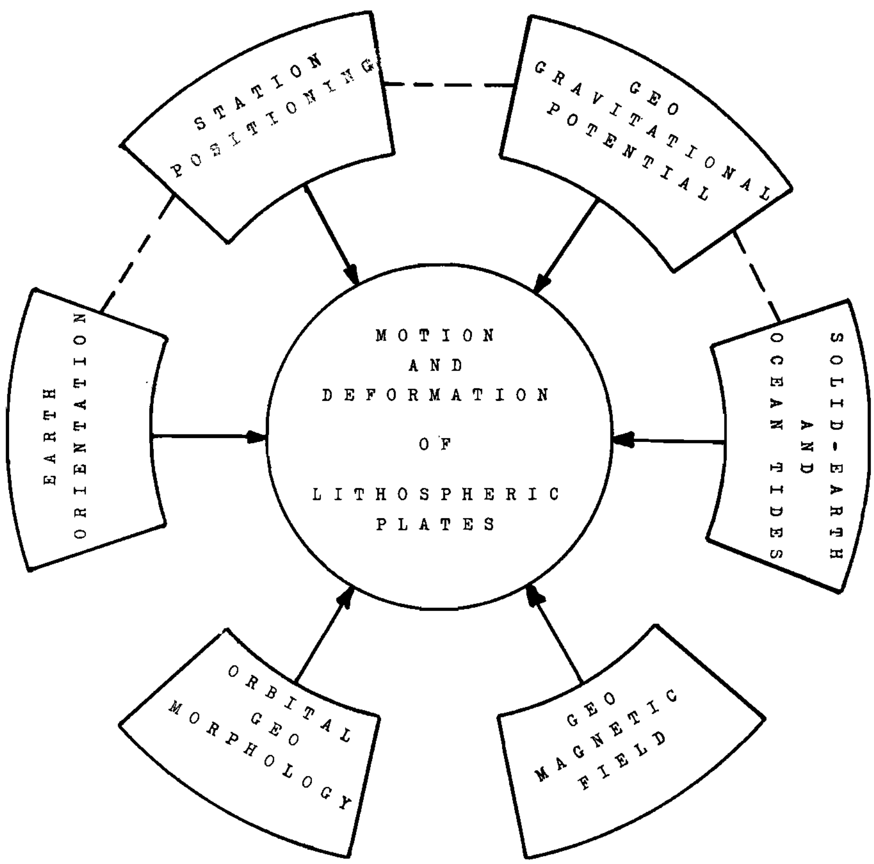

Fig. 4. Space techniques contributing to study of lithospheric plate mobility as central theme.

When adopting space techniques to monitor lithospheric plate mobility a geodesist may base his selection on a combination of the following features:
- 3-dimensionality;
- precision of measurement;
- reliability of network structure;
- actuality of results;
- cost-effectiveness;
- logistics.

3 Satellite laser ranging applied

Fig. 5 gives the hierarchy of geodetic techniques in use or envisaged for monitoring crustal mobility. Ground-based laser ranging to artificial satellites appears as one possibility of potential [2].

Although a purely geometric approach of relative station positioning based on simultaneous ranging from at least four ground stations is possible, such an approach is not practical, mainly because of weather restrictions on the observations. More useful is an orbital approach, in particular since such approach is more flexible in terms of observation schedules. Because the satellite orbits interfere, on the other hand, orbital approaches are geometrically more complex.

An orbital approach to detect and measure crustal mobility requires two reference frames for its convenient modeling: an inertial frame to describe the satellite's motion and a terrestrial frame to describe station positions and relative station movements. These two frames then are interrelated by their relative orientation, the variability of which is the result of

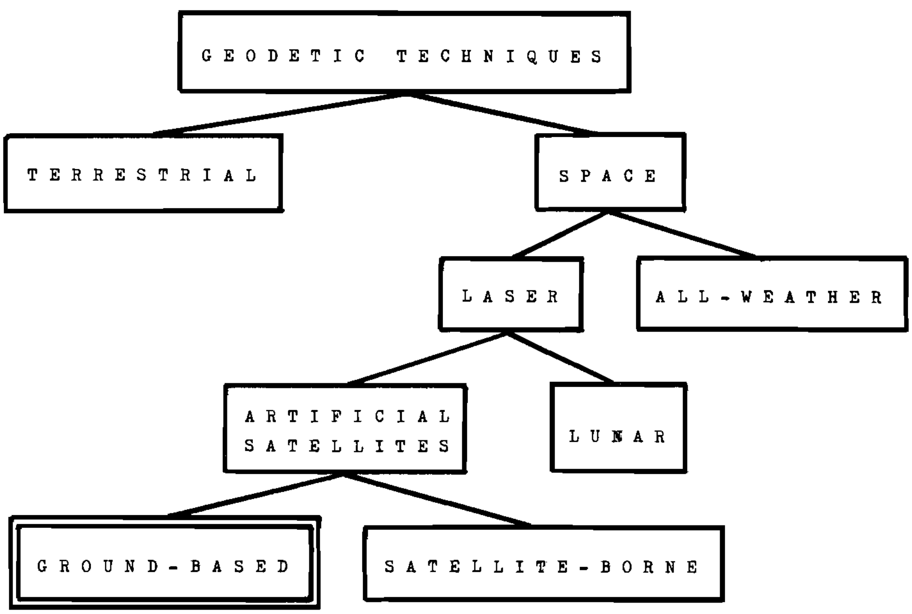

Fig. 5. Hierarchy of geodetic techniques to monitor crustal mobility.

mainly luni-solar precession and nutation, UT1 and polar motion. The satellite's position depends on its initial state with respect to the inertial frame and on the acting terrestrial and extra-terrestrial forces. The dominating terrestrial force is the geogravitation including its variable part as brought about by the lunar and solar tidal forces. Station positions with respect to the terrestrial frame depend on their initial positions and on crustal motion, the latter being the resultant of a spectrum of composite motions ranging from secular to transient phenomena. The lithospheric plate motion as considered here is, generally speaking, at both extremes of the spectrum, secular creep being at one end and co-seismic motion at the other.

Short arc orbital approaches in which the orbital motion of the satellites is easier to model, offer a compromise between flexibility of application and complexity of analysis.

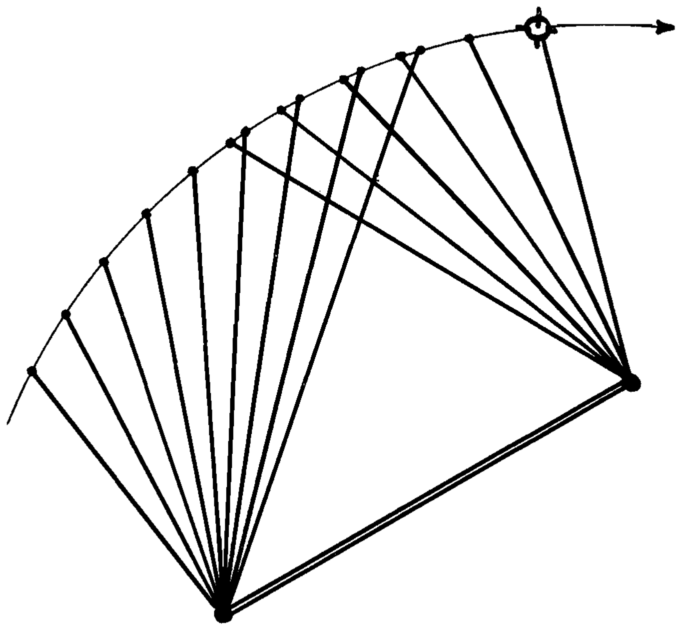

Fig. 6. Interstation chord line distance from tracked (not necessarily) overlapping satellite arcs.

Interstation chord-line distances (see Fig. 6) up to some thousands of kilometres have been derived to sub-metre formal standard deviations, in this way. Of particular interest in this respect is the San Andreas Fault Experiment (SAFE), where interstation distances of up to more than 1000 km have repeatedly been obtained with sub-decimetre precision, although the reliability of these determinations may be less [3]. Repeated determinations over a period of four years yielded an estimated strike slip motion along the fault in the expected direction and order of magnitude [4].

4 Strategies of space geodetic involvement

SAFE is one among a variety of geodetic experiments in the almost classical test area for earthquake research in a potential hazard zone. Other space techniques applied or planned for application to that area are radio-interferometry, with both stellar and satellite-borne radio sources, and satellite-borne laser ranging [1], [5]. As yet all these different space techniques are considered complementary, rather than competitive and extensive tests should point out how an ultimate plan of measurement will be based on a combination of a number of these and terrestrial geodetic techniques, emphasizing the strong points of each of them. Initial application tests of space techniques in earthquake zones are performed or will be planned in areas where the delineation of faults or plate boundaries is obvious and the expected order of magnitude allows detection of the movement [6]. The latter consideration calls for a pre-measurement analysis of network reliability.

Similar considerations are in order as regards broader scale interplate and intraplate mobility. Tracking site selection will be a critical issue; the site should be representative for an area of some extent and local surveys should monitor the non-tectonic kinematic effects.

Pre-measurement analysis and station siting are all-important items in a dialogue among geophysicists and geodesists, a result of which will be the formulation of relative motion hypotheses to be statistically tested using the collected measurement data as input [7], [8].

Various classes of precise artificial satellite laser ranging equipment, from fixed-site observatory type to highly mobile devices exist or are being designed [9], [10]. The fixed-site and transportable equipment will be useful for long-term interplate and intraplate secular relative motion studies. Mobile equipment will be applicable in earthquake zones, the really highly mobile versions having brief on-site times and a relatively small number of them would be able periodically to re-survey several seismically active areas and to be moved into such an area at rather short notice to support pre- and post-seismic crustal dynamic investigations. In the long run such investigations could lead to the identification of valuable earthquake precursor phenomena.

5 Relation to earth-orientation

As already indicated, the orientation of an "earth-fixed" frame of reference is related to the problem of lithospheric plate motion. It is common practice to identify this orientation with the orientation of "the earth" with two contemporary problem-constituents: the rotation rate as measured by UT 1 and polar motion. The relationship with lithospheric plate motion is two-fold: geometrically, because a joint motion of all plates is in fact a total motion of the crust, thus of the crust-fixed reference frame; dynamically, because of a supposed correlation between earth-rotation anomalies and earthquake occurrence.

To refer the orientation of the earth to orbits of artificial satellites is rather obvious and laser ranging is one of the potential techniques to do so [11]. A multi-station approach yields the orientation of the instantaneous rotation axis of the earth with respect to a "crust-fixed" reference frame as defined by conventional coordinates of the laser stations. Recently preliminary pole positions obtained in this way have been made available [12]. Because of a basic longitude ambiguity with a "blind" observing system as laser ranging, it is substantially more difficult to extract UT-1 information from laser-derived satellite-orbits.

6 In retrospect

In Fig. 4 research on earth orientation, station positioning, the earth's gravity field and tides are presented in their mutual relationship as a joint space geodynamic contribution to the study of lithospheric plate mobility. Other important contributions are expected from satellite-borne geomorphologic and geomagnetic studies.

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5 Lecture by ARNE BJERHAMMAR*
MATHEMATICAL TIES BETWEEN DIFFERENT FIELDS IN GEODESY AND GEOPHYSICS

Scientists who work today in the field of geodesy have sometimes a rather diffuse idea of the boundaries of their own science. So let us ask ourselves, what is geodesy? The answers we get when we approach different colleagues will reflect the uncertainties that are natural for a complex situation. There was a time when geodesy was called *geometry*. However, our early colleagues were so skilful that their science was fully assimilated by pure mathematics and nowadays nobody associates geometry with any geo-science. Still we will find some geodesists who dream about a "geometrical geodesy". If this dream refers to a Euclidean geometry, then we must accept a geodesy without mass, without plumblines and without levels. This means that we cannot measure horizontal angles or vertical angles. And of course, we cannot make any levelling or compute any "horizontal distances". A geodesy with all these restrictions is of course only a dream of a yesterday that never was. If we look through the haze of ignorance in our science, then we perhaps will find a colleague who claims that our science is still the science of geometry, but his geometry is a non-Euclidean geometry. Not very many of his colleagues will believe him. He will of course be considered to be a "nut". His only satisfaction will be that he knows he is right. (But all scientists have of course this feeling in common). A geodesy which is *non-Euclidean* has some important merits. It allows us to include mass in our geometrical system.

Geodesists have been speaking about physical geodesy for a considerable time. This concept is in fact somewhat provocative because there never was a pure *non-physical geodesy*. Any meaningful geodesy of today must be considered to be a *physical geodesy* where the masses inside (and outside) the earth are considered to some extent. For a physical geodesy we can of course find ties to geophysics in a number of directions. We can with some justification claim that geophysics was born in the field of geodesy. However, nowadays geodesy is only a branch of geophysics.

We know that early geodesy had a main ambition to give a geometrical presentation of the shape of the earth. The size of the earth made it more or less impossible to use exclusively geometrical methods. It was therefore natural to introduce an auxiliary reference system defined as *mean sea level*. This concept was not restricted to the oceans but also the extension under the continents was included. This extremely important reference surface for geodesy was called "the geoid" (LISTING).

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The main mathematical tool for the study of the geoid has been the spherical harmonics where the geoid is presented with the use of a power series. Terrestrial methods gave about 20 coefficients up to 1957. Modern satellite observations have in the last 20 years given much more information than in all the previous 2000 years of scientific work and we know now about 300 coefficients in the spherical harmonic expansion. Data acquisition as well as mathematical analysis is taken care of by the geodesists. The geophysical evaluation is mostly made by pure geophysicists.

Many different procedures were used in the search for "the best geoid". The geophysical properties of the geoid were early recognized and it was only natural to look for geophysical theories in this study. The *isostatic* hypothesis was inherited from ARCHIMEDES and explored by PRATT and AIRY. Later HEISKANEN developed these theories further and it could be proved that isostasy had solid foundations in a mechanism of the crust-mantle system. It was earlier believed that the earth should be in isostatic equilibrium at least for the second degree harmonic which compensates for the centrifugal force. Modern satellite observations indicate that the flattening is about 1/298.25 but the actual rotational velocity corresponds to a flattening of the earth of 1/299.8. This means that there is an excessive bulge of about 200 m. WANG (1966) suggested that the unloading of the polar icecaps could give the explanation. MUNK and MACDONALD (1960) concluded that the non-hydrostatic *bulge* indicated a *time lag* in obtaining equilibrium as the earth's rotation is slowing down. The flattening of today corresponds to the rotational velocity 10 000 000 years ago! This should correspond to a viscosity of the lower mantle of 10^{26} poise. GOLDREICH and TOOMRE (1969) questioned the existence of the non-equatorial bulge and pointed out that the pole of rotation has wandered relative to the mantle in geological time!

Theoretical studies of an earth with finite viscosity indicate that there should be a correlation between gravity anomalies and vertical movements of the earth. However, earlier analyses of the gravity anomalies from Scandinavia and Hudson Bay indicate that there is a lack of correlation between movements and gravity anomalies. JEFFREYS (1962), VENING MEINESZ (1939), MAGNITSKY and KALASHNIKOVA (1970), INNES (1966), LAMBECK (1976) and KAULA (1970) give slightly different interpretations. (The lack of correlation has been called the Jeffreys' Paradox).

VENING MEINESZ (1948) pioneered submarine gravity measurements and he could prove that the mid-Atlantic ridge at 40°N is in approximate isostatic equilibrium.

The gravity field of the earth has often been studied in order to estimate density anomalies in the interior of the earth. Studies by LAMBECK (1976) have indicated that most of the power in spherical harmonics of degree $\geqslant 6$ reflects heterogeneities in the first 300–400 km of the mantle. "The lower degree harmonics reflect conditions down to about 800–1000 km". It is known that harmonics of degree $\geqslant 6$ indicate no correlation between gravity anomalies and *deep mantle seismic signals*. Some evidence is given for a correlation between *lateral temperature* anomalies and gravity anomalies. HIDE and HORAI (1968) supposed that the gravity anomalies originated at the core-mantle interface. BOTT (1971) concluded that the transition zone of the mantle was the origin of the anomalies. See also KOCH (1972), ARNOLD (1978) and TSCHERNING (1974). KAULA (1972) evaluated the gravity field of Gaposchkin and Lambeck as flow in the asthenosphere and a corresponding response in the lithosphere. DORMAN and LEWIS (1970) claimed that there is an isostatic compensation which is significant down to a depth of 400 km.

If we summarize the results from presented geodetic-geophysical studies, then we find that there is some evidence of a correlation between low harmonics and density anomalies down to 800–1000 km. However, there seems to be a number of contradictions built into the pattern of the gravity field of the earth. A scientist who asks for a common denominator for geodesy and geophysics will find this in the field of geodynamics.

For a very long time, geodesists considered stationary situations in the study of the earth. The geometrical aspects dominated this approach to geodesy. Geodesy was first some type of refined surveying justified mainly by cadastral and legal aspects.

More advanced scientific evaluations of the geodetic results have normally had a geophysical backing. Pioneers in this field were VENING MEINESZ and H. JEFFREYS. Independently they gave the formulation of modern geodesy with a solid foundation in geophysics. VENING MEINESZ can be considered as the founder of the "new geodesy" where the measurements were not enough. More than any other geodesist of his time he tried to find the physical explanation of his observations. His evaluation of the gravity field of Scandinavia with respect to uplift problems is famous. He estimated the viscosity of the upper mantle to 10^{22} poise from these observations.

The Netherlands and Scandinavia have one major geodetic-geophysical problem in common. Both areas are subject to vertical movements but in different directions. The origin of these movements is not obvious. In Scandinavia we have believed that the previous glaciation was the source of energy. (New studies of MÖRNER have questioned this classical explanation. MÖRNER (1976)). What is the explanation for The Netherlands? I do not know if anybody has the final answer. One explanation could be a "bulge effect" from the Scandinavian uplift. The enormous ice cap caused a large "bulge" outside the glaciated area. The isostatic compensation gives an uplift in Scandinavia with a sinking "bulge" outside the glaciated area all the way to The Netherlands. If this is a correct explanation of the mechanism then we have a joint interest in an important geodynamical problem. See NISKANEN (1939) and BURGERS and COLLETTE (1958) for further details.

We have made some recent studies of the Fennoscandian gravity field which indicate that the Jeffreys' Paradox should be questioned. Most presentations of the gravity field have so far been given with respect to a global mathematical reference figure. In such a presentation we find that Scandinavia is 40–50 m up in the "highlands" of the geoid of Western Europe. This seems contradictory if we believe that there is an isostatic uplift process still going on. A mathematical analysis showed that the icecap above Fennoscandia could have no impact on harmonics below degree 10. We used the harmonic coefficients from Goddard Flight Center GEM 10 and made a local geoid in the "harmonic" window between degrees 10 and 23. (Complete data are only available to degree 23.) Then we found full evidence in the gravity field for the depression from the icecap. Furthermore, the present maximal uplift area corresponds almost exactly to the peak value at the geoidal subsidence. Finally, the isoline for zero uplift corresponds well with the isoline for zero geoidal subsidence in the harmonic window. This information from the icecap is completely hidden in the joint presentation of the global geoid. A convenient mathematical procedure has made it possible to reveal interesting geophysical information which hopefully can give some understanding of the physical nature of the problem.

There is a little doubt that we also have some additional "tectonic" (or non-isostatic) movements. However, we do not think it could be expected that such independent movements should have exactly the same location as the uplift from the glaciation for the last 10 000 years. Nor do we believe that a tectonic component should have the same relative size all over Fennoscandia. We do not see any explanation for a very close correlation between the two completely independent geophysical movements. We think we have found a conclusive proof for the isostatic origin of the Fennoscandian uplift. If this is correct, then there seems to be a good justification for the hypothesis of a bulge effect from the previous icecap as the explanation of the present sinking in The Netherlands. This means that we have more than a mathematical tie between our countries.

Most of the problems we have discussed so far have deep foundations in geodesy as well as in geophysics. If we look upon the mathematical tools that are used in our scientific efforts, then we easily recognize that any evaluation of numerical data requires some type of discriminator. The natural tool for these operations is *hypothesis testing*. The most thoroughly developed system for hypothesis testing in geo-science was developed here in The Netherlands by TIENSTRA and BAARDA. Numbers of scientists in geodesy and geophysics have accepted these methods as their standard tools. KRARUP pioneered the application of *Hilbert space* operations in geo-science and numerous applications have followed. Studies by the Copenhagen School have enhanced the mathematical approach to a very high level. MORITZ has followed a similar path but has selected a procedure based on the theory of *stochastic processes*. He has developed methods for the estimation of covariance functions of various geophysical quantities. KRARUP and MORITZ have both mainly concentrated on the solution of the boundary value problem of physical geodesy. This main procedure has been based on a method of *harmonic reduction* of the discrete boundary values down to *an interior sphere*. The procedure looks highly provocative because it is well known that the Laplace condition is not satisfied below the topographical surface. Still we can find a mathematical explanation. A full justification for this unconventional procedure is found in the functional analysis by theorems of Keldych-Lavrentieff. This type of solution looks "risky" from a purely geophysical point of view. The mass distribution is of course completely "falsified" in this approach. However, we should remember that most *inverse problems* in geoscience are more or less singular.

The *singularity aspects* cause a joint concern for geodesy and geophysics. If we accept the traditional definition of bias and unbiasedness, then almost only biased solutions can be found. The statistical definition of an unbiased estimator requires that there is one and only one answer (BOSE, RAO-MITRA (1971)). Generalized matrix inverses have been frequently explored in all our geosciences. However, the answers they give are all biased according to the traditional definitions. This is more or less unacceptable from a physical point of view. A more optimistic approach is found if we accept that *unbiased estimators* are not restricted to point estimators. A whole space can then be unbiasedly estimated. Any estimator with expectation inside the solution space is then unbiased. This is the "optimistic" approach to any type of *inverse geoscience problem.*

Still we have to require that the solution space is invariant with respect to the choice of a coordinate system. The concept of estimable quantities has been further discussed by GRAFAREND and SCHAFFRIN (1974). SANSÒ (1978) gave a mathematical presentation of a rigorous mathematical-geodetic system for a non-rotating earth (gravity space system). This system should also be quite useful for pure geophysics.

The dynamical earth presents of course a number of problems which are of equal interest for geodesy and geophysics. Professor MELCHIOR has already covered this field and I do not think further comments are needed.

If we want to summarize the present situation, then it seems important to emphasize that mathematics is only a tool in the study of our earth. The mathematical method should of course never *direct* our studies. However, only by knowing how to use the various methods of mathematics will we be able to make the correct choice of adequate mathematical tools. Then we will also be better prepared for the geophysical evaluation of geodetic information. The ties between geodesy and geophysics will then not only be mathematical, they will also be physical.

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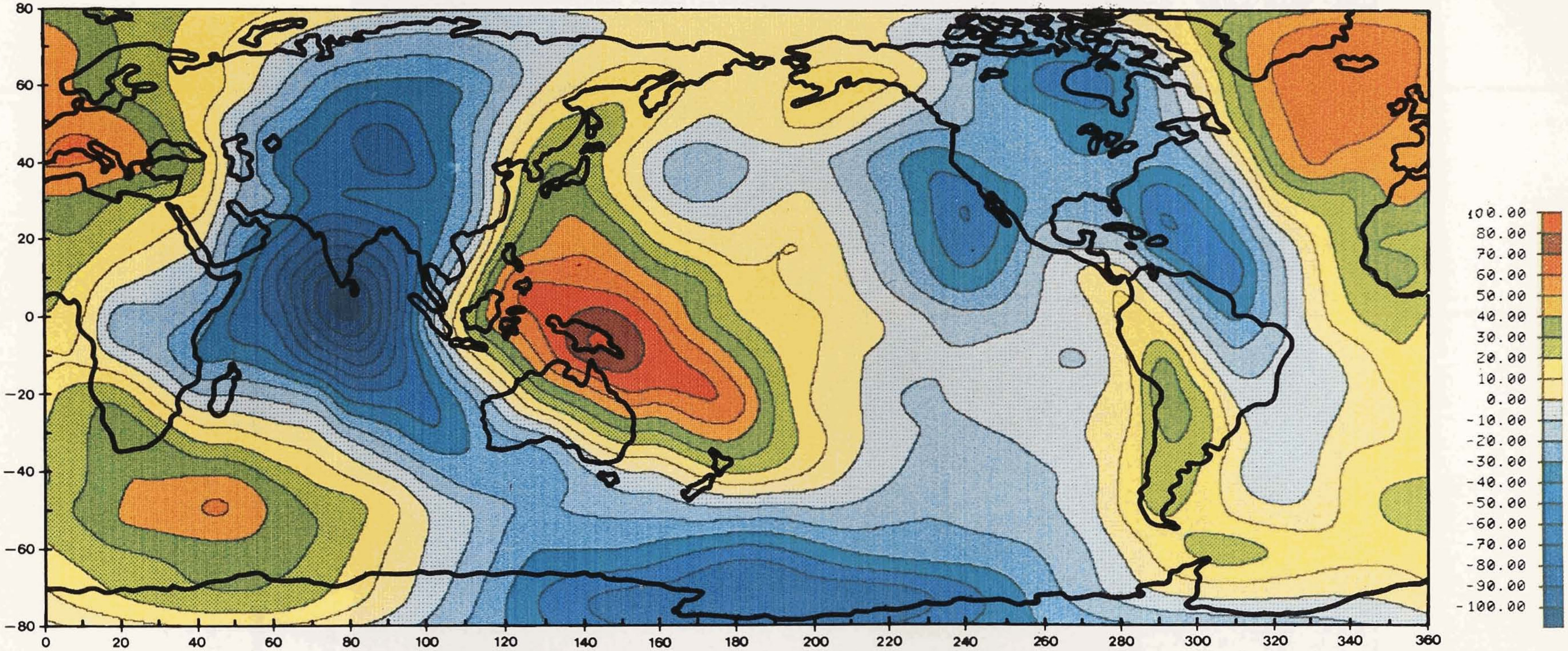

Fig. 1. Satellite geoid: Harmonics 2.01–30.00. Reference ellipsoid: IAG 1967. Data: Goddard (10). Note the Canadian (Laurentide) "glacial" suppression of the geoid. The Fennoscandian geoid is uplifted in spite of the previous glacial depression. Unit 10 m.

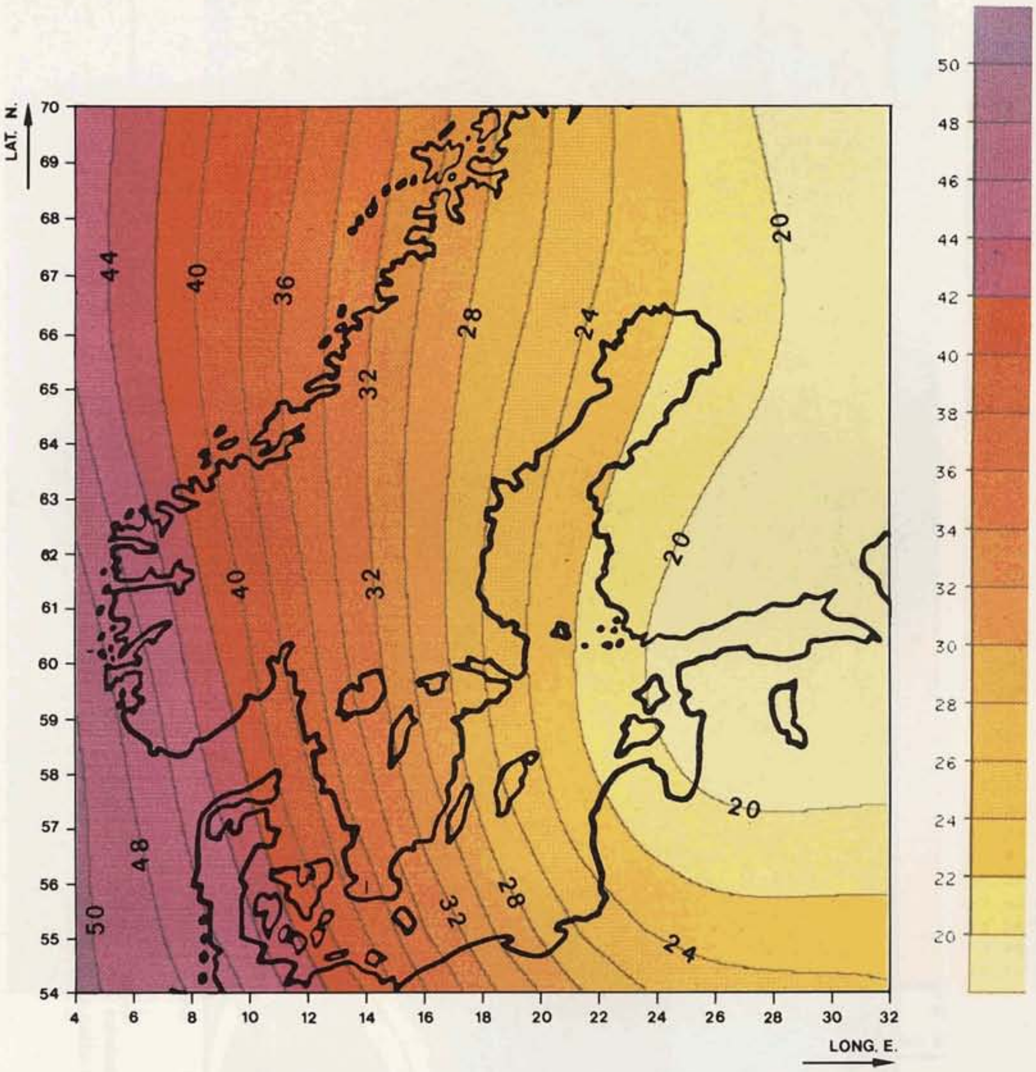

Fig. 2. Satellite geoid of Fennoscandia. All available harmonics included.

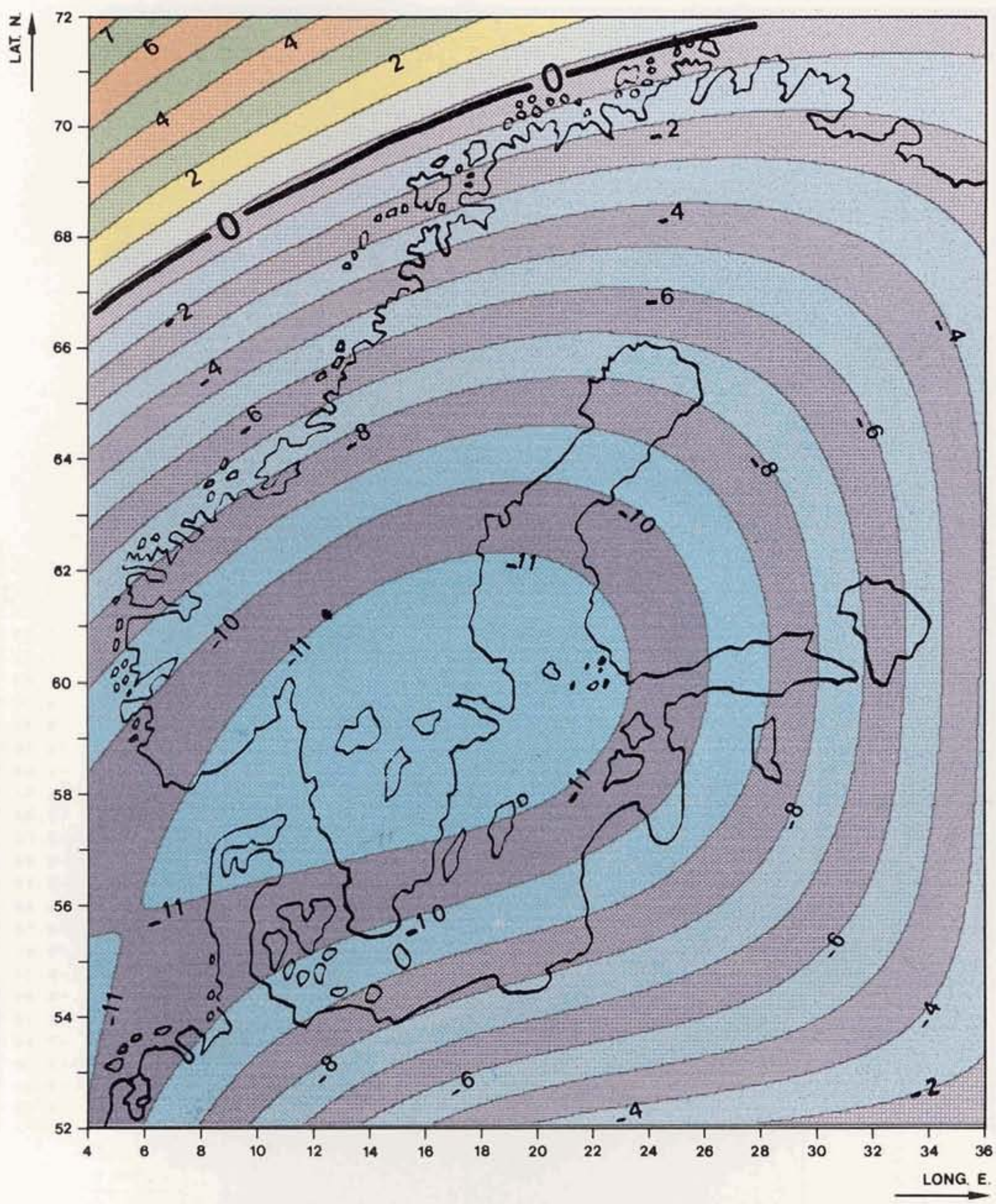

Fig. 3. Harmonic window in the satellite geoid of Fig. 1. Harmonics: 6.0–23.01. At this lower limit we have no clear correlation with the present uplift. Unit 1 m.
The size of the Fennoscandian glaciation is expected to give an influence in the harmonics from 10 and above.

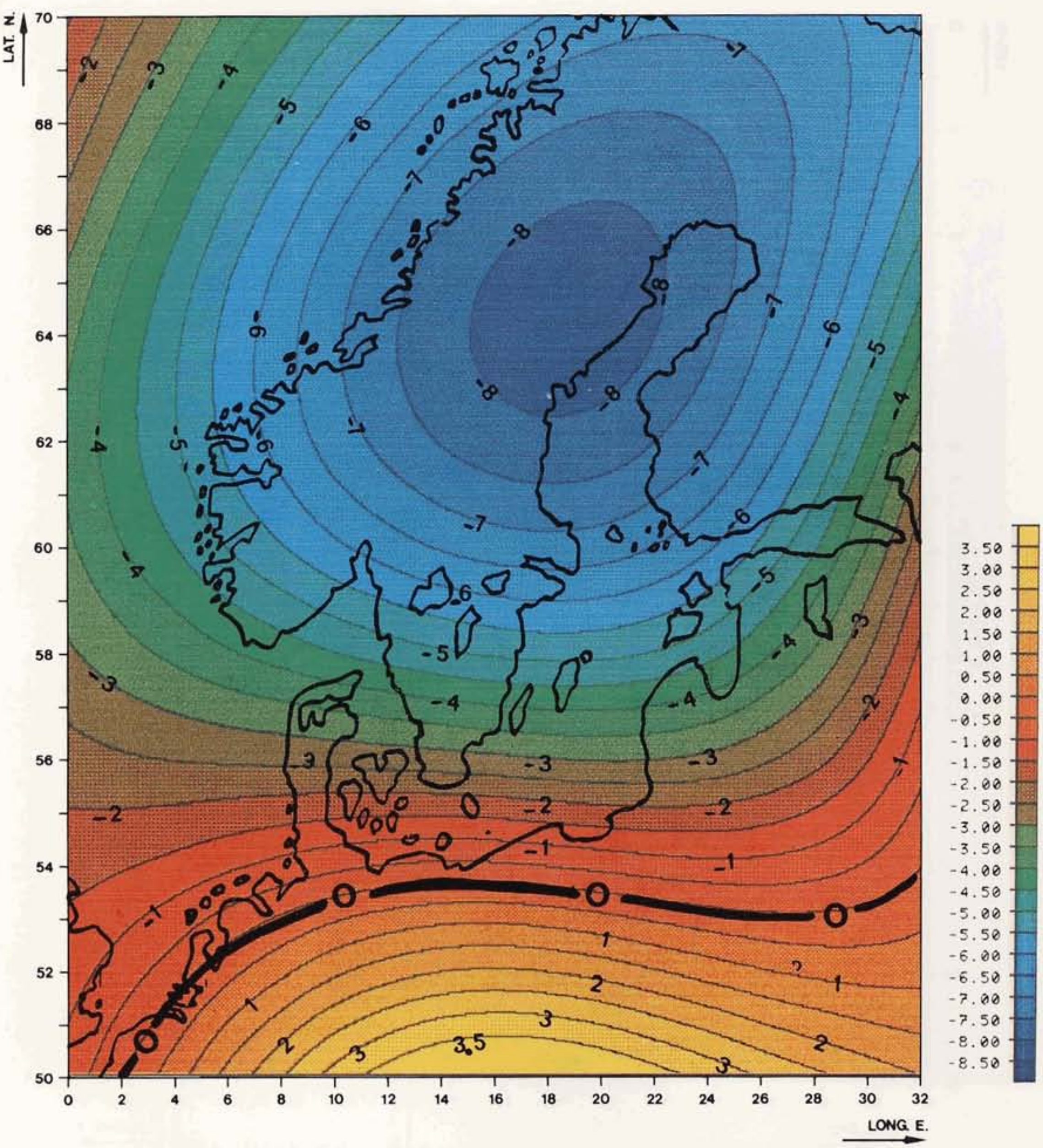

Fig. 4. Harmonic window in the satellite geoid of Fig. 1. Harmonics: 10.0–23.01. The depression has now moved to its maximal height above the equator. The maximum depression corresponds very well with the present maximum uplift area. Uplift figures are extremely well correlated with the absolute value of the depression depths in Sweden and Finland. (Very few values of the uplift are available for the Norwegian area). One metre of geoidal depression corresponds approximately to 1.2 mm uplift per year. See Fig. 5 for the uplift data of Fennoscandia. Unit: 1 m.

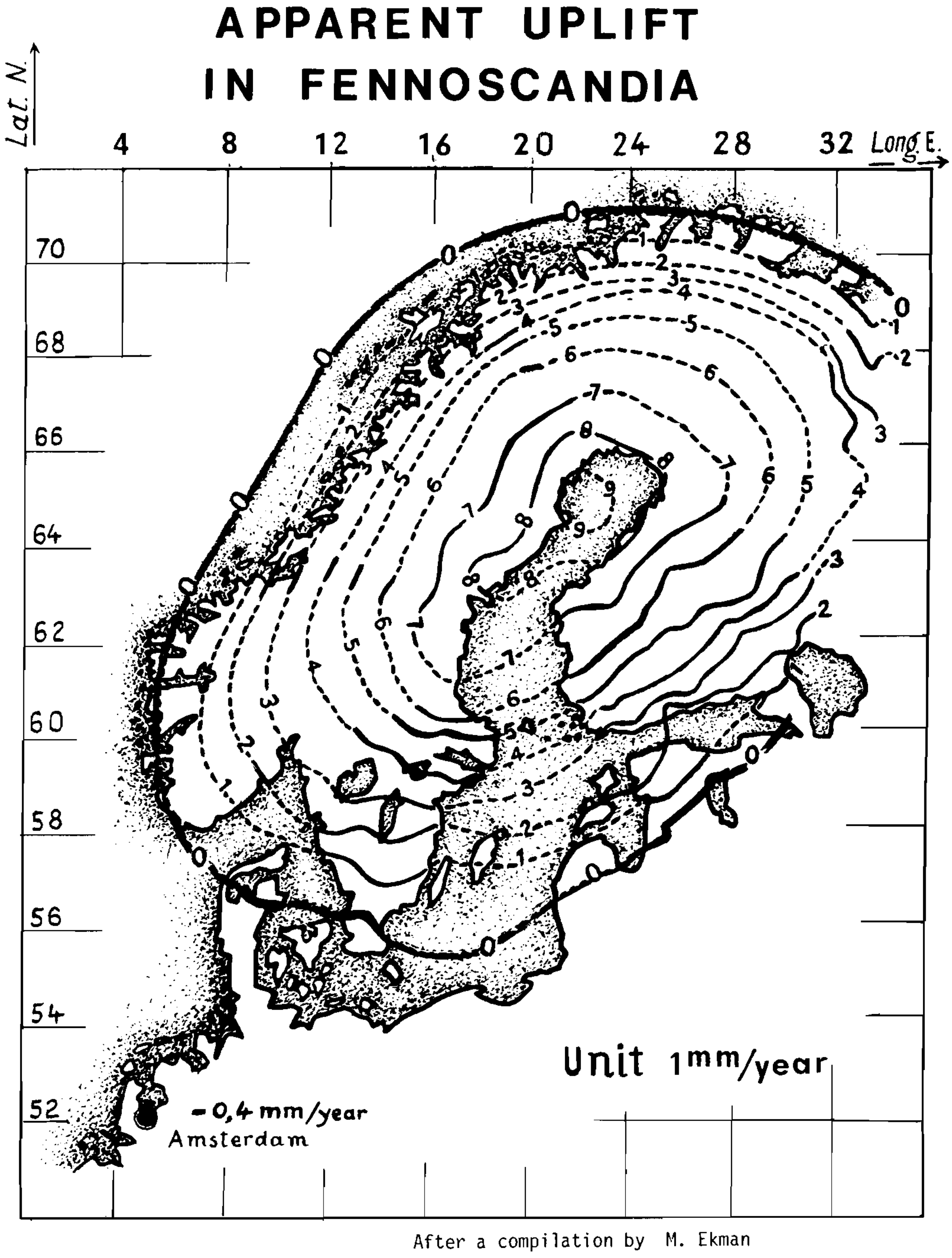

Fig. 5. "Apparent uplift" in mm per year. Main source is a compilation by M. EKMAN. The correction for eustatic effects is here 1 mm per year. The excellent correlation between the uplift figures and the geoid in the harmonic window 10.0–23.01 gives a convincing proof of the isostatic origin of the present uplift in Fennoscandia. The subsidence figure of Amsterdam is probably not statistically significant.

PART II

HISTORY OF THE NETHERLANDS GEODETIC COMMISSION

by

N. van der Schraaf

1 Introduction

The Netherlands Geodetic Commission was set up by Royal Decree of 20th February 1879, No. 3, following an advice of the Royal Netherlands Academy of Sciences. The Science Division of this learned society had received a letter from the Minister of the Interior, dated 19th June 1878, asking whether it was justified to continue providing funds for the triangulation measurements carried out by Prof. Dr. F. J. STAMKART for the "Europäische Gradmessung" (European Arc-measurement)*. The minister had become somewhat impatient because these measurements, begun in 1868, had already cost about twice the amount originally estimated and had taken up three times as much time as planned [1, p.8], [2, p. 96].

The letter of the minister was discussed in the meeting of the Science Division of 29th June 1878. Prof. STAMKART, who was present in that meeting, explained that hazy weather, smoke of factory chimneys in the neighbourhood of Amsterdam and lack of sight to and from some stations owing to high trees, were responsible for the delay in completing the measurements. To investigate the matter and to draft a reply to the minister's letter, the Science Division decided to set up a special committee. The following members were invited to sit on this committee: Prof. Dr. J. A. C. OUDEMANS, director of the Utrecht Observatory and formerly director of the triangulation of the island of Java, Prof. Dr. J. BOSSCHA, professor of physics at the "Polytechnical School" (the forerunner of the present Delft University of Technology), and Prof. Dr. H. G. VAN DE SANDE BAKHUYZEN, director of the Leiden Observatory. A proposal of OUDEMANS to send a provisional reply to the minister recommending the continuation of Stamkart's measurements was accepted [3].

At the next meeting of the Science Division (28th September 1878) OUDEMANS presented the results of the investigation in the form of a letter to be sent to the minister. It gave an account of the work done so far. At 39 stations the angle measurements were completed, leaving another nine to be observed. The computation of the triangulation, however, lagged far behind and that of the base measurement (carried out in 1868–69) was still to be completed. Although STAMKART hoped to complete the triangulation in the next few years, the committee did not rule out the possibility that he might not be able to do so in view of his age (he was 73 then).

The computations especially were a matter of great concern. It was therefore suggested to appoint a competent person to assist him with the computations and the preparation of a publication of the results so far obtained. He should also make himself familiar with Stamkart's work so that a smooth take-over would be ensured if the necessity should arise. STAMKART was not happy with this proposal. He preferred to finalize the work all by himself. The other members of the Science Division, however, agreed to the proposal of the committee and STAMKART had to give in [4].

At the same meeting two letters of the Minister of the Interior, dated 15th and 26th August 1878, were discussed, asking advice about the continuation of the precise levelling in The Netherlands. Since 1875 this levelling was being carried out under the direction of Dr. L.

*) In 1886 the German name "Europäische Gradmessung" (European Arc-measurement) was changed in "Die Internationale Erdmessung" (in English called "International Geodetic Association"). In 1919 the organization was re-established as "Geodetic Section" (of the International Union of Geodesy and Geophysics), the name of which was changed in "International Association of Geodesy" in 1930.

COHEN STUART [2, p. 86] but because of his sudden death on 24th July 1878, it was now without a leader. It was then that the idea of creating a geodetic commission was born [4]. At the next meeting (26th October 1878) this matter was further elaborated by OUDEMANS. He proposed that this commission should be put in charge of the primary triangulation and the primary levelling network including activities related to these projects, such as longitude- and azimuth-determinations, tidal observations and pendulum observations. The commission should consist of five members, i.e.: STAMKART, OUDEMANS, BOSSCHA, VAN DE SANDE BAKHUYZEN en Dr. G. VAN DIESEN, senior engineer of the "Waterstaat" (Department of Public Works). The continuation of the primary triangulation and the primary levelling would in this way be guaranteed and STAMKART would get the necessary help [5]. This proposal was accepted and by letter of 17th December 1878 it was submitted to the minister [6] and resulted in the above-mentioned Royal Decree of 20th February 1879 [7]. The commission was called "Rijkscommissie voor Graadmeting en Waterpassing" (State Commission on Arc-measurement and Levelling). In 1937 the name was changed to "Rijkscommissie voor Geodesie" (State Commission on Geodesy). In this historical review the current English name "Netherlands Geodetic Commission" (or the Commission for short) is used throughout.

2 Terms of reference and organization of the Commission

The Royal Decree defined the duties of the Commission as follows:

a. To continue and complete the triangulation measurements on behalf of the European Arc-measurement.
b. To continue and complete the precise levelling network.
c. To coordinate the work for these two surveys.

At the first meeting of the Commission (8th April 1879) STAMKART was elected president, OUDEMANS vice-president and BOSSCHA secretary. The work was divided over three sub-commissions, i.e.:

a. Triangulation (STAMKART and OUDEMANS).
b. Levelling (VAN DE SANDE BAKHUYZEN and VAN DIESEN).
c. Astronomical observations (VAN DE SANDE BAKHUYZEN and OUDEMANS).

About the other aspects of the work, i.e. pendulum observations and tidal observations, a decision would be taken later.

By order of the Minister of the Interior of 14th May 1879, the Commission was instructed to submit annual reports about its activities [8]. With the exception of the one for the year 1879, of which only hand-written copies exist, these annual reports are published by the government printing office. Until 1917 they also appeared in the "Staatscourant" (Official Gazette). In the period 1944–58 the annual reports were replaced by reports covering irregular periods while from 1958 onwards they appear every three years [9]. In these reports a detailed account of the progress of the work is given. In 1929, on the occasion of its 50th anniversary, a short historical review of the first fifty years appeared in the professional journal "De Ingenieur" [10]. It was written by Prof. Dr. J. J. A. MULLER, at that time president of the Commission.

The composition of the Commission changed in the course of the years, not only as far as persons were concerned but also with respect to government services and fields of sciences represented in it. A complete membership list is included as Appendix I. The main changes are mentioned below.

2.1 *Period 1879–1937*

In 1881, by Royal Decree of 23rd July, No. 2, Prof Dr. Ch. M. SCHOLS of the Delft Polytechnical School, was appointed a member of the Commission [11]. Schols had made some outstanding contributions to geodesy and the Commission had proposed his appointment with a view to the computations to be made of the final results of the triangulation. At the meeting of 19th November 1881 he was elected secretary of the Commission in place of BOSSCHA who wished to be relieved of this position for health-reasons [12].

STAMKART died after a short illness on 15th January 1882, at the age of almost 77. In the first meeting after his death (21st January 1882) VAN DE SANDE BAKHUYZEN was elected president of the Commission while SCHOLS took his place in the subcommission Triangulation [13]. Stamkart's measurements were rejected after an investigation had shown that their precision was below the standards set for the European Arc-measurement [1, p. 9].

In 1889, after the Commission was charged with the new secondary triangulation, A. W. E. KWISTHOUT, "ingenieur-verificateur" (inspector) of the Cadastral Service was appointed a member by Royal Decree of 26th July 1889, No. 26. In the covering letter, however, it was stipulated that he should only deal with matters related to the secondary triangulation [14].

SCHOLS, who always had been in poor health, died suddenly in 1897 at the age of 48 [1, p. 140]. Since he became a member in 1881, he had devoted himself to the triangulation "with an earnestness, a diligence and a skill, seldom equaled, and deserving the highest esteem" [9, 1897]. His fundamental work on the relation between probability theory and adjustment theory and his studies on map projections had become well known among his colleagues abroad (see e.g. E. CZUBER – Theorie der Beobachtungsfehler, B. G. Teubner, Leipzig, 1891). As leader of the triangulation he was succeeded by Hk. J. HEUVELINK, his second in command. In 1897 HEUVELINK also was appointed a member of the Commission and professor of geodesy at the Polytechnical School in his place. VAN DIESEN replaced SCHOLS as secretary of the Commission until July 1900 when HEUVELINK was entrusted with this task [9, 1897, 1900].

Dr. J. J. A. MULLER, retired chief of the Triangulation Brigade of the Topographical Service in the former Dutch East Indies, became a member in 1903 [9, 1903].

OUDEMANS died 14th December 1906. He was replaced by Dr. J. C. KAPTEYN, professor of astronomy at the University of Groningen [9, 1906, 1907].

In view of their age VAN DIESEN and KWISTHOUT resigned in 1910 and 1911 respectively and BOSSCHA died 15th April 1911 [9, 1910, 1911]. Of the original members of the Commission VAN DE SANDE BAKHUYZEN was then the only one still alive.

In 1911 the first *ex-officio* members were appointed in addition to *personal* members. The Commssion, considering that not only the sciences in the fields related to its work should be represented but also the users of that work, proposed to the minister to appoint as ex-officio members the director of the General Service of Rijkswaterstaat, the chief of the Hydrographic Department of the Navy and the director of the Military Reconnaissance in addition to an ingenieur-verificateur of the Cadastral Service. By Royal Decree of 1st June 1911, No. 37, the minister officially approved this proposal [15]. This structure of the Commission was maintained until 1937.

BOSSCHA was succeeded by Dr. J. P. KUENEN, professor of physics at Leiden University [9, 1911]. KAPTEYN, who frequently was unable to attend meetings of the Commission, resigned in 1915. His place was taken by Dr. A. A. NIJLAND, professor of astronomy at Utrecht University [9, 1915]. KUENEN died on 25th September 1922 and in his place Dr. A. L. SIERTSEMA, professor of physics at the Delft University of Technology, was appointed a member on 6th April 1923 [9, 1922, 1923].

VAN DE SANDE BAKHUYZEN died on 8th January 1923. He had been a member of the Commission since its foundation in 1879 and was elected president in 1882 after Stamkart's death. For over 40 years he had lead the Commission with great ability and had taken an active part in several of its scientific projects [9, 1922]. From 1900-16 he was secretary of the International Geodetic Association (possibly better known by its German name "Internationale Erdmessung") and from 1916 onwards secretary of the Reduced Geodetic Association among Neutral Nations [16]. As member of the Commission VAN DE SANDE BAKHUYZEN was replaced by Dr. W. DE SITTER, professor of astronomy at Leiden University while MULLER succeeded him as president [9, 1923].

Dr. Ir. F. A. VENING MEINESZ, professor of geodesy and cartography at Utrecht University, was appointed a member by Royal Decree of 24th May 1927 [9, 1927]. Since 1910 VENING MEINESZ was employed by the Commission to carry out pendulum observations, first on land, later at sea. In later years he became one of the most prominent members of the Commission, well known for his method of studying the earth's gravitional field at sea and for his theories concerning the origin of mountains and island arcs.

In 1929, the Commission was enlarged with Ir. J. W. DIEPERINK, professor of geodesy at the Agriculture University at Wageningen and Ir. W. SCHERMERHORN, professor of geodesy at the Delft University of Technology [9, 1929]. Schermerhorn's name became closely associated with the development of photogrammetry in its early days. On his initiative the International Training Centre for Aerial Survey (ITC) was founded at Delft in 1950, of which institute SCHERMERHORN became the first director.

In 1932 the director of the Military Reconnaissance was replaced by the director of the Topographic Service as ex-officio member when the Military Reconnaissance and the Topographic Map Making Establishment were amalgamated and the name Topographic Service was given to this new department of the Ministry of Defence [9, 1932].

DIEPERINK and DE SITTER died in 1934 and NIJLAND in 1936. SIERTSEMA resigned in 1937. Pending a forthcoming reorganization no new members were appointed in the meantime [9, 1934, 1936, 1937].

2.2 *Reorganization of the Commission in 1937*

About 1930 a milestone was reached in the history of the Commission. Its original assignments were then completed, i.e. the precise levelling in 1888, the primary triangulation in 1921 and the secondary triangulation in 1929 [9, 1888, 1921, 1929]. The responsibility for the precise levelling had been handed over to the General Service of Rijkswaterstaat on

29th December 1888 [9, 1888] and the updating and revision of the triangulation was turned over to the Cadastral Service on 1st January 1930. A special office "Bijhoudingsdienst der Rijksdriehoeksmeting" (Netherlands Triangulation Service) was created for this purpose [9, 1929].

Some time before the completion of the secondary triangulation the Commssion started thinking about its future. This subject was first raised in the meeting of 13th June 1928. It was then proposed that the Commission should return to its original task, i.e. scientific work in connection with a better determination of the figure of the earth [17]. The matter was discussed in several subsequent meetings but it took some years before the ideas about a reorganization of the Commission had sufficiently crystallized. These ideas were explained by the president and secretary to the minister in a meeting they had with him on the 4th June 1934 [18]. In this case it was the Minister of Education, Arts and Sciences. This department of the Ministry of the Interior became a separate ministry in 1918. For completeness sake it should be mentioned that from 1st January 1922 – 1st January 1930 the Commission was subsidized by and reported to the Ministry of Finance in view of the fact that during that period only measurements for the secondary triangulation were carried out for the Cadastral Service, a department of the Ministry of Finance.

Following the meeting with the minister, a formal proposal for a reorganization and a draft of a new Royal Decree with the new terms of reference were submitted on 16th October 1934 [19]. The minister sent this proposal for advice to the Netherlands Academy of Sciences. A complication arose when the minister asked the Academy at the same time to consider the possibility of incorporating the Triangulation Commission of the Ministry of Defence in the reorganized Commission [20]. The Triangulation Commission, established in 1925, acted as a coordinating and advising body to two military survey departments and the Cadastral Service about measurements of mutual interest. Although three of its members were also a member of the Netherlands Geodetic Commission, very little was known about the activities of the Triangulation Commission since these members were bound by military secrecy.

The Academy advised against a merger of the two commissions in view of their difference in nature, i.e. one dealing with scientific and the other with practical matters. The Netherlands Geodetic Commission, asked by the minister to give their opinion, replied that in case of abolition of the Triangulation Commission, they were prepared to take over its *advisory* task but proposed that the *coordinating* task should be delegated to the existing government services [21]. A formal proposal on these lines was sent by the minister to his colleague of Defence who agreed to dissolve the Triangulation Commission on these terms [22]. However, considerable time elapsed before the Minister of Defence decided about his representatives in the Commission after the reorganization. Consultations between the Minister of Education, Arts and Sciences and the Commission about its ultimate composition and new terms of reference caused some further delay. Finally on the 5th October 1937 a new Royal Decree [9, 1938] was promulgated by which the "Rijkscommissie voor Geodesie" was established. The task of the new commission was "to continue the scientific work of the old commission and at the same time act as general coordinator of the various government services in the field of geodesy".

The terms of reference were in the Royal Decree specified as follows:

a. To supervise, if necessary, the effectuation of work resulting from its task.
b. To give advice to government services, if requested.
c. If necessary, to attend meetings, or take part in activities of scientific geodetic or related organizations.

As *personal* members were appointed: VENING MEINESZ (president), SCHERMERHORN (secretary), HEUVELINK, MULLER, Dr. J. H. OORT, professor of astronomy at Leiden University, J. M. TIENSTRA, professor of geodesy at the Delft University of Technology and Dr J. H. F. UMBGROVE, professor of geology at the Delft University of Technology. The last three persons were new members while the first four were already a member before the reorganization.

The *ex-officio* members were in the Royal Decree specified as follows:
- the director of the General Service of Rijkswaterstaat;
- a senior officer of the Ministry of Finance (as such was always appointed the director of the Cadastral Service);
- the chief of the Hydrographic Department of the Navy;
- the director of the Topographic Service;
- the head of the Triangulation Service of the Artillery;
- an officer of the School of Surveying of the Artillery.

The last two were new ex-officio members and must be considered as representatives of the abolished Triangulation Commission of the Ministry of Defence.

2.3 *Period 1937–79*

MULLER resigned in 1938 in view of his age [9, 1938]. His place was filled in 1940 by Prof. Ir. J. H. G. SCHEPERS. He was, like MULLER, retired chief of the Triangulation Brigade of the Topographic Service in the former Dutch East Indies.

During World War II the composition of the Commission underwent the following changes [9, 1940, 1942, 1944–46, 1948–49]. Following the capitulation of the Dutch defence forces in 1940, the ex-officio members of the Ministry of Defence i.e. the chief of the Hydrographic Department of the Navy, J. C. F. HOOYKAAS, the director of the Topographic Service, A. VAN HENGEL, the head of the Triangulation Service of the Artillery, P. J. HAMELBERG, the head of the School of Surveying of the Artillery, L. EZERMAN, were dismissed by the German occupation authorities.

HOOYKAAS was as chief of the Hydrographic Department and as member of the Commission succeeded by R. VAN TYEN. The latter was interned in a prisoner of war camp in May 1942 where he died one month later. C. TER POORTEN acted as chief of the Hydrographic Department until the end of the war. In May 1945 he was succeeded by Th. K. BARON VAN ASBECK. The Topographic Service was in 1940 placed under direct control of the German army and for this reason VAN HENGEL's seat on the Commission remained vacant during the war years. He resumed his duties as director of the Topographic Service in September 1945. HAMELBERG and EZERMAN did not return as ex-officio members since their departments were not re-established after the war. EZERMAN, although no longer a member, continued to attend the meetings of the Commission until his internment in a prisoner of war camp in 1942.

SCHERMERHORN was interned in a hostage camp for civilians from May 1942–December 1944. In 1945 he became prime minister of the first post-war government. Being unable then to participate in the work of the commission, he resigned in 1946 as member and secretary but, after finishing his term in office, accepted a re-appointment in 1948.

TIENSTRA succeeded SCHERMERHORN as secretary in 1946. R. ROELOFS, professor of geodesy at the Delft University of Technology, was appointed a member of the Commission by the same Royal Decree [9, 1944–46]. VENING MEINESZ handed over the presidency to TIENSTRA in 1947 but remained an ordinary member of the Commission. ROELOFS succeeded TIENSTRA as secretary [9, 1947].

In the years 1948–49 the Commission was enlarged with two personal members, A. KRUIDHOF and Dr. G. J. A. GROND, and two ex-officio members, i.e. the Director-General and the director of the Geophysical Department of the Royal Netherlands Meteorological Institute. For VENING MEINESZ, who was Director-General until 1951, this meant a double membership for about a year and a half [9, 1948–49]. KRUIDHOF was professor of land surveying, levelling and geodesy at the Agriculture University at Wageningen and GROND was professor of the theory of mining subsidence at the Delft University of Technology [9, 1948–49].

HEUVELINK died in 1949 at the age of almost 88. He had been a member of the Commission for almost 52 years of which he served 36 years as its secretary. Although handicapped by blindness, he managed to attend meetings of the Commission until 1940 [9, 1948–49]. In 1951 TIENSTRA passed away after a long illness at the early age of 56. As president he was succeeded by VENING MEINESZ and as member of the Commission by his successor as professor of geodesy at the Delft University of Technology, Ir. W. BAARDA. Both appointments were effected by Royal Decree of 24th May 1952, No. 38 [9, 1950–51, 1952–55].

Dr. G. VAN HERK, astronomer of Leiden Observatory, became a member in 1952. In view of his moving abroad he resigned in 1958 but was re-appointed in 1963 after his return to Leiden Observatory [9, 1952–55, 1958–60, 1961–63].

UMBGROVE died in 1954. The same year Ir. E. C. W. A. GEUZE, professor of soil mechanics and Ir. G. J. BRUINS, lecturer, later professor of geodesy, both of Delft University of Technology, were appointed as members [9, 1952–55]. VENING MEINESZ resigned for the second time as president in 1957. He was succeeded by ROELOFS whose place as secretary was taken by BAARDA [9, 1956–57]. Dr. J. G. J. SCHOLTE, professor of geophysics at Utrecht University, became a member in 1958. In 1959, the ex-officio membership of the Rijkswaterstaat was transferred from the director of the General Service to the head of the Survey Department.

GROND resigned in 1961 in view of his age and GEUZE in 1962 because of his emigration to U.S.A. GROND's personal membership was changed to an ex-officio membership, i.e. a mining surveyor appointed by the Ministry of Economic Affairs upon recommendation of the association of colliery-owners in the province of Limburg. Dr. J. VELDKAMP, director of the Geophysical Department of the Royal Netherlands Meteorological Institute, ex-officio member since 1949, became a personal member in 1961 when his ex-officio membership was abolished [9, 1958–60, 1961–63]. Dr. Ir. C. KOEMAN, lecturer, later professor of cartography at Utrecht University and Ir. A. J. VAN DER WEELE, rector of the International Institute for Aerial Survey and Earth Sciences (ITC) joined the Commission in 1963 [9, 1961–63].

VENING MEINESZ died in 1966 and SCHEPERS in 1968 at the age of 79 and 83 respectively. Both had a long relationship with the Commission. Upon its recommendation SCHEPERS was in 1908 engaged by the Ministry of the Colonies for triangulation work in the former Dutch East Indies while VENING MEINESZ entered the service of the Commission in 1910 as a young scientist to carry out pendulum measurements [9, 1964–66, 1967–69].

In 1967, Ir. G. F. WITT, professor of geodesy at the Delft University of Technology was appointed a member. SCHERMERHORN and OORT resigned in view of their age in 1966 and 1969 respectively [9, 1967–69]. SCHOLTE died suddenly in 1970 of a heart-attack at the age of 63. Ir. G. A. VAN WELY, lecturer of land surveying at the Agriculture University at Wageningen, and Dr. Ir. L. AARDOOM, lecturer of satellite geodesy at the Delft University of Technology, were appointed a member in 1971. KOEMAN resigned in 1972 [9, 1970–72]. ROELOFS resigned as president in 1973 and as member in 1975. He was succeeded by BRUINS as president (1973). VAN HERK and KRUIDHOF resigned in view of their age in 1973 and 1975 respectively. Dr. F. J. ORMELING, professor of cartography at ITC, and Ir W. LANGERAAR, professor of science of navigation at the Delft University of Technology, became a member in 1974 [9, 1973–75]. The latter resigned in 1978 [9, 1976–78]. VELDKAMP resigned in 1976 in view of his age. In 1977 his place was taken by Dr. A. R. RITSEMA, seismologist at the department of Geophysical Research of the Royal Netherlands Meteorological Institute [9, 1976–78]. Dr. W. N. BROUW, lecturer of astronomy at Leiden University, Dr. N. J. VLAAR, professor of geophysics at Utrecht University and Dr. Ir. M. J. M. BOGAERTS, professor of land information systems of the Delft University of Technology, were appointed a member in 1976, 1977 and 1978 respectively [9, 1976–78].

In 1978 the ex-officio membership of the Ministry of Economic Affairs underwent a change as a result of the closing down of the coal-mines in Limburg and subsequent dissolution of the association of colliery-owners. As ex-officio member was then appointed a geodesist of "Staatstoezicht op de Mijnen" (State Control of the Mines) [9, 1976–78].

At the request of the Commission a new Royal Decree was promulgated on 29th September 1978, in which the ex-officio members were specified as follows [9, 1976–78]:

- the head of the Survey Department of Rijkswaterstaat;
- the director-general of the Cadastral Service;
- the chief of the Hydrographic Department of the Navy;
- the director of the Topographic Service;
- the director-general of the Royal Netherlands Meteorological Institute;
- an official appointed by the Minister of Economic Affairs.

Observant readers will have missed the names of the various ex-officio members in the above résumé. Omitting these names does not mean that these members were less important or did not take an active part in the work of the Commission but mentioning all the changes in the course of the years would have resulted in a rather dry summing-up of names. A complete list of these members is given in Appendix I.

2.4 *Subcommissions and working groups*

To study special subjects or to advise on certain matters, subcommissions or working groups

were set up from time to time, some of which have become more or less permanent. Presently the following subcommissions and working groups are in existence:
- subcommission Triangulation;
- subcommission Gravity Measurements;
- subcommission Maintenance Standard Base;
- subcommission Crustal Movements;
- subcommission Marine Geodesy;
- working group Positioning (in particular at sea);
- working group Satellite Doppler Positioning;
- working group Uniformity (field of study: uniformity in coding, classification, accuracy indication and generalization of geodetic data referring to land information systems).

Originally the subcommissions and working groups were only composed of members of the Commission but since the reorganization in 1937 also outsiders, experts on the field under investigation, are invited to sit on them.

3 Triangulation

3.1 *Rejection of Stamkart's triangulation*

In the years 1879–80 STAMKART continued his work on the triangulation, begun by him in 1866. OUDEMANS, as co-member of the subcommission Triangulation, was supposed to assist him but apparently STAMKART was not prepared to accept help from anyone. He had never disclosed any details about his method of observation or results obtained and that gave rise to suspicion, even before the Commission was officially established. It was feared that it would be difficult for someone else to take over in case STAMKART would not be able to complete the triangulation. Under pressure by the other members of the Commission STAMKART allowed OUDEMANS in November 1881 to inspect his notes and records. In the meeting of 19th November, in which STAMKART was present, OUDEMANS reported: "that he had found the records to be in good order so that an expert who had not taken part in the triangulation would be able to carry out the final computation" [12]. When STAMKART died on 15th January 1882, the measurements for the triangulation were not quite completed. At three stations in the utmost northeastern part of the network some directions to adjacent stations had to be measured still. With regard to the computation of the main network, the base and base extension net much remained to be done.

In the first meeting after STAMKART's death (18th February 1882) it was decided that SCHOLS would study the documents relating to the main triangulation net and OUDEMANS those of the base and base extension net [23]. Three months later, in the meeting of 24th May 1882, SCHOLS submitted an unfavourable report about Stamkart's measurements and computations [24]. His objections were:

a. The poor condition of the instruments did not allow accurate observations to be made.
b. The observation method used was not the most suitable one and certainly did not eliminate instrumental errors.
c. The method of least squares was not correctly applied in the computations. Moreover the computational errors were numerous.

OUDEMANS reported that the base measurement, apart from the many errors in the computations, could possibly be retained but the base extension net suffered from the same defects as the main triangulation net.

A recomputation would have been justified if the accuracy of the angle measurements had been sufficient but since this was not the case, it was concluded that Stamkart's triangulation work should be rejected. In the same meeting SCHOLS was requested to draw up a plan for a new triangulation. Instead of the chain of triangles between Leiden Observatory and the Belgian and German borders, measured by STAMKART for the European Arc-measurement [1], he proposed that the new net should cover the whole country. This had the advantage that it could serve as a control network for a new secondary triangulation, badly needed for cadastral surveying.

The commission, embarrassed by the outcome of the investigation of Stamkart's work, hesitated to inform the Minister of the Interior. In the annual report of 1882 it was mildly stated: "the investigation has shown that the results of the measurements and computations are not satisfactory". The report for the year 1883 contains the following sentence: "Work on the triangulation has been restricted to a further examination of Stamkart's measurements and a plan for continuation thereof is being prepared". In the covering letter to the report of 1882 a confidential report with details about Stamkart's work was announced [25].

Meanwhile the Commission had received a letter dated 3rd October, 1883 from the Trigonometrical Department of the Prussian "Landes-Aufnahme", requesting them to indicate the Dutch stations to which their triangulation, which was nearing the border, should be connected [26]. In the covering letter to the annual report of 1883 the Commission asked an amount of D.fl. 2,000,— to carry out a reconaissance for the connection between the Dutch and German triangulation nets [27]. The Minister of the Interior replied that he first wished to receive the long-promised report about Stamkart's work before deciding about funds for this reconnaissance [28]. This report, based on the investigations of SCHOLS and OUDEMANS, was submitted on 21st April 1884. The Dutch text of this important document is included as Appendix III [29]. As could be expected, it condemned all Stamkart's work for the European Arc-measurement. His measurements were considered to be of a poorer quality than those of KRAYENHOFF which they were supposed to replace [30, 31]. Although recognizing his merits in many other fields, the Commission concluded that STAMKART had lacked the qualifications necessary for executing a primary triangulation. This adverse criticism put to an end his reputation as a scientist at home and abroad. But the blame for the failure should not fall entirely on him. He was not a geodesist by profession but an inspector of weights and measures. He only agreed to carry out the triangulation after the geodesist COHEN STUART and the astronomer HOEK had refused this assignment [2]. He failed because he lacked geodetic knowledge and his character probably prevented him from seeking guidance from those who possessed this knowledge.

In 1953 C. W. MOOR studied the files of Stamkart's triangulation for his thesis [32]. He arrived more or less at the same conclusion as SCHOLS but did not attempt to compute the measurements. This was done recently by N. D. HAASBROEK who compared the thus obtained results with those of the present (more accurate) triangulation; his judgement is much milder than that of SCHOLS [1].

3.2 *Proposal for a new triangulation*

The report about Stamkart's work, sent to the Minister of the Interior on 21st April 1884 [29], contained a proposal for a new triangulation drawn up in accordance with Schols' suggestions. Since for cadastral and topographical purposes a new secondary triangulation would be absolutely necessary, time and money would be saved if the new primary net was designed in such a way that it could be used as a control network for the secondary triangulation. The time needed for measuring a new primary net covering the whole country was estimated at 6 years, assuming a measuring season of 6 months per year. The estimate of the cost amounted to D.fl. 10,000.— per year with an initial expenditure of D.fl. 4,500.— for reconnaissance and the purchase of new instruments.

The reaction of the minister to this proposal was negative. In his letter of 26th June 1884, he stated very clearly that he "did not wish to spend any money on a new triangulation". With regard to the connection between the Dutch and Prussian triangulations, he was prepared to take the Commission's proposal in consideration [33]. The amount of D.fl 2,000.— requested for this purpose in [27] was finally granted 23rd August 1884 [34]. The season was then too far advanced and it was decided to postpone the reconnaissance to the spring of 1885.

The Commission, convinced that a connection with the rejected net of Stamkart was of no use, decided to ask the minister to receive them in person in order to explain the necessity of a new net [35]. From the discussion with the minister on 16th September 1884 the Commission gathered that he was favourably disposed towards their proposal for a new triangulation [36]. Consequently the Commission inquired in a letter dated 11th December 1884 if they could reckon on funds for this purpose in 1885 [37]. The reply was disappointing, the minister stuck to his decision of 26th June 1884 [33], i.e. no money for a new triangulation [38]. This attitude of the minister was discussed in the meeting of 14th February 1885. BOSSCHA informed the other members that he had talked things over with A. VAN DELDEN, member of the Lower House of Parliament for the district Deventer. VAN DELDEN had advised him to approach the minister again by letter and to inform the members of the Lower House about this letter [39]. The Commission decided to follow this advice and the letter in question was sent to the minister on 28th February 1885 with a copy to all members of the Lower House [40]. It was also published in "Tijdschrift voor Kadaster en Landmeetkunde", the national professional journal for surveyors [41]. In this letter the proposal for a new triangulation included in the report about Stamkart's work [29], was repeated. This action had succes; in the debate on the budget for the year 1885 an amendment tabled by members of the Lower House asking for funds for a new triangulation was adopted [42].

The minister was displeased with this course of things. In a sharp letter dated 17th June 1885 he rebuked the Commission for having sent a copy of the letter of 28th February 1885 [40] to the members of the Lower House without his consent and his foreknowledge [43]. He was still reluctant to give permission for a new triangulation. It was not until 15th April 1886 that he authorized the Commission to use the yearly subsidy for this purpose [44]. The minister made it very clear, however, that the total costs of the new triangulation should not exceed the amounts mentioned in the letters of 24th April 1884 [29] and 28th February 1885 [40]. The above details are included to illustrate how long and tough the fight with the minister was. Meanwhile the postponed reconnaissance for the connection between the Dutch and German networks was started in the summer of 1885 [9, 1885]. It goes without saying that SCHOLS, who had rejected Stamkart's work and made the plans for a new triangulation, was put in charge. The new triangulation, consisting of a primary and secondary triangulation, was completed in 1929 and is known as "Rijksdriehoeksmeting" (State Triangulation). In the next sections some features of the Rijksdriehoeksmeting are described. More details are to be found in the annual reports [9] and [32], [45], [46].

3.3 *The Rijksdriehoeksmeting*

3.3.1 Introduction

In order to eliminate some of the sources that had adversely affected the quality of Stamkart's work, SCHOLS adopted the following rules for the new triangulation [32, p. 62]:

a. A careful reconnaissance should be carried out before starting the measurements.
b. The instruments should be thoroughly checked and adjusted.
c. The observations at all stations should be made systematically according to a fixed measuring programme.
d. Pointings should be made to heliotropes and not to the spires of church towers (in a flat country like The Netherlands most stations are church towers).
e. To decrease the influence of lateral refraction, the instrument and the heliotropes should be placed as high as possible.
f. The instrument and the heliotropes should be placed at the same height at a station in order to facilitate determination of their mutual position.
g. The heliotropes should be operated by skilled personnel.
h. A careful and accurate description of every station should be made including a map showing the sites of observations, the sites of the heliotropes, the projection of the spire of the tower and some angles measured to nearby towers.

Since in those days there was no university course for geodesists in The Netherlands, SCHOLS recommended appointing two civil engineers who should start studying geodesy in general and, with a view to the adjustment of the triangulation, the method of least squares in particular. As such were appointed Ir. Hk. J. HEUVELINK in 1885 and Ir. N. WILDEBOER in 1886. Both stayed with the Rijksdriehoeksmeting until its completion in 1929. After Schols' death HEUVELINK was put in charge and then also appointed a member of the Commission. In later years more personnel was employed to speed up the work. It consisted of civil engineers (average 7) supplemented by Cadastral Service Surveyors (average 2) temporarily posted with the Rijksdriehoeksmeting for a shorter or longer time.

3.3.2 The primary triangulation

The reconnaissance of the primary net, mainly performed by HEUVELINK, started in 1885 and was completed in 1896. The measurements, carried out by 1 or 2 observing parties, began in 1888 and were finalized in 1904 [9, 1885–1904] [32], [45], [46]. Horizontal angles were measured applying Schreiber's method [47]. Details of this method are also given in [32] and [45]. The primary net consists of 77 stations, of which 71 are situated in The Netherlands, 4 in Belgium (Tongeren, Peer, Hoogstraten and Assenede) and 2 in Germany (Uelsen and Hinsbeck). When carrying out the observations at these primary stations, 103 so-called "intermediate stations" were determined by intersection, i.e. angles were measured between the direction to an intermediate station and the directions to at least two primary stations [32, p. 68] [46, p. 32]. Only at a few intermediate stations measurements were carried out at the station itself. These intermediate stations were considered as first order points since they form, together with the primary stations, the framework for the secondary triangulation.

3.3.3 The secondary and lower order triangulations

In preparing the lay-out of the new primary network, SCHOLS reckoned with a new secondary triangulation to be carried out in the near future. Many were the complaints about the accuracy of the existing one, executed in the years 1836–55 [48], and SCHOLS knew that these complaints were justified. When Stamkart's work proved to be inadequate, he therefore proposed a new primary triangulation covering the whole country that could be used as control network for lower-order work later [24]. The same argument was used in trying to persuade the Minister of the Interior to sanction a new primary triangulation [29], [40], [41]. After the minister had finally given his approval [44], the matter of a new secondary triangulation was raised again in a meeting of the Commission on 13th June 1887 [49]. Instead of approaching the Minister of the Interior directly, the Commission decided to await a formal request from the Minister of Finance, the authority responsible for the Cadastral Service and the most interested party in such a triangulation. Very likely it must have been known that the association of inspectors (ingenieurs verificateur) of the Cadastral Service had, in a meeting in May 1887, concluded that a new secondary triangulation was essential for reliable cadastral mapping and that a report on this subject would be submitted to the Minister of Finance. This report with covering letter was forwarded by the Minister of the Interior to the Commission on 7th October 1887 [50]. The matter was thoroughly discussed in the meeting of 19th November 1887 [51] and the Minister of the Interior was by letter of 6th January 1888 informed about the result of this discussion [52]. In this letter the Commission stated that it was prepared to undertake the new secondary triangulation under the condition that a free hand was given about the way in which the work was carried out and the personnel to be employed. Another condition was that suitable accommodation should be provided for checking and testing the instruments and carrying out the computations. The duration of the secondary and lower order triangulations was estimated at 10 years at a total cost of D.fl. 400,000. Owing to a change of government the reply of the Minister of Finance was delayed for more than a year. In his letter of 18th February 1889, he informed the Commission that in the budget of the same year an amount of D.fl. 10,000 was appropriated for a new secondary triangulation [53]. Although no reference was made to the conditions set out in the letter to the Minister of the Interior [52], the Commission thought it wise to repeat these conditions in its reply to the Minister of Finance [54]. Work on the secondary and lower order triangulations was carried out in conjunction with that of the primary network. In the years 1888–97 pointings were made at the primary stations to potential lower order points, circumstances and time permitting. However, the results of these unsystematic measurements did not come up to expectations. Therefore from 1898 onwards work on the secondary triangulation, like that on the primary one, was done systematically according to a fixed programme. A careful reconnaissance always preceded the measurements, which were carried out applying the method of Bessel [55]. Field work was completed in 1928;

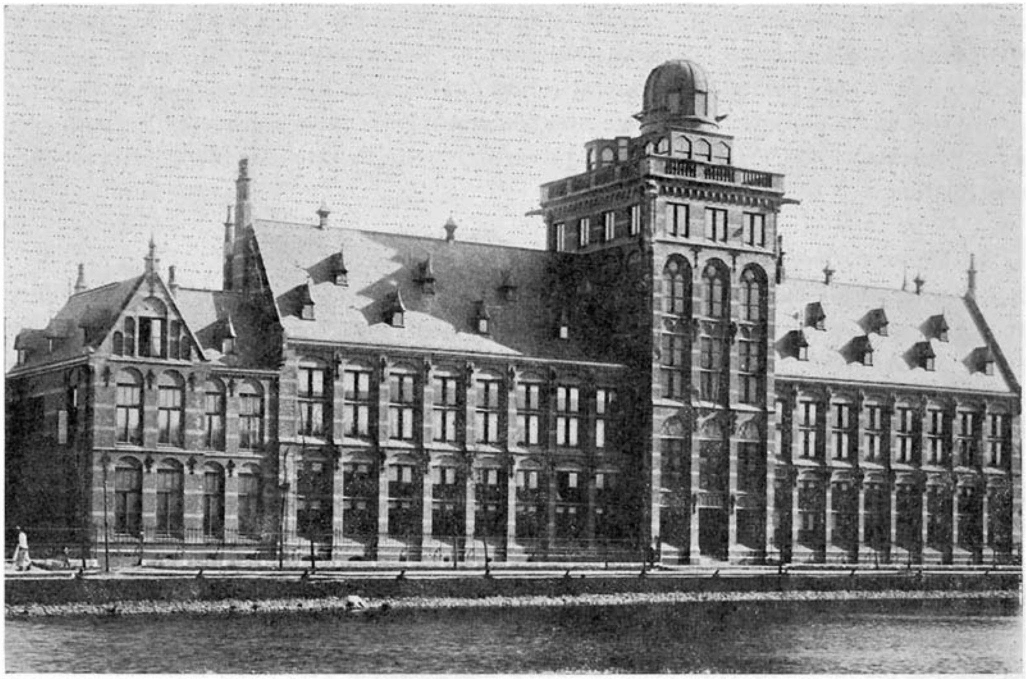

Fig. 1. Delft Geodetic Institute, Kanaalweg 4. Headquarters of the Netherlands Geodetic Commission 1895–1975.

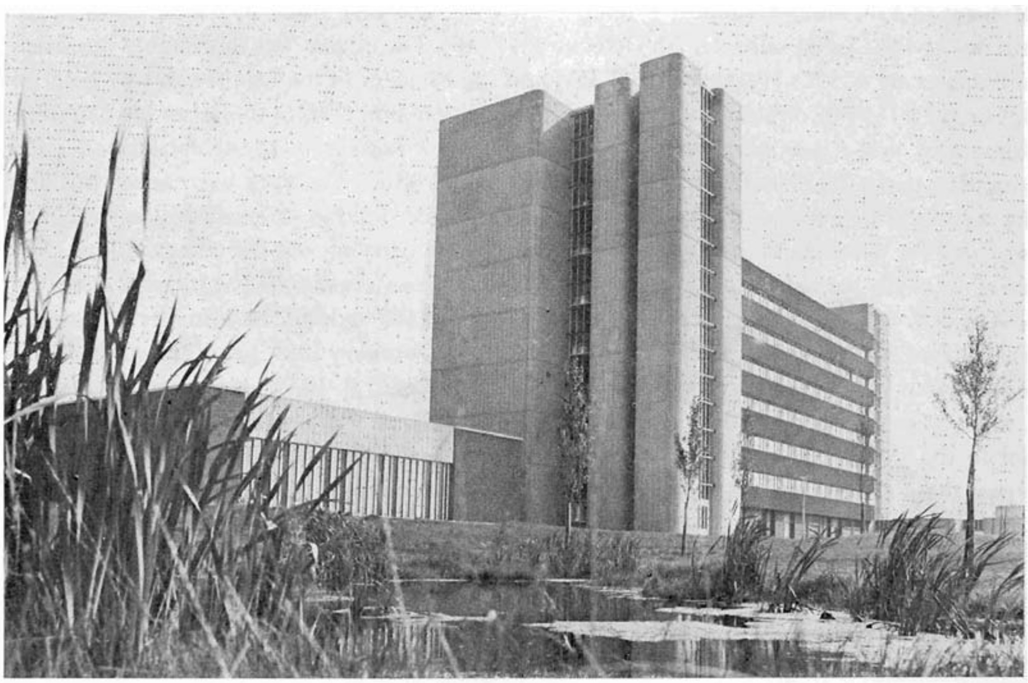

Fig. 2. Department of Geodesy, Delft University of Technology, Thijsseweg 11. Headquarters of the Netherlands Geodetic Comission since 1975.

the annual reports give the progress from year to year [9]. In total 3552 secondary and lower order stations were determined.

3.3.4 Duration and cost

From the above it should be clear that the estimates about duration and costs of the Rijksdriehoekmeting had been far too optimistic, as was the case with Stamkart's work and one of the reasons why the Commission was established. In 1889 SCHOLS still estimated that the measurements for the new primary and lower order triangulations could be completed by ten field parties in eight years [56].

In 1891, almost six years after the new primary triangulation had been approved (the duration of which was originally estimated at six years!) the Commission had to admit that its completion would take another 4–5 years [57]. The following reasons were given for the the delay: (a) Reconnaissance and station building took far more time than anticipated, (b) unfavourable weather conditions and (c) lack of sight at some stations because of trees coming into leaf after the reconnaissance had been made retarded the measurements considerably.

The slow progress of the secondary triangulation in the period 1889–97 was attributed to the lack of adequate accommodation for testing the new instruments and training of personnel [9, 1889–95). Sheer perseverance of SCHOLS led ultimately to what he wanted: his own building for the triangulation and geodesy teaching. The construction of the new building situated at Kanaalweg 4, Delft, started in 1892 and was completed in 1895 [58], [59]. For the next 80 years it was also the headquarters of the Commission (Fig. 1). When this building no longer met the needs of the Department of Geodesy, Delft University of Technology, a new building was erected on the outskirts of Delft, Thijsseweg 11. It was completed in 1975 and it is also the present headquarters of the Commission (Fig. 2) [60].

In 1903 the Minister of the Interior and his colleague of Finance inquired when the triangulation would be completed. The Commission replied that the primary triangulation would take another 3–4 years [61] but that a reliable estimate regarding the completion of the secondary and lower order triangulations could not be made [62]. The same reply was given to the Minister of Finance in 1905 in answer to comments made by the budget committee of the Lower House [63]. The same committee asked in 1910 when the completion of the triangulation could be expected [64]. In 1912 the budget committee enquired whether the yearly subsidy granted to the Commission should be considered as a permanent budget item or as a temporary one [65]. In later years no more questions were asked. The government was apparently reconciled to the idea that money for the triangulation would be needed for many years to come.

The Commission received during the period 1886–1929 subsidies to a total amount of D.fl. 1,669,000.—; specified as follows; D.fl. 432,000.— from the Minister of the Interior (years 1886–1921) and D.fl. 1,237,000.— from the Minister of Finance (years 1889–1929). However, not all the money was spent on the field work for the triangulation; it also covered expenses for astronomical observations, base measurements, pendulum measurements and publication of the results of all these activities. Besides, it should be borne in mind that a guilder of 1886 was not the same as the one of 1929.

3.3.5 Instruments used

The Pistor and Martins theodolites Stamkart had used were thoroughly investigated by

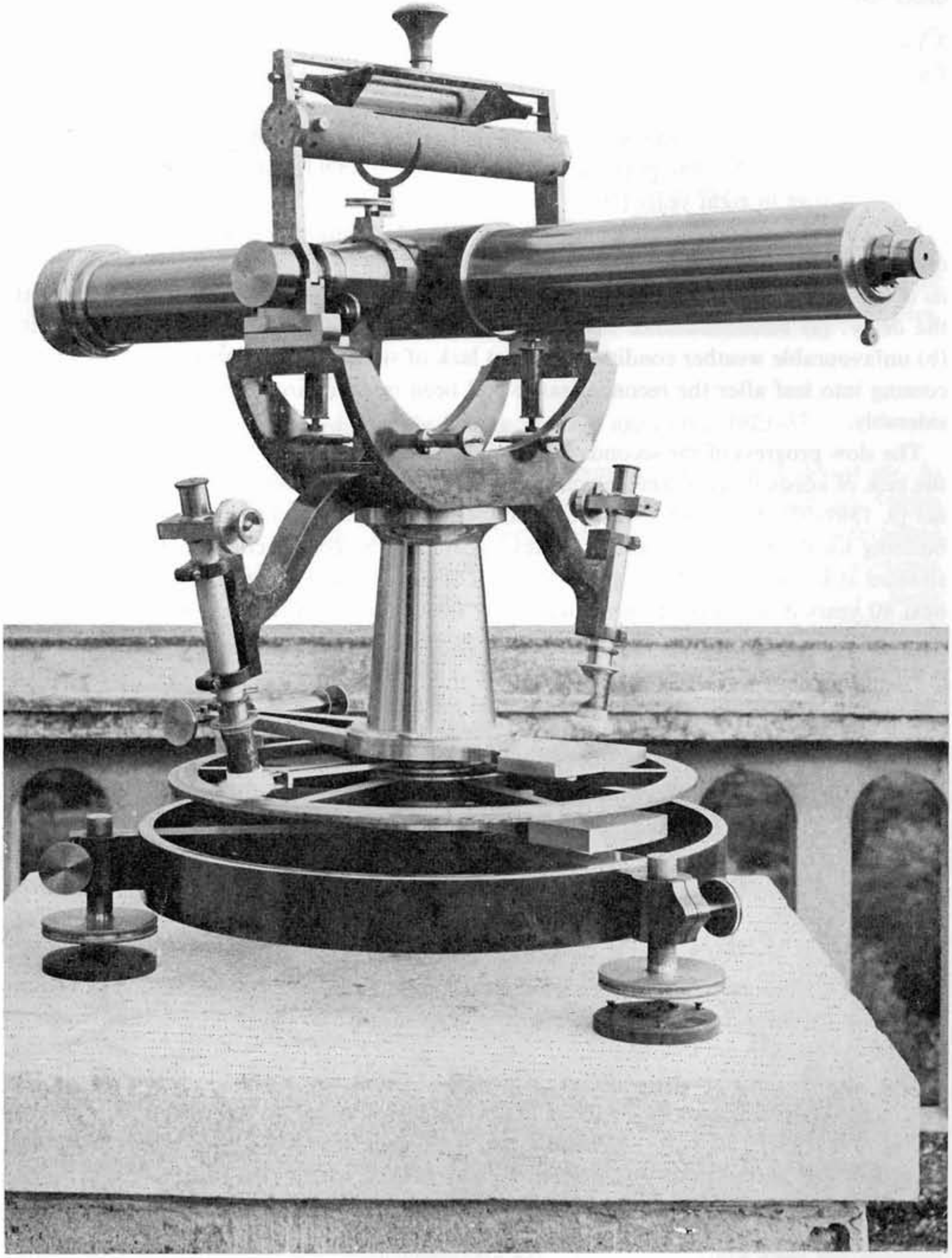

Fig. 3. Wanschaff theodolite, diameter horizontal circle 35 cm.

SCHOLS. It proved that they had many defects STAMKART had ignored or failed to discover since he never had checked his instruments properly [1, pp. 20–24], [29], [32, pp. 40–42]. In Schols' opinion they were obsolete and completely unsuitable for first order measurements. New instruments were therefore ordered as soon as the Minister of the Interior had agreed to the new triangulation. They were supplied by JULIUS WANSCHAFF (Berlin) who according to SCHREIBER, had provided the Prussian "Landesaufnahme" with theodolites of very good quality [9, 1887], [66].

Three different types of Wanschaff theodolites were used for the angle measurements. Essentially they were all of the same construction, the only difference being the diameter of the horizontal circle, i.e. 35 cm, 21 cm and 14 cm (Fig. 3). The 35 cm-instruments were used for primary measurements and the 21 cm ones for the secondary and lower order triangulations, including local triangulations for the reduction to centre at the various stations. The 14 cm-instruments were used for the latter measurements only in the cases when lack of space in a church tower did not permit setting up a 21 cm-instrument. For the reconnaissance use was made of a Wanschaff 9 cm theodolite, a small but handy and fairly accurate instrument.

Before the instruments were put into use they were carefully tested and returned to the manufacturer for rectification if they did not meet the standards set by SCHOLS. These standards were very high but the result was that the Commission obtained a set of theodolites that were among the best then available on the market. In particular the graduation of horizontal circles was thoroughly investigated applying a special method. This method is described by HEUVELINK in [67]. The results of the investigation of the horizontal circles of the 35-, 21- and 14 cm-theodolites are also given in [68].

3.3.6 Computations and results

Station and network adjustment were carried out using the method of least squares. Adjusting the network of the 77 primary stations as a whole implied the solution of 164 normal equations. In the pre-computer age this would have been a cumbersome affair and therefore the stations of the network were divided into three groups. Group I covered the central and southern parts, Group II the southwestern part and Group III the northern part of the country (Fig. 4). It had moreover the advantage that the computations could be started before the measurements were completed. Group I and Group II had three and Group I and Group III six stations in common. The standard deviations of an adjusted direction at a station, resulting from station adjustment, triangular conditions and net adjustment were 0.″214, 0.″298 and 0.″342 respectively. The net adjustment was mainly performed by Ir. E. A. J. H. MODDERMAN [45, p. 203]. In the years 1965–68 the net was adjusted as a whole by means of a computer, the results of which are given in [69]. The results of the primary network, consisting of 77 primary and 103 intermediate stations, were published in "Triangulation du Royaume des Pays-Bas, Tome premier" (1903) and "Tome second" (1921) [70], [71]. The first volume contains the observations and the station adjustments of the primary stations in the Groups I and II and the net adjustment of I and II. The second volume gives the same data for the primary stations and the net adjustment of Group III. It also includes to observations to the intermediate stations of the Groups I, II and III and the geographical and rectangular coordinates of all primary and intermediate stations. The publication of this volume was delayed until the length of the base "Stroe", measured

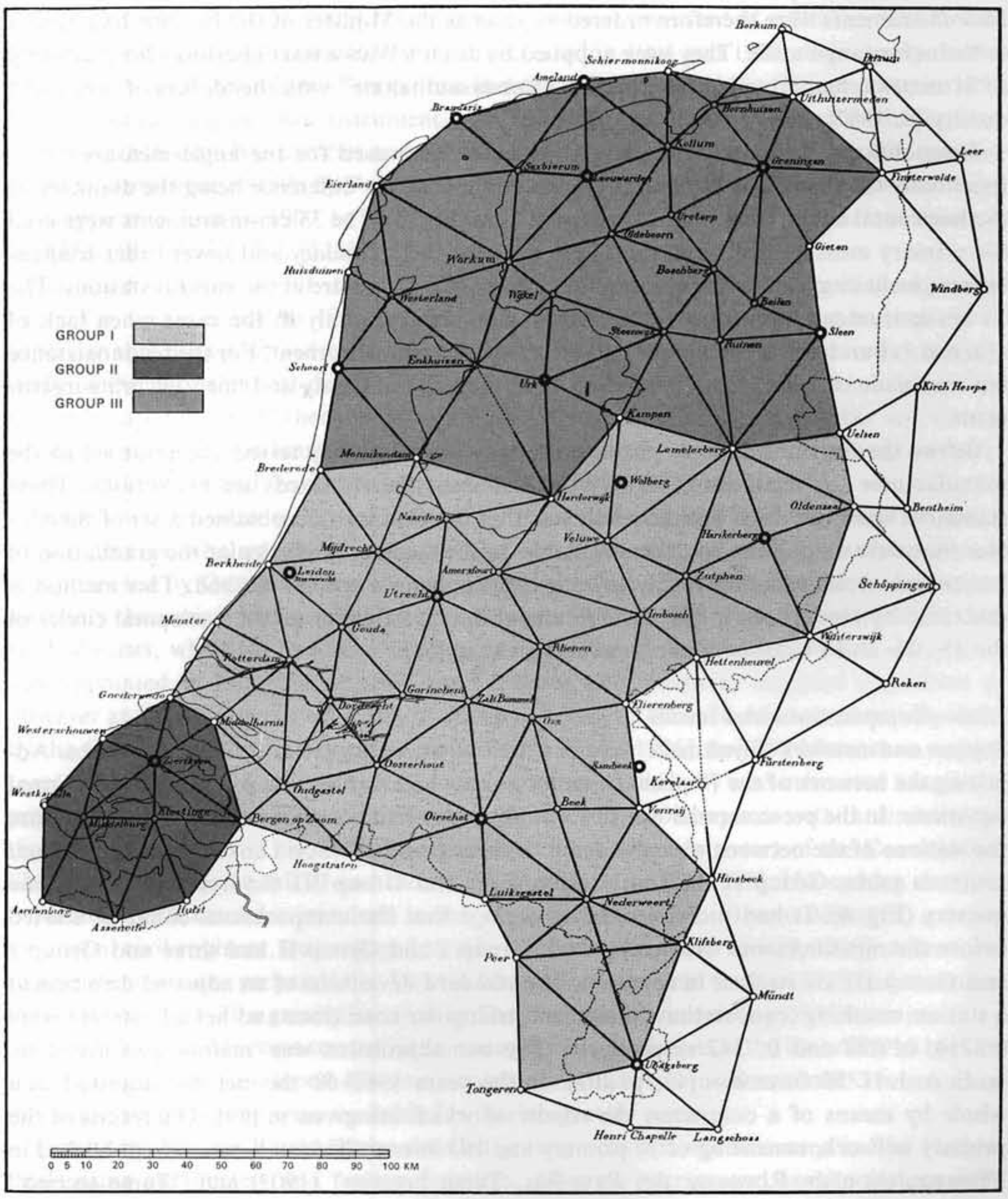

Fig. 4. Adjustment primary network.

in 1913 and necessary for the scale of the network, was definitely established [9, 1918].

Lacking a base length to start from, the net was computed using provisionally the length of the side Ubachsberg-Klifsberg. This length was via four triangles determined from the German base "Bonn", measured in 1892. The rectangular coordinates of the primary stations computed in this manner were published in 1909 [71]. A recomputation after the length of the base Stroe became known was not necessary because the differences using that length were so small that they could be neglected. Hence the provisional values became the definite ones [9, 1918, 1923].

Bessel's ellipsoid and the stereographic map projection were used for computing geographical and rectangular coordinates. Details of these computations are given in [72], [73], [74]. The rectangular coordinates have as origin the primary station Amersfoort, situated about in the centre of the network. The longitude of Amersfoort was derived from the longitude of Leiden Observatory using the longitude differences computed from the triangulation net and its latitude and the azimuth Amersfoort-Utrecht from astronomical observations at 13 stations distributed over the network (see section 5.25 and [1, p. 132], [74, p. 26]).

The final results of both the primary and secondary triangulations were published in 1928/29 [75], [76]. The quality of this work was such that it could stand comparison with the best carried out elsewhere. Due credit for this achievement should be given to SCHOLS who planned the Rijksdriehoeksmeting and derived the methods and procedures to be used but also to HEUVELINK who, after Schols' death, directed field work and computations for more than 30 years with great care and skill and brought the whole undertaking to a successful conclusion.

3.3.7 Netherlands Triangulation Service

After the completion of the Rijksdriehoeksmeting the updating and revision of it was entrusted to the Cadastral Service on 1st January 1930. A special department called "Bijhoudingsdienst der Rijksdriehoeksmeting" (literaly Updating Service of the State Triangulation but the current English name is Netherlands Triangulation Service) was established for this purpose. Th. L. KWISTHOUT became its first head. He represented the Cadastral Service in the Commission from 1925 and was the son of A. W. E. KWISTHOUT, member of the Commission from 1889–1925. Th. L. KWISTHOUT had much experience with triangulation work because as cadastral surveyor with the Rijksdriehoeksmeting he had worked for the Commission from 1898–1914 [9, 1937].

Details of the activities of the Netherlands Triangulation Service are included in the annual reports of the Commission. As an addition to the final results of the Rijksdriehoeksmeting published in 1928/29 [75] and [76], a register containing details of the witness marks and the reduction to centre of all permanently marked stations was published in 1936 [77].

From 1930–61 a total of 3012 new stations were determined but in the same period 1338 of the original lower order stations were considered as lost owing to the unreliability or absence of station and/or witness marks. In the years 1940–54 much time was devoted to the redetermination of coordinates of stations (church towers) damaged or destroyed during the Second World War and afterwards rebuilt. In 1961 a complete revision of the system of lower order stations was considered necessary to ensure a homogeneous and reliable network. The original 77 primary stations are maintained but some of the less well determined intermediate stations are now regarded as secondary stations. A number of unreliable secondary and lower order stations have been cancelled and are being replaced by new ones. As a result the renewed system of stations will ultimately consist of 140 primary, 596 secondary and 2288 tertiary stations [78].

At the 10th General Assembly of the International Association of Geodesy (Rome, 1954) a resolution was adopted requesting countries participating in the readjustment of the European Triangulation to improve and complete the observations along the borders between the various nets (Bulletin Géodésique, 1955, No. 35, pp. 96 and 97). In order to comply with this request first order measurements were carried out in the period 1956–62 to strengthen the connection between the triangulation of The Netherlands and those of Germany and Belgium [79].

4 Base measurements

4.1 *Introduction*

In 1889 it was investigated whether the baseline in the Haarlemmermeer measured by STAMKART in 1868/69 [1, p. 43] could be used for the computation of the new triangulation. Although the length of the base had been determined with sufficient accuracy, it proved that the adjacent primary stations were not visible from the end stations of the base because trees had grown up and houses had been built since STAMKART carried out his measurements. To obtain the necessary intervisibility, 12 m high structures at the end stations of the base would be required. Erecting such structures on the unconsolidated soil of the Haarlemmermeer, stable enough for accurate observations, would have been a very costly affair. For this reason it was decided not to use Stamkart's base and to measure a new one in an area with a more stable soil at a later date [9, 1889].

The matter of base measurement was raised again in 1901 but a final decision was not taken until 1912. In the meetings during this period the discussions concentrated on two subjects, i.e. (a) the equipment to be used and (b) standardization of the bars, tapes or wires belonging to this equipment. At the meeting of 29th May 1901, it was decided to measure a new base about in the centre of the network. The Repsold equipment used by STAMKART for measuring his base in the Haarlemmermeer (and by OUDEMANS for bases in the island of Java) was considered to be out of date. OUDEMANS proposed having new equipment built according to specifications set by the Commission but since the high construction costs of such equipment for just one base measurement were hardly justified and standardization of the measuring bar(s) would be difficult and time-consuming, this idea was rejected [80], [81]. Buying or borrowing modern equipment was then considered.

In the meantime a suitable area for staking out a base of $\pm 5{,}100$ m was found on the "Garderbroeksche heide" (between the towns of Amersfoort and Apeldoorn) [82]. In the meeting of 27th October 1903 it was decided to measure this base in 1904 with equipment borrowed from the "Royal Prussian Geodetic Institute" in Potsdam but at the next meeting this decision was reversed because the equipment was rather obsolete and in particular the bar was considered to be of poor quality. Moreover, only slow progress could be made with this clumsy instrument and the transportation costs would be high [83], [84].

Since in those years base measurement equipment with tapes or wires came into use, an instrument equipped with 48-m steel tapes was ordered from SAEGMÜLLER (Washington) in 1904. When it proved that various components of this instrument were of very poor quality, it was decided to procure also a *Jäderin-Guillaume* instrument with 24-m invar wires from CARPENTIER (Paris). The latter instrument arrived in 1905 but contained some poorly constructed or defective parts, [9, 1904, 1905] [85]. Neither the American nor the French equipment has ever been used for actual base measurement, not because of the above-mentioned shortcomings but because the Commission could not agree on the standardization of the wires or tapes belonging to them. BOSSCHA, supported by VAN DE SANDE BAKHUYZEN, took the stand that the Dutch standard metre should be used while other members, in particular HEUVELINK and MULLER, favoured comparison with the international standard metre of the Bureau International des Poids et Mesures. BOSSCHA, who had been secretary of the "Comité Permanent" of the "Commission International du Mètre", had strongly opposed the creation of this bureau, proposed at the "Conférence Diplomatique du Mètre" (Paris, 1875) and stubbornly refused to have anything to do with it when the International Bureau became a fact. Because of his opposition The Netherlands did not sign the "Convention du Mètre" in 1875 and it was not until 1929 that our country officially joined other nations in accepting the international metre as standard [86].

The difference of opinion about standardization brought the matter to a deadlock until 1911 when VAN DE SANDE BAKHUYZEN attended a base measurement of the French "Service Géographique de l'Armée" near Lyon. He was so impressed by the equipment, whose main component was a 4-m invar bar, that he proposed to borrow this equipment for measuring the base. A subcommission was set up to work out the details and in the meeting of 27th November 1912 the decision was taken to ask for the loan of the French equipment. The French authorities complied with this request and in the summer of 1913 a base was measured along the road Amersfoort-Apeldoorn near the village of Stroe [9, 1911, 1912], [87]. The then local road was widened later on with the consequence that the underground marks disappeared under the pavement. Since no measures had been taken to preserve these marks this resulted in the loss of the base. Because of the increased traffic it was not possible to carry out a remeasurement afterwards.

In 1965 a new 24-km base line was measured along the "Afsluitdijk" (the dam between the provinces Noord-Holland and Friesland), by which was carried into effect a resolution adopted at the Third Symposium on the New Adjustment of the European Triangulation, Munich, 1962. In this resolution it was recommended to measure a new base line in the northwestern part of the geodetic network of The Neterlands to replace the lost base at Stroe [88].

Some years earlier, in 1957, a 576-m standard base line for calibrating invar wires or tapes and electromagnetic distance measuring equipment had been established in the Loenermark near Apeldoorn (province of Gelderland). It was measured by the Finnish Geodetic Institute, applying the interference method of Väisälä. To check its stability, the base was remeasured in 1969, again by Finnish geodesists.

4.2 *Base "Stroe"*

The base Stroe was measured from 12th July–5th August, 1913, using the equipment of the French "Service Géographique de l'Armée". The total length of the base, about 4320 m, was divided into seven sections of 576 m and one section of 288 m. The 576-m sections were measured twice and the 288-m section six times. The main problem was again the standardization of the 4-m invar bar belonging to the French equipment. Its length was determined by the Bureau International des Poids et Mesures (BIPM) at Sèvres in April 1913 and May 1914 using working-copy No. 26 of the international metre. VAN DE SANDE BAKHUYZEN, however, insisted on a determination based on the Dutch standard (copy No. 27 of the international metre) which was carried out in December 1913 under his personal supervision [9, 1913, 1914]. The result was of course two different values for the length of the bar and thus for the length of the base.

Computing the length of the base using the length of the side Ubachsberg-Klifsberg (derived from the German base "Bonn") and used for the provisional computation of the triangulation, gave a value in between the values resulting from the bar standardizations of BIPM and VAN DE SANDE BAKHUYZEN. Because of the First World War a direct comparison between the copies No. 26 and 27 was not possible; it had to be postponed until 1921. In 1918 the Commission decided to accept as definite length of the base the value derived from the length of the side Ubachsberg-Klifsberg. This had the advantage that no recomputation of the lengths of the sides of the triangles was necessary [9, 1918].

In 1923 after the report on the comparison between the Dutch standard No. 27 and the international standard No. 26 had been received, it proved that the base length (and thus all side lengths) would increase one part in a million using the international standard metre instead of the values derived from the side Ubachsberg-Klifsberg. As the small differences resulting from such a recomputation could be neglected, the provisional values of all distances of the network were considered to be the definite ones [9, 1923]. A full report on the measuring of the base Stroe was published in 1932 [89]. Details are also given in [9, 1913, 1914, 1918, 1923], [32], [45].

4.3 *Standard Base "Loenermark"*

At the 10th General Assembly of the International Association of Geodesy (Rome, 1954) countries taking part in the new adjustment of the European triangulation network were requested to establish a standard base line using the Väisälä method for assuring a uniform scale in all networks and for calibrating invar tapes and geodimeters [90]. This method, developed by the Finnish geodesist Y. VÄISÄLÄ, makes use of the interference of white light and a special comparator. This comparator and the measuring procedure are described in detail in [91]. The Finnish Geodetic Institute, having available the necessary equipment and experienced observers, offered assistance to countries interested in establishing such a base. The Netherlands Geodetic Commission decided to accept this offer and as the most suitable site for the new base was chosen the "Loenermark", about 14 km south of the town of Apeldoorn. Preparations were started early 1955 and the interference measurements were carried out by the Finnish geodesists Prof. Dr. T. J. KUKKAMÄKI and Prof. Dr. T. HONKASALO in October 1957. The base has a length of 576 m, divided into two parts of 288 m. A report on final results was published in 1964 [92].

Since it is advisable to check such a base from time to time, it was remeasured in 1969 by HONKASALO and P. GRÖHN of the Finnish Geodetic Institute, using the same equipment as in 1957. The final computations indicate that the length of the first half of the base (0–288 m) had increased by 0.4 mm and that of the second half (288–576 m) by 0.2 mm. The results of the remeasurements were published in 1971 [93].

4.4 *Base "Afsluitdijk"*

At the Third Symposium on the New Adjustment of the European Triangulation (Munich, 1962) a resolution was adopted requesting The Netherlands to measure a new base in the northwestern part of the country to replace the base at Stroe, lost as a result of road reconstruction [88]. Terrain conditions limited the choice of the site practically to the dam across the former Zuiderzee, known as "Afsluitdijk". By choosing the sluice towers at both ends of the dike as end stations, it was possible to measure a 24-km base with only two slight bends at about 2 km from the northeastern end.

Preparations started in 1964 and consisted of careful reconnaissance, test measurements for the base extension network, and statistical investigations on precision and accuracy attainable in the measurement of the base and its extension to a side of the primary network. The base itself was measured twice (in direct and reversed direction) by four measuring parties. Hence each section was measured 8 times. Immediately before and after the base measurement the wires were standardized on the standard base Loenermark. The length of the base was also determined from geodimeter measurements. The instrument was set up on a pillar in the middle of the base at equal distance of both end stations. The main purpose was to obtain information about the accuracy when a certain distance (in this case half the base length) is doubled using a geodimeter. At the same time it served as a check on the invar wire measurements. It proved that doubling of an invar wire base is possible without almost any loss of accuracy. The angle measurements of the base extension net were first carried out in 1965. The results obtained were not entirely satisfactory and for this reason the measurements at some stations were repeated in 1966 and 1967. A comprehensive report on the base and base extension net "Afsluitdijk" was published in 1972 [94].

5 Astronomical observations

5.1 *Introduction*

When the Netherlands Geodetic Commission was set up in 1879, the following astronomical observations had already been carried out by the Leiden Observatory on behalf of the European Arc-measurement:

- determination of the longitude difference between Leiden and Göttingen (1867);
- determination of the longitude difference between Leiden and Brussels (1868);
- determination of the longitude difference between Leiden and Bonn (1870);
- determination of the latitude of Leiden (1863–68);
- determination of the azimuth Leiden-Delft (1870).

Leiden Observatory was one of the about 30 astronomical stations involved in the European Arc-measurement and above determinations were agreed upon by Prof. Dr. F. KAISER, director of the observatory and the Prussian general J. J. BAEYER, the originator of this project. Details of the measurements and results obtained are given in [1, pp. 111–139], [95], [96, pp. 120–195]. Originally BAEYER had proposed to determine also the difference in longitude between Leiden and Greenwich but owing to lack of funds and personnel, this project could not be carried out for the time being. Moreover KAISER considered a direct determination not strictly necessary since the difference in longitude between Brussels and Greenwich had been determined in 1853. This would make it possible to derive the difference Leiden-Greenwich as soon as the difference Leiden-Brussels had been determined [2, pp. 83–84], [97, 1889, p. 297].

Astronomical observations carried out in the period 1879–1979 under the auspices of the Netherlands Geodetic Commission comprise:
- latitude, longitude and azimuth determination for the Rijksdriehoeksmeting and the International Geodetic Association (1880–99);
- polar motion observations at Leiden Observatory at the request of the International Geodetic Association (1899–1921);
- measuring twin Laplace stations for control of the national triangulation and for a new adjustment of the European triangulation network (1947–73);
- geodetic-astronomical observations at Curaçao during the International Geophysical Year (1957–59);
- measuring Laplace stations to connect the satellite observation stations Delft and Kootwijk to the high precision traverse Malvern-Graz (1970–75);
- latitude and longitude determinations for computing the deviations of the vertical (1974–77).

In the following sections only a brief description of the various projects will be given since final reports, containing details of the methods applied, the instruments used and the results obtained, have been published. Moreover, their progress has been reported in the annual reports [9].

5.2 *Latitude, longitude and azimuth determinations in the period 1880–99*

5.2.1 Azimuth determination Utrecht-Amersfoort

At the first meeting of the Commission (8th April 1879) OUDEMANS offered to determine the azimuth Utrecht-Amersfoort and VAN DE SANDE BAKHUYZEN that of Leiden-Delft [98]. The latter azimuth had already been determined in 1870 by Dr. E. BECKER, observer at Leiden Observatory, [1, pp. 114–132], [95, pp. 207–215] but when VAN DE SANDE BAKHUYZEN became director of the observatory after Kaiser's death in 1872, he soon discovered that the instrument used for measuring the azimuth Leiden-Delft had an instrumental error that already must have existed in 1860. Consequently he concluded that this azimuth might have an error of several seconds and the measurements should be repeated [1, p. 131], [97, 1889, p. 295]. However, a redetermination would have been of no use for Stamkart's triangulation since the tower of Delft had been repaired after a fire in 1872 and STAMKART had made his observations at the stations Delft and Leiden before the fire [1, p. 132].

The azimuth Utrecht-Amersfoort was determined by OUDEMANS in the years 1879–80. The results were published in 1881 [99].

5.2.2 Determination of the difference in longitude between Leiden and Greenwich

In 1880–81 the postponed determination of the difference in longitude between the observatories of Leiden and Greenwich was carried out by VAN DE SANDE BAKHUYZEN and his brother E. F. VAN DE SANDE BAKHUYZEN, observer at Leiden Observatory. A final report of his determination is included in Volume 7 of the Annals of Leiden Observatory [100].

5.2.3 Determination of the difference in longitude between Leiden and Paris

The observations for this determination were made in 1884 by H. G. VAN DE SANDE BAKHUYZEN and lieutenant-colonel L. BASSOT. The results were published in [101].

5.2.4 Latitude, longitude and azimuth determination at Ubachsberg

The measurements at Ubachsberg, a station common to the triangulations of The Netherlands, Belgium and Germany, took place in 1893 at the request of Prof. Dr. F. R. HELMERT, director of the Central Office of the International Geodetic Association. The observations were carried out by H. G. VAN DE SANDE BAKHUYZEN and his assistants J. H. WILTERDINK and J. WEEDER. The latitude was determined using two differents methods, i.e. the Sterneck method and the Horrebow-Talcott method. The final results were published in [102]. At the same time Prof. Dr. Th. ALBRECHT and his assistant Mr. BORASS of the Royal Prussian Geodetic Institute determined the difference in longitude between Ubachsberg and Göttingen and Bonn [103].

5.2.5 Latitude and azimuth determinations at 13 stations of the Rijksdriehoeksmeting

Between 1896 and 1899 the latitude and an azimuth were determined at the following stations: Oirschot, Utrecht, Sambeek, Wolberg, Harikerberg, Sleen, Schoorl, Zierikzee, Terschelling (Brandaris), Ameland, Leeuwarden, Urk and Groningen. The purpose of these measurements was twofold: (a) to derive deviations of the vertical and (b) to determine a reference ellipsoid for the national network. The observations were carried out by A. PANNEKOEK (later professor of astronomy in Amsterdam) and R. POSTHUMUS MEYJES. Full details of these measurements were published in 1904 [104]. From the astronomical data of these stations and the geodetic data of the network, 13 values for the latitude and azimuth were computed for Amersfoort, the origin of the national triangulation network. The means of these 13 values were adopted as the geodetic latitude of Amersfoort and the azimuth Amersfoort-Utrecht (see section 3.3.6 and [1, pp. 132–139], [74, p. 26]).

5.3 *Polar motion observations at Leiden Observatory*

From 1899–1906 and from 1915–21 observations were carried out at Leiden Observatory to determine the variation in latitude as a result of polar motion. The observations were performed by J. W. J. A. STEIN (1899–1900). H. J. ZWIERS (1900–06) and C. DE JONG (1915–21). The results obtained by STEIN were published in [105] while a study of ZWIERS of the declinations and proper motion of stars used for this purpose in the period 1899–1906 appeared in 1918 [106]. ZWIERS and DE JONG completed their computations of the periods 1899–1906 and 1915–21 in 1921 and 1926, respectively [9, 1921, 1926]. Final reports about Zwiers' and De Jong's observations were apparently never prepared although the Commission had stated in 1924 that publication of Zwiers' work was desirable but owing to lack of funds it had to be postponed [107].

5.4 *Twin Laplace stations*

To check the national primary triangulation in connection with the readjustment of the European triangulation network, three twin Laplace stations, i.e. Leeuwarden-Ameland, Ubachsberg-Tongeren and Zierikzee-Goedereede, were determined in the period 1947-73. A detailed report of the measurements and the results obtained was published in 1975 [108].

5.4.1 Leeuwarden-Ameland
The longitude determination at both stations took place in 1947. Details of the measurements are described in [109]. The latitude and azimuth of both stations were determined in 1897 (see section 5.2.5.), the results of which were published in [104].

5.4.2 Zierikzee-Goedereede
The measurements for determining the longitude of Zierikzee and Goedereede were carried out in 1949 and 1950, respectively. The results of Goedereede are included in [108] and those of Zierikzee in [109]. The latitude of Zierikzee and the azimuth Zierikzee-Goedereede had been determined in 1897 [104]; the azimuth measurement was repeated in 1973 [108]. The measurements for the azimuth Goedereede-Zierikzee took place in 1969 [108], and those for the latitude of Goedereede in 1976 [115].

5.4.3 Ubachsberg-Tongeren
The primary station Ubachsberg was determined as a Laplace station in 1893 (see section 5.2.4). In view of some doubts about the polar motion correction and the reliability of the azimuth Ubachsberg-Sittard, it was in 1964 decided to undertake new measurements and make the stations Ubachsberg-Tongeren (Belgium) into a twin Laplace station [110]. The latitude, longitude and azimuth were simultaneously determined applying the Black method, the results of which were published in [111].

5.5 *Geodetic-astronomical observations at Curaçao during the International Geophysical year*

As one of the contributions of The Netherlands to the International Geophysical Year (1957–58) geodetic-astronomical observations were carried out at a temporary station established on the island of Curaçao (Netherlands Leeward Islands). This project, started August 1957 and completed January 1959, included:
- simultaneous determination of local time, longitude and latitude by equal altitudes of stars using a Danjon Impersonal Astrolabe;
- determination of local time and longitude by meridian transits of stars using a classic transit instrument;
- photographing the moon and surrounding stars using a Markowitz Moon Position Camera;
- determination of corrections to radio time signals by means of a specially constructed time oscillograph.

The originator and supervisor of this project was ROELOFS, then secretary and later president of the Commission. The results obtained were published in [112].

5.6 *Laplace stations in the high precision traverse Malvern-Graz*

At the joint symposium of the Commissions European Triangulation and Satellite Geodesy of the International Association of Geodesy, held in Paris 24th February-1st March 1969, a resolution was adopted recommending connecting the Western European Satellite observation stations by a high precision traverse between Malvern (U.K.) and Graz (Austria). In a meeting at Munich on 3rd November 1969 it was decided that distance measurements between primary stations should be carried out using tellurometers and geodimeters and that every second station should be determined as a Laplace station [113].

For The Netherlands this implied linking the satellite observation stations Delft and Kootwijk to the Belgian primary stations Kester and Tongeren, which are both included in the traverse Malvern-Graz, and determining the stations Axel 6, Rijswijk 3, Oss and Luiksgestel as Laplace stations. At Axel and Rijswijk the measurements were carried out in 1970 and the results were reported in [114]. Oss and Luiksgestel were observed in 1975. A report on the results obtained is in preparation.

5.7 *Astronomical observations for determining the deviation of the vertical*

In the years 1974–77 latitude and longitude were determined simultaneously at 25 stations, evenly spread over the country. Together with the results of the 7 Laplace stations, the deviation of the vertical is now known at 32 stations. This will allow drawing a more detailed map of the geoid in The Netherlands. The results of the astronomical observations were published in [115], a report on the geoid determination is being prepared.

6 **Pendulum observations and gravity measurements**

6.1 *Introduction*

Knowledge of the direction and the intensity of the gravity is essential for the determination of the figure of the earth. For that reason countries attending the first General Conference of the European Arc-measurement (Berlin, 1864) were requested to perform pendulum observations at astronomically determined stations [116, p. 30]. Some countries (Austria, France, Prussia, Switzerland) complied with this request. In The Netherlands pendulum observations were carried out in 1870 at Leiden Observatory during the determination of the longitude difference between Leiden and Bonn. The observations were not made by the staff of the observatory but by Dr. Th. ALBRECHT (Royal Prussian Geodetic Institute) using a reversible Repsold pendulum [[95, p. 177], [117, p. 109–162].

The Netherlands Geodetic Commission considered pendulum measurements also part of its duties towards the European Arc-measurement. In 1880 VAN DE SANDE BAKHUYZEN proposed performing pendulum observations at Leiden, Utrecht and Haarlem with the Repsold apparatus belonging to the "Teylers Stichting", a museum and a learned society at Haarlem [9, 1880], [119]. When a request to borrow this equipment met with a refusal, the Commission let the matter rest for some years.

Towards the end of the century, however, the importance of gravity measurements for determining the shape of the earth was internationally more and more emphasized. In particular, Prof. Dr. F. R. HELMERT, the director of the Central Office of the International Geodetic Association (Internationale Erdmessung) was very active in this respect. Moreover two instruments allowing more accurate measurements then became available, i.e. the *Defforges* instrument and the *Von Sterneck* instrument. The first one was manufactured by BIANCHI (Paris) and the second one by STÜCKRATH (Berlin).

Prompted by the developments abroad, the Commission decided in October 1890 to set up a subcommission, consisting of BOSSCHA and VAN DE SANDE BAKHUYZEN, to make the necessary preparations to start pendulum observations in The Netherlands too [120]. Two instruments were acquired for this purpose, a Defforges type in 1895 and a Von Sterneck one in 1905 [9, 1894, 1895], [9, 1905]. The timing equipment consisted of a Strasser und Rohde pendulum clock and a Nardin chronometer, received in 1904 and 1905, respectively. In the meantime several pendulum observations had taken place at Leiden Observatory, in 1892 by DEFFORGES using his own instrument, in 1895 by VAN DE SANDE BAKHUYZEN, his brother E. F. VAN DE SANDE BAKHUYZEN and J. H. WILTERDINK with the new Defforges-instrument of the Commission, in 1898 by Prof. GORE (Columbia University, Washington) with a Repsold apparatus and in 1900 by Prof. HAID (Karlsruhe) with a Von Sterneck instrument [9, 1892], [9, 1895]. [121], [122].

Serious discussions about starting the pendulum observations took place in the meetings of the Commission held in 1901 and following years. OUDEMANS, who first had agreed to supervise this project, asked to be relieved of this assignment when he discovered that the study of the mathematical-physical theories associated with it was too arduous a task for him at his age (he was 74 then!) [123], [124]. In 1903 MULLER became a member and he was willing to take over Oudemans' task [125]. He remained in charge of the gravity measurements until he resigned from the Commission in 1938 [9, 1938].

Several persons were initially considered for the actual making of measurements. R. POSTHUMUS MEYJES, who was then carrying out astronomical observations for the Commission, was proposed by OUDEMANS but the other members were of the opinion that he lacked the necessary theoretical background for such work (he was a former naval officer) [123], [126]. H. J. ZWIERS, who also had been making astronomical observations for the Commission, was appointed in 1906 but resigned some months later when he accepted a position as observer at Leiden Observatory. His place was taken by E. A. J. H. MODDERMAN, employed by the Commission for triangulation work since 1896 [9, 1906]. In 1907 MODDERMAN spent some time with Prof. L. HAASEMAN (Geodetic Institute, Potsdam) who instructed him in the practical use of the Von Sterneck instrument [9, 1907]. In 1908 he made with this instrument the first observations at the Delft Geodetic Institute, the headquarters of the Commission. Shortly, afterwards he fell ill and died a few months later [[9, 1908]. His sudden death in September 1908 caused a standstill in the work. In 1910 F. A. VENING MEINESZ, a newly graduated civil engineer, was engaged to take over Modderman's task [9, 1910]. After completing the necessary preparations, VENING MEINESZ started field work in 1913 and measured in the period 1913–21 a gravity network in The Netherlands, consisting of 51 stations.

In 1923 VENING MEINESZ started his famous gravity expeditions at sea for which he became world-famous. He developed his own equipment which was used until 1957 when more modern instruments became available for marine gravity work.

During the Second World War a detailed gravity network was measured in The Netherlands using gravimeters and torsion balances. After the war several gravity surveys were carried on land as well as at sea.

6.2 *Pendulum observations in The Netherlands, 1913–21*

VENING MEINESZ started his work in 1911 by checking the constants of the Defforges and Von Sterneck instruments and the timing equipment. He also trained himself in the practical

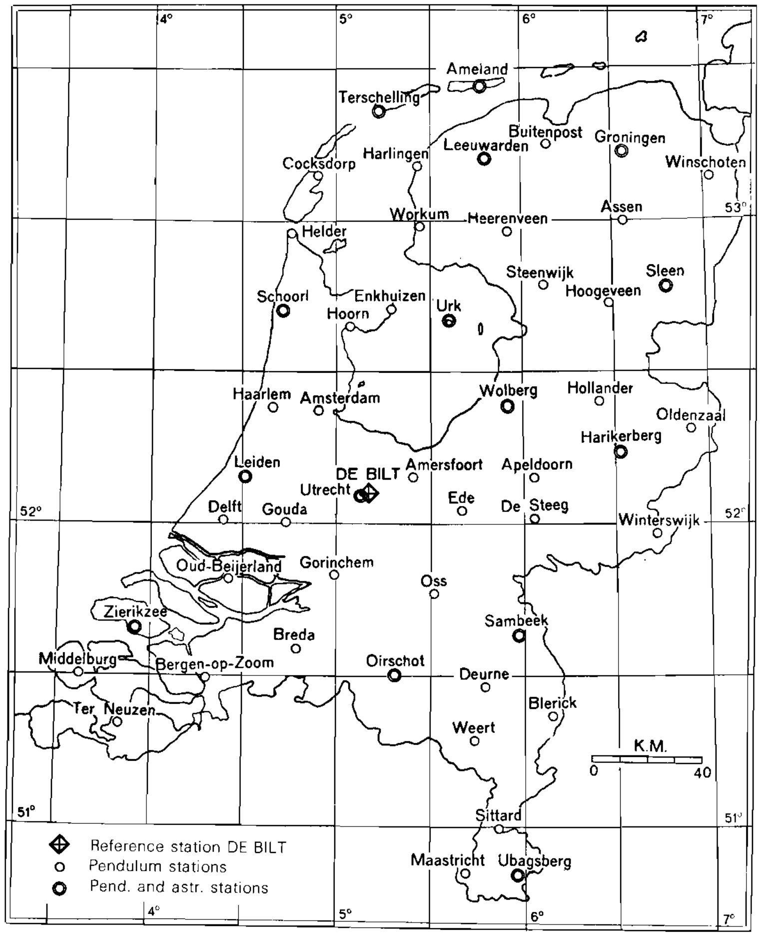

Fig. 5. Pendulum measurements in The Netherlands by VENING MEINESZ, 1913–1921.

use of the instruments and, like MODDERMAN, received some additional instruction from Prof. HAASEMANN in 1912. In 1913 he started fieldwork using both instruments. However, it proved that the observations made with the Defforges instrument were considerably less accurate than those obtained by the Von Sterneck instrument. Consequently only the latter instrument was used for all observations from 1914 onwards.

VENING MEINESZ soon discovered that the unconsolidated peat- and clay layers found at the surface in many parts of The Netherlands made pendulum measurements difficult. The micro-seismic movements of these layers had a totally different character compared with those of rock and sand surface layers encountered elsewehere. They were more violent, slower and irregular [9, 1913]. He made a thorough research of the effect of these oscillations on the pendulum movement and developed a method which made it possible to eliminate these disturbances. It resulted in a thesis, entitled "Contributions to the Theory of Pendulum Observations" for which he received a doctor's degree *cum laude* in 1915. In its simplest form the method developed by VENING MEINESZ consists of swinging two pendulums in the same plane on the same support with equal amplitudes and in opposite phase [127].

Consequently this so-called two-pendulum method was applied to measure 51 stations, evenly spread over the country, in the period 1913–21. The observations were made with the Von Sterneck instrument, in which four pendulums swing two by two in planes, perpendicular to each other [127]. As base station a site was chosen in the basement of the Royal Netherlands Meteorological Institute at De Bilt. The original choice, the Delft Geodetic Institute, proved to be completely unsuitable because of the above-mentioned movement in the soft surface layers. The difference in gravity between De Bilt and Potsdam was determined in 1913 and 1921. The computations were finalized in 1922 and a detailed report on the results obtained was published in 1923 [128]. In 1925 VENING MEINESZ used his instrument to carry out pendulum observations at Cambridge, Uccle, Paris and again at De Bilt and Potsdam for the interconnection of the gravity networks of The Netherlands, Belgium, U.K. and Germany [9, 1925].

6.3 *Gravity measurements at sea with the Vening Meinesz apparatus, 1923–57*

Prof. HELMERT not only had propagated gravity measurements on land but also at sea. At his request Prof. Dr. O. HECKER carried out observations in the Atlantic, Pacific and Indian Ocean and the Black Sea on board of surface ships in the period 1901–09. He determined gravity at sea by comparing the atmospheric pressure obtained with mercury barometers with that derived from the observed temperature of boiling water [129], [130], [131]. Since the results obtained did not come up to expectations, no further attempts were made using this method.

After the success of his two-pendulum method for determining gravity on land, VENING MEINESZ studied the possibility of applying the same method on board a surface ship. Of course in this case it would be necessary to eliminate the effect of much larger movements. He hit then upon a brilliant idea, that brought about substantial progress in the theory of pendulum measurements. He demonstrated that the effect of the component of the horizontal acceleration of the knife-edges in the plane of oscillation, by far the most important disturbance of the pendulum movement, could be eliminated by swinging two isochronous pendulums simultaneously on the same support in the same vertical plane. The difference of the angular displacements of these two pendulums is then unchanged. This angular difference may be regarded as the angular displacement of a fictitious pendulum with the same period as that of the original pendulums.

Trials on board a surface ship showed that observations would only be possible under exceptionally favourable weather conditions. In normal conditions the ship's movements would be still too large. Then the idea was born of making the observations on board a submerged submarine. Besides reducing the rolling and pitching of the ship, a submarine has the advantage that during submergence the ship is not subject to vibrations, a condition which is of vital importance for swinging pendulums. Trials also proved that it was necessary to provide the instrument with a photographic recording device since even the smallest movement of the submarine caused sudden changes in amplitude and phase which made visual observations impossible.

The method was tested using the Von Sterneck instrument on board of the submarine

K II during a voyage from The Netherlands to Java in the autumn of 1923. It proved to be a complete success. Based on the experience gained during the first voyage a new pendulum instrument was built, especially adapted to the method developed by VENING MEINESZ. The fundamental principle of the instrument is to record simultaneously the difference of the angular displacements of a pair of pendulums swinging in the same plane rather than photographing each pendulum separately. In this way the record became very regular and made the computations straightforward, less time-consuming and more accurate. The principle was incorporated in an apparatus with three pendulums swinging in the same plane. The recording light rays strike first the mirror of one pendulum of one pair and then the mirror of the other pendulum of the same pair and in this way a record of the corresponding fictitious pendulum was obtained. The same was done for the other pair.

In later years several improvements were made to the instrument. In particular should be mentioned the one resulting from a study by Mr. B. C. BROWNE (Cambridge) about the second-order corrections for the ship's movement published in 1937. BROWNE pointed out that these second-order corrections are not always negligible and that in the case of strong wave movements their effect on the gravity results may attain values of 10 milligals and more,

Date	Ship's route	Name submarine	Observer
Sept. 18–Dec. 24, 1923	Den Helder (Neth.)-Suez Canal-Java	K II	VENING MEINESZ
Oct. 15–Nov. 12, 1925	Den Helder-Alexandria (Egypt)	K XI	VENING MEINESZ
May 27–Dec. 13, 1926	Den Helder-Panama Canal-Java	K XIII	VENING MEINESZ
June 12–Aug. 12, 1929	Surabaya (Ind.) through the eastern part of the Indonesian Archipelago as far as New Guinea and back to Surabaya	K XIII	VENING MEINESZ
Oct. 8–Nov. 14, 1929	Surabaya, around the island of Celebes and back to Surabaya	K XIII	VENING MEINESZ
Jan. 2–Febr. 15, 1930	Surabaya, around the island of Sumatra and back to Surabaya	K XIII	VENING MEINESZ
July 5–Aug. 14, 1932	Den Helder-the Azores-Madeira and back to Den Helder	O 13	VENING MEINESZ
Nov. 14–July 11, 1935	Den Helder-Buenos Aires-Cape Town-Fremantle (Austr.)-Surabaya	K 18	VENING MEINESZ
Jan. 11–March 12, 1937	Den Helder-Washington-Lisbon	O 16	VENING MEINESZ
Nov. 23–Dec. 24, 1937	Curaçao-Den Helder	O 12	VENING MEINESZ
May 3–May 10, 1938	Den Helder-end of the English Channel-Den Helder	O 13	VENING MEINESZ NIEUWEKAMP
July 10–July 13, 1939	North Sea	O 19	
Sept. 15–Oct. 9, 1948	Rotterdam-Azores-Curaçao	O 24	BRUINS VESSEUR
March 1–April 7, 1949	Curaçao-Paramaribo (Surinam)-Casablanca-Rotterdam	O 24	BRUINS VESSEUR
Jan. 23–Apr. 22, 1951	Rotterdam-Lisbon-Curaçao-Key West-Azores-Rotterdam	Tijgerhaai	VENING MEINESZ BRUINS DORRESTEIN
Sept. 10–Sept. 23, 1956	Northern part of the North Sea	Zeeleeuw	COLLETTE SCHUILING
Nov. 18–Dec. 21, 1957	Caribbean Sea and the Pacific Ocean	Walrus	BAKKER OTTO

even if the observations are made in submerged submarines. By constructing in the instrument two additional pendulums of very long period, one for each component of the horizontal acceleration and each swinging in a vertical plane parallel to this component, the horizontal accelerations and with them the second-order corrections could be measured and computed.

VENING MEINESZ has given a detailed description of his instrument and the method of observation in [132] and [133]. At present the instrument is in the museum of the Department of Geodesy at Delft. The instrument was so unique that it was on several occasions borrowed by foreign institutes, namely the Geophysical Laboratory of the Carnegy Institution (1928), the Italian Geodetic Commission (1931), the Department of Geology of the Princeton University (1932), Comité National Français de Géodésie et Géophysique (1933/34, 1936), Geophysical Department of Cambridge University (1938, 1946), the Institute of Geophysics of the University of California, Los Angeles Branch (1953–56 [9, 1928, 1931, 1932, 1933, 1934, 1936, 1938, 1944–46, 1952–55]).

After the first successful gravity expedition at sea on board a submarine many more followed in the next few decades. This scientific work would not have been possible without the cooperation of the Royal Netherlands Navy. Their unfailing support is gratefully acknowledged. From 1923–39 VENING MEINESZ made all the observations personally but later this work was taken over by younger scientists. In the table op page 81 a summary is given of the various expeditions in chronological order. The 1957 expedition was a contribution to the International Geophysical Year.

Details of the various expeditions and final results obtained were published in "Gravity Expeditions" Vol. I-V [134], [135], [136], [137] and [138] and the tables used for computing regional and local isostatic reduction in [139]. During the Second World War J. E. DE VOS VAN STEENWIJK computed deviations of the vertical from the gravity observations in the eastern part of the Indonesian Archipelago. The results were published in [140].

6.4 *Gravity measurements at sea using surface ships, 1955–78*

After the Second World War remote control gravimeters came into use for measurements in shallow waters. These instruments were lowered from a surface ship and placed at the bottom of the sea. All other operations such as levelling the instrument and taking the readings were done on board of the ship using remote control. In this way the southern part of the North Sea was surveyed in 1955 by Dr. B. J. COLLETTE. The instrument used was a North American gravimeter and remote control equipment developed by the American geophysical exploration firm Robert Ray. In 1957 a detailed gravity survey was made of the Moray Firth (Scotland) using the same type of equipment. The results of both surveys were published in [138].

In 1964–65 the "Snellius" a surveying vessel of the Royal Netherlands Navy, carried out the third part of the NAVADO-project* (NAVADO III). Ten east-west crossings were made on the Atlantic along the parallels between 22° and 49° North during which gravity observations were made under auspices of the Netherlands Geodetic Commission. The measurements were carried out by G. L. STRANG VAN HEES of the Department of Geodesy

* NAVADO is an abbreviation of "North Atlantic Vidal and Dalrymple Oceanography" named after the two British naval surveying ships originally selected to carry out this project. The "Snellius" replaced the "Dalrymple".

of the Delft University of Technology. The instrument used was an Askania sea gravimeter Gss-2. This instrument, placed on a gyroscopically stabilized platform, allows observations to be made on a moving ship. The results of NAVADO III were published in [141], [142] and [143].

In 1964 during NAVADO III gravity observations were made with the Askania sea gravimeter on board of the "Snellius" along some lines in the Caribbean Sea near the Netherlands Leeward Islands Aruba, Bonaire and Curaçao. It was an extension of the gravity survey on these islands carried out in 1962 by R. A. LAGAAY. The results of both surveys are included in [144, part II].

In 1966 and 1969 gravity measurements were carried out in the coastal waters of Surinam. The observations were again made with the Askania sea gravimeter on board of the surveying vessels "Snellius" (1966) and "Luymes" (1969). The final results were published in [145] and [146].

6.5 *Gravity measurements in The Netherlands, 1937–78*

At the request of the Commission pendulum measurements were made at about 60 stations by Dr. J. J. PANNEKOEK VAN RHEDEN in the years 1937–39. The instruments used were Holweck-Lejay pendulums borrowed from the Bataafsche Petroleum Maatschappij (now called Shell International Petroleum Company) and the "Hollandsche Maatschappij van Wetenschappen" (a learned society at Haarlem) [9, 1937, 1938, 1939].

During the Second World War detailed gravity surveys were carried out in certain parts of the country in which the Netherlands Geodetic Commission, the Bataafsche Petroleum Maatschappij (BPM), the Geological Institutes of the Universities of Leiden and Utrecht and the Dutch State Mines collaborated. The instruments used were torsion balances and Thyssen and Graf gravimeters. After the war this survey was continued by BPM. A Bouguer isogam map in colour, compiled by BPM and based on 26,400 readings, was published in 1957 [147]. A copy with more colours is included in the Atlas of The Netherlands [148].

In 1952, BRUINS, the present president of the Commission, took the initiative to include in the curriculum of the Department of Geodesy of the Delft University of Technology knowledge and handling of gravimetric instruments in addition to the theoretical principles of gravimetric geodesy. For this purpose several types of gravimeters (Askania Gs 9, Worden, North American) were acquired to train students in fieldwork. These instruments were calibrated on the German base line Bad Harzburg-Torfhaus. These calibrated gravimeters were used to establish a gravimeter base line in The Netherlands between De Bilt and Eindhoven in the years 1956–57 [79, 1954–57].

A new primary gravity network, consisting of 52 stations was measured in the years 1960–63 by G. L. STRANG VAN HEES. The instruments used for these measurements were an Askania Gs 9, a Worden and three North American gravimeters. The new network was connected to a number of primary gravity stations of the German and Belgian networks. The base line for calibrating gravimeters between De Bilt and Eindhoven was then for practical reasons replaced by the base Schiphol Airport-Eindhoven. Schiphol became then the national reference station instead of De Bilt, in use since VENING MEINESZ started his measurements in 1913.

In 1971 the connection between the network of The Netherlands and Germany was strengthened by making accurate measurements in a network comprising the Dutch stations Delft, Schiphol, Utrecht, Eindhoven, Arnhem and the German stations Werl, Hamburg, Hannover, Bad Harzburg, Torfhaus. The German stations, with the exception of Werl, are included in the International Gravity Standardization Net 1971 (IGSN 71). The measurements were made with a Worden, a North American and two LaCoste-Romberg gravimeters. Based on these results the primary gravity network of The Netherlands was recomputed. The results were published by the Deutsche Geoditische Kommission in 1973 [149]. In 1975 the primary network was remeasured using a Worden and two LaCoste-Romberg gravimeters. The results of this remeasurement are included in [9, 1973–75].

In 1978 a high precision gravity survey was carried out across the Groningen gasfield. The purpose of this survey was to determine, in conjunction with precision levelling, the surface subsidence as a result of gas production from the subsurface.

6.6 *Gravity measurements in Surinam and the Netherlands Leeward Islands, 1957–62*

In 1957, VELDKAMP carried out gravity measurements in Surinam along the Marowijne river and the railway track Paramaribo-Dam. The instrument used was the Askania Gs 9 gravimeter belonging to the Commission. This project was one of The Netherlands' contributions to the International Geophysical Year. The results were published in [138, part III].

Since the results obtained in 1957 appeared to be of much interest, it was decided to extend the survey to the coastal area of Surinam. The measurements were made in 1958 and 1960 by J. J. G. M. VAN BOECKEL, Veldkamp's assistant in 1957. The instruments used were the Askania gravimeter of the Commission and two Worden gravimeters belonging to Shell International Petroleum Company and Geological and Mining Service in Surinam. The final results and interpretation were published in 1973 [144, part I].

In 1966 and 1969 this gravity survey was extended on the continental shelf by G. L. STRANG VAN HEES with the Askania sea gravimeter (see section 6.4). The final results and interpretation were published in [145] and [146]. In 1976 a gravity survey was made in the Kabalebo area with a Worden gravimeter and in 1978 measurements were made in the southern part of Surinam along the levelling lines with two Worden gravimeters by L. HERINCKX.

In 1962, R. A. LAGAAY carried out a gravity survey on the Netherlands Leeward Islands Aruba, Bonaire and Curaçao. The measurements were made with a North American gravimeter. In 1964 this gravity survey was extended to the coastal water using an Askanian sea gravimeter (see section 6.4). The results of the whole survey were published in [144, part II].

7 **Precise levelling**

7.1 *First precise levelling*

Completing the precise levelling, started by COHEN STUART in 1875 but interrupted by his sudden death in 1878, was included in the terms of reference of the Netherlands Geodetic Commission when it was set up in 1879 (see section 1). The measurements were resumed in 1879 under the direction of the subcommission levelling (VAN DE SANDE BAKHUYZEN and VAN DIESEN) applying the same method as that used by COHEN STUART. Details of this method are described in [150], [151], [152]. Fieldwork and computations were directed by VAN DE SANDE BAKHUYZEN since Van Diesen's official duties did not permit him to take

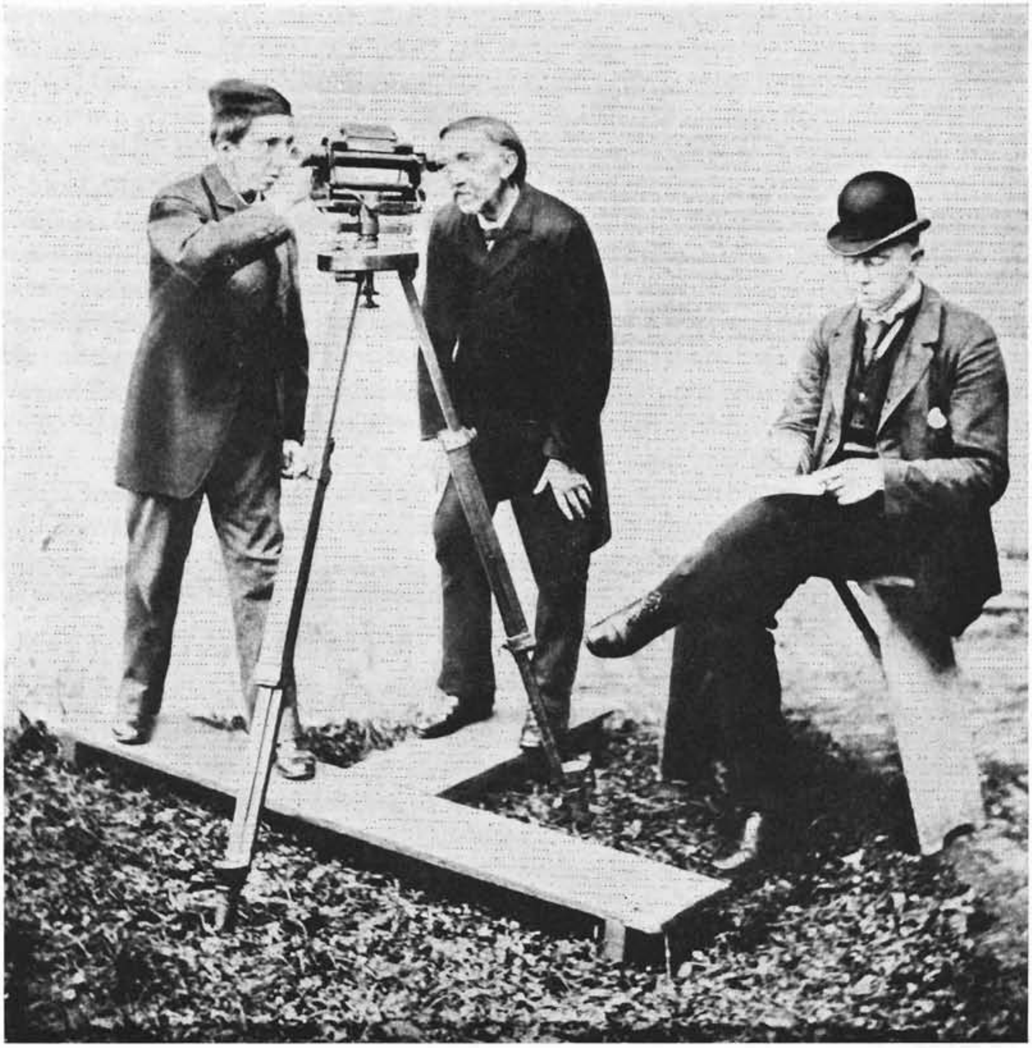

Fig. 6. First precise levelling. Van de Sande Bakhuyzen taking a reading.

an active part in this project. Pressure of work forced VAN DE SANDE BAKHUYZEN in his turn to give up the direct supervision from 1st July 1881–1st September 1883. C. LELY, a young civil engineer (who later became famous for his Zuyderzee land reclamation project) relieved him during that period [152].

Fieldwork was carried out during the summer by 2–4 parties, each party comprising 8 persons, i.e. one young civil engineer (party leader), two undergraduates of the "Polytechnical School" (now known as Delft University of Technology), two rodmen and three helpers. The short measuring season and the frequent changes in personnel had an adverse effect on the progress of the work [152].

The Minister of the Interior, thinking only in terms of money, became impatient. In the covering letter to the annual report of 1882 the Commission stated that fieldwork would be completed in 1885 [25]. The minister inquired in his letter of 13th March 1884 whether it was possible to curtail the programme in such a way that it could be completed in 1884 [28]. The Commission replied in the covering letter to the report about Stamkart's work [29] that a reduction of the original programme was not advisable and a guarantee that fieldwork would be completed in 1884 could also not be given. In a letter dated 16th June 1884 the minister informed the Commission that only a small sum of money would be allocated for levelling in 1885 [33]. When in the beginning of 1885 a substantial amount was required, the minister became really annoyed. He demanded an explanation and a detailed cost estimate for the work still to be done. At the same time he informed the Commission that after 1885 no more money would be made available for the levelling work. And this decision was irrevocable, he added [153]. The Commission actually succeeded in completing the fieldwork in 1885 [154] and the computations were finalized in the next few years. The precision obtained was very good: for the whole network a standard deviation of 0.75 mm per km. The final results were published in 1888 [150].

The Commission considered this part of its task then completed and proposed to the minister that the General Service of "Rijkswaterstaat" (Department of Public Works) be charged with the maintenance of the levelling network and replacing, if necessary, the benchmarks. By letter of 29th December 1888 the minister agreed to this proposal [9, 1888], [152].

7.2 *Second, third and fourth precise levellings*

The second, third and fourth precise levelling were carried out by Rijkswaterstaat in the years 1926–40, 1950–59 and 1964–77, respectively. In part III-13 these levellings are described in some detail.

The second levelling was undertaken after the Netherlands Geodetic Commission had recommended a repeat of the first levelling to the Minister of Public Works. The director of the General Service of Rijkswaterstaat, in charge of this work, was advised about the method to be employed [9, 1925, 1926].

The third and fourth levellings were regularly discussed in meetings of the Commission and their progress was reported in the annual reports [9].

7.3 *United European Levelling Net (UELN)*

At the 10th General Assembly of the International Association of Geodesy (IAG) held in Rome in 1954 a resolution was adopted recommending a joint adjustment of the European levelling networks [155]. Details of how this should be done were worked out at a symposium organized by IAG-Commission II (International Commission for European Levelling) held in Florence in 1955. It was decided that this adjustment would be computed independently by three institutions, i.e. Deutsches Geodätisches Forschungsinstitut (Munich), Institut Géographique National (Paris) and the Computing Centre of the Geodetic Department of the Delft University of Technology. The latter institute is headed by BAARDA, the present secretary of the Netherlands Geodetic Commission. The results of the Delft computations were published by the Commission in [156].

7.4 *North West European Lowlands Levelling (NWELL)*

The 13th General Assembly of IAG, held at Berkeley in 1963, adopted a proposal to adjust the levellings of the northwest European coastal region into one system, the North West European Lowlands Levelling, in order to form a base for future research on recent crustal movements. A special working group was set up for this purpose in which WAALEWIJN, the present head of the Survey Department of Rijkswaterstaat, represented The Netherlands. The adjustment was performed by the Geodetic Institute of the Technical University Hannover (Germany) under the direction of Prof. Dr. J. NITTINGER. The adjusted heights of the nodal points together with their accuracy and the basic data were published in a report presented at the 15th IAG General Assembly (Moscow 1971) [157]. The heights of the intermediate bench marks lying on the NWELL-lines between the nodal points were computed in the NWELL-system by each country individually. The results of The Netherlands, computed by the Survey Department of Rijkswaterstaat, were published by the Commission in 1975 [158].

8 Tidal observations

In the letter of 17th December 1878 from the Science Division of the Royal Netherlands Academy of Sciences to the Minister of the Interior, the origin of the Netherlands Geodetic Commission, it was proposed to include tidal observations in its terms of reference [6].

In 1853 the Science Division had established the "Commissie voor het onderzoek van de daling van de bodem in Nederland" (Committee for the Investigation of Surface Subsidence in The Netherlands). The committee consisted of three members and STAMKART was one of them. Computing mean sea level from tide gauge observations was an essential part of its work. The computations were carried out according to a method devised by STAMKART [159].

In the first years of its existence the Netherlands Geodetic Commission supervised the computations of the records of the automatic tide gauge at Den Helder. The actual work was done by two school teachers in their spare time but progress was very slow. They had started with the observations of 1854 but in 1880 they only had advanced up to 1868. It was then decided to continue the computations with the observations of 1880 and leave the period 1868–80 for the time being [9, 1880]. This procedure was continued until Stamkart's death in 1882. Since he was the last living member of the above-mentioned committee (the other two had died earlier and had not been replaced), the Science Division of the Royal Netherlands Academy of Sciences asked the Netherlands Geodetic Commission for advice on whether a new committee should be appointed to continue the original task. The matter was investigated by VAN DE SANDE BAKHUYZEN and SCHOLS. They concluded that setting up a new committee should be postponed until the data of other automatic tide gauges erected in the meantime by "Rijkswaterstaat" (Department of Public Works) along the coasts of the North Sea and the Zuyderzee had been worked out. Their argument was that in conjunction with the precise levelling then being carried out a better insight could be gained about possible subsidence of the surface in The Netherlands. The decision was then also taken to stop the computations of the data of Den Helder in the way it was then being done and resume them at a later date in another manner [159], [9, 1883].

In 1884 the Commission investigated the difference between mean sea level at Amsterdam and the Amsterdam Ordnance Datum (AP = Amsterdams Peil). From a study of the observations in the period 1856–71 it appeared that the mean derived from *all* the hourly observations during a whole year was, except for a single millimetre, equal to the mean of the same year computed from observations at twelve noon only. This, of course, simplified the computations considerably [9, 1884]. In 1889 a report was submitted to the International Geodetic Association (now called International Association of Geodesy) giving the difference between mean sea level and AP at Den Helder and 8 other tide gauges along the coasts of the North Sea and Zuyderzee.

Mean sea level at Den Helder in the years 1854–67 and 1880–81 was computed using the earlier obtained figures (see above). For the mean of the period 1851–88 VAN DE SANDE BAKHUYZEN acted as follows: In studying a period of 19 years he had discovered that the difference between the yearly mean derived from half tide and the mean of all observations in the same year was almost constant. For Den Helder this figure averaged 106.4 mm. Since the means for half tide were being published in the Journal of the Royal Institution of Engineers the difference between mean sea level and AP at Den Helder could in this way be computed easily. Mean sea level at nine other tide gauges for the period 1884–88 was computed by the General Service of Rijkswaterstaat from the observations at 02.00, 05.00, 08.00, 11.00, 14.00, 17.00, 20.00 and 23.00 hours. Test computations had shown that the mean obtained in this way differed only a few millimetres from the mean derived from the hourly observations [9, 1889]. In 1890 and 1891 the General Service of Rijkswaterstaat continued the computations using this method for ten and six tide gauges respectively [9, 1890, 1891].

In 1892 a start was made with the derivation of a formula that could be used to predict high and low tide at certain places along the coast. Applying the method of harmonical analysis developed by THOMSON and DARWIN for this purpose, the constants in this formula for Den Helder were determined using the tide gauge data of the years 1880–82 and 1892. In 1894–95 the constants of IJmuiden and Hoek van Holland were computed from the data observed at these places in 1892 and 1893 [9, 1892–95]. In 1895 and early 1897 tide tables were computed and published for Hoek van Holland and Den Helder, predicting the tides at these places in 1896 and 1897. Since from 1897 onwards tide tables are being published by the General Service of Rijkswaterstaat, the Commission considered this no longer a part of its task.

9 International relations

Maintaining contacts with international organizations in the field of geodesy and allied sciences is one of the duties of the Netherlands Geodetic Commission. In the course of the past one hundred years several members have played a prominent role in these organizations or made important contribution to their scientific work. A summary of the Commission's international activities is given in the next sections. A more detailed account is given in the annual reports [9].

9.1 *International Association of Geodesy (IAG)*

The Netherlands has been a member of the International Association of Geodesy and its predecessors, European Arc-measurements and International Geodetic Association (see note p. 51), since 1865. The first national representative in this organization was Prof. Dr. F. KAISER, director of Leiden Observatory. After his death, in 1872, he was succeeded by STAMKART. After its creation in 1879, the Netherlands Geodetic Commission took over the task of representing the country in the IAG. Members of the Commission have since then attended the General Conferences (now known as General Assemblies), held normally every three years, and the meetings of the "Permanent Commission" which met almost every year until 1895. The Permanent Commission, originally a sort of executive committee, became then mainly a consultative body with no regular meetings [10], [16]. In 1882 the Commission hosted a meeting of the Permanent Commission in The Hague. In 1886 VAN DE SANDE BAKHUYZEN was elected a member of the Permanent Commission and in 1900 he became permanent secretary (now called secretary-general) of the International Geodetic Association. In 1912 at the General Conference in Hamburg the fiftieth anniversary of the association was celebrated and on this occasion VAN DE SANDE BAKHUYZEN presented a report on the development of the IAG since 1862 [160].

During the First World War the International Geodetic Association officially ceased to exist. The convention between the adhering nations was always concluded for a period of ten years and on the 31st December 1916 such a period expired. A renewal of the convention was then of course out of the question. The Netherlands and Switzerland, however, took the initiative of continuing some of the international work, in particular that of the International Latitude Service which studied the polar motion from 1898. As a result, the Reduced Geodetic Association among Neutral Nations (Association Géodésique réduite entre États neutres) was established in 1917 with Prof. Dr. R. GAUTIER, president of the Swiss Geodetic Commission, as president and VAN DE SANDE BAKHUYZEN as secretary. The following countries joined the Reduced Association: Denmark, Norway, The Netherlands, Spain, Sweden, Switzerland and the United States until it entered the war. Spain resigned in 1920 after joining the International Union of Geodesy and Geophysics [9, 1916, 1922], [10], [16].

The International Union of Geodesy and Geophysics (IUGG) was established in 1919 and subdivided in a number of "Sections". The Geodetic Section, the name of which was changed in International Association of Geodesy (IAG) in 1930, continued the work carried out by the International Geodetic Association before the First World War. A report on the international geodetic activities during the period 1912–22, prepared by VAN DE SANDE BAKHUYZEN, was submitted to the first IUGG General Assembly held in Rome in 1922 [161]. At the same Assembly the members of the Reduced Association pleaded for autonomy of the Geodetic Section. They argued that its predecessors had always been independent but now the section would be subject to the rules and regulations of IUGG. As a compromise the members of the Reduced Association were allowed to join the Geodetic Section without the obligation of adhering to IUGG as a whole. However, this should be considered as an exception and only for a limited time. As a result The Netherlands became a member of the Geodetic Section in 1923 and a full member of the IUGG in 1927. Consequently a National Committee for the IUGG was set up with Heuvelink as its first president [9, 1922, 1923, 1927], [10].

Also at the 1922 Rome Assembly of the IUGG it was decided that the International Latitude Service would continue its work under joint sponsorship of the Geodetic Section and the International Astronomical Union. The liquidation of the Reduced Association was entrusted to the presidents of the Swiss and Netherlands Geodetic Commissions GAUTIER (after his death in 1931 succeeded by Prof. Dr. C. F. BAESCHLIN) and MULLER (successor of VAN DE SANDE BAKHUYZEN who died early 1923). Their main task was to prepare a publication on the results of the International Latitude Service during the period 1912–22 which finally appeared in 1932 [9, 1922, 1932], [10].

After the resumption of the international geodetic cooperation in 1922, many a member of the Netherlands Geodetic Commission took an active part in the work of the sections, commissions and special study groups (SSG's) of the IAG, just like their predecessors in the pre-war organizations. In particular should be mentioned Vening Meinesz' pioneering work in the field of gravity measurements at sea (see section 6). After an interruption due to the Second World War new international geodetic projects were taken in hand by the IAG such as the readjustment of the European triangulation, the adjustment of the European levelling network, recent movements of the earth's crust, satellite geodesy, etc. All these new projects were actively supported by the Netherlands Geodetic Commission.

In 1959 the Commission acted as host to a meeting of representatives of the computing centres carrying out the adjustment of the United European Levelling Net (UELN) (see section 7 and Part III-13) and in 1961 to a meeting of experts reorganizing the International Geodetic Bibliography [9, 1958–60, 1961–63]. Both these IAG-projects were strongly supported by the Commission and the meetings were held at Delft.

In 1977 the "International Symposium on Electromagnetic Distance Measurement and the Influence of Atmospheric Refraction" was held at Wageningen. It was sponsored by the IAG (SSG 1.42: Electromagnetic Wave Propagation and Refraction in the Atmosphere) and hosted by the Netherlands Geodetic Commission and the Agricultural University at Wageningen.

The most important international geodetic projects to which the Netherlands Geodetic Commission has contributed since its establishment are:

- unification of the European geodetic triangulations (European Arc-measurement), including base measurements, latitude, longitude and azimuth determinations and determining deviations of the vertical (see sections 3, 4.2, and 5.2);
- polar motions observations (see section 5.3);
- pendulum and gravity observations (see section 6);
- readjustment of the European triangulation, including measuring new bases and Laplace stations (see sections 4.3, 4.4 and 5.4);
- adjustment of the European levelling network (see section 7.3);
- International Geophysical Year (see sections 5.5, 6.3 and 6.6);
- NAVADO-project (see section 6.4);
- North West European Lowland Levelling (NWELL) (see section 7.4);
- determinations of the deviations of the vertical (see section 5.7).

Since the first General Assembly of the IUGG and the IAG in 1922, some members have held important positions in these organizations:

- HEUVELINK was a member of the executive committee of the IAG from 1922–30;

- VENING MEINESZ was president of the IAG from 1933–48 and president of the IUGG from 1948–51;
- ROELOFS was president of IAG-section III (Geodetic Astronomy) from 1957–60.

At present the following members participate in the work of several IAG-sections, Commissions and Special Study Groups (SSG's):

- AARDOOM is secretary of Section II (Space Techniques) and a member of SSG's 1.26 (Contributions from Satellite Geodesy to Terrestrial Geometric Geodesy) and 4.45 (Mathematical Structure of the Gravity Field);
- BAARDA is a member of the subcommissions European Triangulation and European Levelling of Commission X (Continental Networks), a member of Commission IX (Education in Geodesy), president of SSG 4.14 (Statistical Methods as Applied to Specifications of Networks), a member of the SSG's 1.21 (Numerical Computation of Large Triangulation Networks), 4.38 (Computer Techniques in Geodesy) and 4.45 (Mathematical Structure of the Gravity Field);
- BRUINS is a member of Commission III (International Gravimetric Commission);
- WAALEWIJN is president of subcommission European Levelling of Commission X (Continental Networks) and a member of SSG 5.22 (Mean Sea Level and Coastal Geodesy).

9.2 *International Society for Photogrammetry* (*ISP*)

The International Society for Photogrammetry, established in 1910 by Prof. Dr. E. DOLEŽAL (Austria), dormant during the First World War and some years afterwards, was revived after the second International Congress for Photogrammetry held in Berlin in 1926. Three members of the Netherlands Geodetic Commission, SCHERMERHORN, ROELOFS and VAN DER WEELE have since then played an important role in the ISP.

SCHERMERHORN, having fully recognized the possibilities of aerial photogrammetry after some earlier doubts, attended the second and third congresses (Berlin, 1926 and Zürich, 1930) as a private member of the ISP. However, he soon realized that a national membership of ISP was essential for The Netherlands and consequently The Netherlands Association for Photogrammetry was formed on his initiative in 1932. SCHERMERHORN was chosen as its first president and retained this position until 1945. At the fourth ISP congress (Paris 1934) he presented the national report on photogrammetry in The Netherlands for the period 1930–34. Since then and up to 1964, the national report has been presented by him at each successive ISP congress. In 1938, at the Rome congress, SCHERMERHORN was elected president of the ISP, a position he was to hold until the next congress at Scheveningen in 1948. This congress, which originally was planned for 1942, was a great success. After his retirement as president SCHERMERHORN continued to serve the ISP as a member of the council until the London congress (1960). In 1952 at the Washington congress he was made an honorary member of ISP.

In 1938, SCHERMERHORN and his great friend Prof. O. VON GRUBER (Zeiss-Jena) founded the international journal "Photogrammetria". At the Paris congress (1934) it became clear that in the coming years many new applications of photogrammetry would be developed and it was felt that a scientific journal was needed for disseminating knowledge about these new developments. The plan for a new journal was further elaborated by SCHERMERHORN and VON GRUBER. The first number of Photogrammetria, edited by SCHERMERHORN, appeared just before the fifth ISP congress (Rome, 1938). It was well received by the General Assembly with the result that the ISP adopted Photogrammetria as its official journal. Soon after the outbreak of the Second World War SCHERMERHORN and VON GRUBER withdrew from the editorial staff. Publishing an international journal in Berlin (as had been the case up till then) was in their opinion no longer possible. VON GRUBER died in 1942 and it was not until 1948 that SCHERMERHORN undertook the revival of Photogrammetria in collaboration with ROELOFS (then secretary of the Netherlands Geodetic Commission). SCHERMERHORN continued to serve the journal as editor-in-chief until 1968. At the 11th ISP congress (Lausanne) he handed in his resignation; as his successor was appointed VAN DER WEELE who is still editor-in-chief at present. ROELOFS, who carried out an appreciable part of the editorial task between 1949–60 resigned from the editorial board in 1964 [162].

In 1972 at the 12th congress (Ottawa) VAN DER WEELE was elected a member of the council of the ISP and acted as treasurer during the period 1972–76. In 1976 at the Helsinki congress he was appointed a member of the financial committee of the ISP.

In 1953, SCHERMERHORN and VAN DER WEELE were chosen as members of the executive committee of the European Organisation for Experimental Photogrammetric Studies (Organisation Européenne d'Études Photogrammétriques Expérimentales, OEEPE)*. SCHERMERHORN, one of the co-founders of this organization, resigned in 1964 because of his age.

In 1950, SCHERMERHORN founded the International Training Centre for Aerial Survey (ITC), now called International Institute for Aerial Survey and Earth Sciences. In 1949, he was invited by the Secretary-General of the United Nations to become a member of a small commission of experts to advise on what this organization could do in the field of mapping. In particular emerging countries felt the need for reliable maps to develop their natural resources. SCHERMERHORN recognized the unique possibility of an international training centre for aerial survey as an important contribution to a programme of international development cooperation. As a result he was requested by the United Nations to set up such a centre for students of developing countries. He succeeded in obtaining the government's approval and the necessary funds to establish the centre at Delft. Details of its foundation are described by SCHERMERHORN in [163]. He was appointed as its first director. After his retirement in 1964 he was succeeded by VAN DER WEELE. Since 1950 ITC has developed into an internationally recognized centre for education and research in all applications of aerial survey. At present more than 200 students per year come from all parts of the world and in many a developing country the management of aerial surveying is in the hands of graduates of ITC. Personally SCHERMERHORN considered ITC as the most important achievement of his scientific career. In 1960 ISP honoured him with the Brock Gold Medal for his work in founding and directing ITC.

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* OEEPE is an inter-governmental organization in which Austria, Belgium, Germany, Italy, The Netherlands and Switzerland cooperate. It was created in response to wishes expressed by various commissions of ISP, especially commission III (Aerial Triangulation) at the Washington-congress (1952). Its object is to increase the accuracy, quality and efficiency of aerial surveys by speeding up the development and improvement of photogrammetric methods, in particular by arranging and carrying out, in mutual cooperation, a joint programme of experimental research.

9.3 *International Federation of Surveyors FIG (Fédération Internationale des Géomètres)*

In 1878, during the world fair, surveyors of seven countries, Belgium, France, Germany, Italy, Spain, Switzerland and the United Kingdom met in Paris at the invitation of the "Comité Central des géomètres français". This meeting, held in the "Palais du Trocadéro", is considered to be the beginning of FIG. However, neither this first congress nor the second one in Brussels in 1910, also held during the world fair, did result in a permanent international organization. More successful in this respect was the third congress in 1926, again held in Paris. This time FIG was firmly established with statutes and rules and a governing body consisting of a "Bureau" and a "Permanent Committee"*. As members are eligible national associations of surveyors or professional organizations in related fields. R. DANGER (France) and J. S. ROUPCINSKY (Belgium) who did much of the preparatory work must be credited for this third attempt to put FIG on a more firm footing. The Netherlands' organization of surveyors joined in 1927 [164], [165], [166] and [167]. The First and Second World Wars interrupted of course all FIG-work.

The Netherlands Geodetic Commission was not represented at the first three FIG congresses but the fourth congress (Zürich, 1930) and every congress since then was attended by members of the Commission and several of them actively participated in the work of FIG.

In 1951 at the meeting of the Permanent Committee in Luxemburg KRUIDHOF, then president of the Netherlands Federation of Surveyors, was elected as one of three vice-presidents of FIG. In 1953 at the 8th congress in Paris he officially accepted the invitation to hold the next congress in The Netherlands. Consequently the Bureau had its seat in Delft during the period 1956–59 with ROELOFS as president, KRUIDHOF as one of the vice-presidents and BAARDA as secretary-general [169, p. 76, 220]. The 9th congress, held in Scheveningen and Delft in 1958, proved to be a great success [170]. ROELOFS and BAARDA continued to serve the Bureau as vice-president and consultative member, respectively, until the 10th congress (Vienna, 1962). At meetings of the Permanent Committee in 1959 (Cracow) and Brussels (1960) they were nominated honorary president (ROELOFS) and honorary member (BAARDA) for their services rendered to FIG. In 1968 at the 12th Congress (London) BAARDA delivered one of the keynote addresses entiteld "The Future of the Géomètre" [171].

WITT has been a member of Commission 7 (Cadastre and Rural Land Management) since 1955. During the period 1976–78 he was vice-president and in 1978 he was elected president of this Commission. Its yearly meetings were held in Delft in 1957 and 1969; both of them were sponsored by the Netherlands Geodetic Commission and hosted by WITT.

In 1958 at the 9th congress (Scheveningen and Delft) it was decided to transfer the International Office of the Cadastre and Land Registry OICRF (Office International du Cadastre et du Régime Foncier) from Switzerland to The Netherlands. This institution, originally called Office International du Régime Foncier (OIRF), was established in 1932 to study

* The Bureau is composed of the president, vice-presidents, secretary-general and treasurer of FIG. These officers are elected by the General Assembly, meeting during each congress, and on the proposal of the country organizing the next congress.
The Permanent Committee is the administrative council of FIG. It is composed of members of the Bureau, and delegates from the national affiliated associations.

cadastral systems and to collect documents on land registration. Since its creation this institution had been under the direction of Prof. Dr. L. HEGG (Lausanne) but pressure of work forced him to resign in 1958. MEELKER, then director of The Netherlands' Cadastral Service, offered to continue the work with assistance of his staff. He became the new president of OICRF and remained in office until his death in 1968 [168, pp. 224–225], [170, pp. 77, 89].

The FIG Multilingual Dictionary (Dictionnaire multilingue de la FIG), the work on which was started in 1932, was finally published in 1963 [172]. It contains 5500 terms, all defined in the basic language French with their equivalents in German and English. The editing of the dictionary was done by F. HARKINK, then a member of the subcommission Geodetic Terminology of the Netherlands Geodetic Commission, while ROELOFS negotiated the printing with the publishing house "Argus". HARKINK also prepared the Dutch index to this dictionary which was published in 1966 by the Netherlands Federation of Surveyors in collaboration with the Netherlands Geodetic Commission [173].

9.4 *International Cartographic Association* (*ICA*)

In 1959 representatives of the cartographic societies of Austria, Belgium, Germany, Finland, France, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, United States and the United Kingdom founded in Bern the International Cartographic Association. Since then former and present members (cartographers) of the Netherlands Geodetic Commission have been active as officer, member of special committees or as speaker of ICA Technical Conferences and General Assemblies.

In 1964 at the second ICA-congress in London ORMELING was elected secretary-treasurer. He remained in office until the fifth congress (Moskow, 1976) when he became president for the period 1976-80. The third ICA Technical Conference was held in Amsterdam in 1967. KOEMAN was on this occasion chairman of the Exhibition Committee. He organized one of the three exhibitions called "World on Paper". One of the technical sessions, having as subject "Airphoto and Map", was presided by VAN DER WEELE [9, 1967–69].

In 1970 at the fifth International Conference in Stresa (Italy) KOEMAN delivered a lecture entitled "The Principle of Communication in Cartography". At the 4th International Conference on the History of Cartography (Edinburgh, 1971) he lectured on "Life and Works of Willem Janszoon Blaue" [9, 1970–72].

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Appendix I

LEDEN RIJKSCOMMISSIE VOOR GRAADMETING EN WATERPASSING EN RIJKSCOMMISSIE VOOR GEODESIE IN DE PERIODE 1879–1979 (MEMBERS OF THE NETHERLANDS GEODETIC COMMISSION 1879–1979)

1 Persoonlijke leden (Personal members)

Prof. Dr. F. J. Stamkart	1879–82
Prof. Dr. J. A. C. Oudemans	1879–1906
Prof. Dr. H. G. van de Sande Bakhuyzen	1879–1923
Prof. Dr. J. Bosscha	1879–1911
Dr. Ir. G. van Diesen	1879–1910
Prof. Dr. Ch. M. Schols	1881–97
A. W. E. Kwisthout	1889–1911
Prof. Ir. Hk. J. Heuvelink	1897–1949
Prof. Dr. J. J. A. Muller	1903–38
Prof. Dr. J. C. Kapteyn	1907–15
P. J. Hogenhuis	1911–24
Prof. Dr. J. P. Kuenen	1911–22
Prof. Dr. A. A. Nijland	1915–36
Prof. Dr. L. H. Siertsema	1923–37
Prof. Dr. W. de Sitter	1923–34
J. W. den Hartogh	1924–25
Th. L. Kwisthout	1925–37
Prof. Dr. Ir. F. A. Vening Meinesz	1927–66
Prof. Ir. J. W. Dieperink	1929–34
Prof. Dr. Ir. W. Schermerhorn	1929–46 1948–68
Prof. Dr. J. H. Oort	1937–69
Prof. Dr. J. H. F. Umbgrove	1937–54
Prof. J. M. Tienstra	1937–51
Prof. Ir. J. H. G. Schepers	1940–68
Prof. R. Roelofs	1946–75
Prof. A. Kruidhof	1948–75
Prof. Dr. G. J. A. Grond	1949–61
Prof. Ir. W. Baarda	1952–
Dr. G. van Herk	1952–58 1963–73
Prof. Ir. E. C. W. A. Geuze	1954–62
Prof. Ir. G. J. Bruins	1954–
Prof. Dr. J. G. J. Scholte	1958–70
Prof. Dr. J. Veldkamp	1961–76
Prof. Ir. A. J. van der Weele	1963–
Prof. Dr. Ir. C. Koeman	1963–72
Prof. Ir. G. F. Witt	1967–
Ir. G. A. van Wely	1971–
Dr. Ir. L. Aardoom	1971–
Prof. Ir. W. Langeraar	1974–78
Prof. Dr. F. J. Ormeling	1974–
Dr. W. N. Brouw	1976–
Dr. A. R. Ritsema	1977–
Prof. Dr. N. J. Vlaar	1977–
Prof. Dr. Ir. M. J. M. Bogaerts	1978–
Ir. J. C. de Munck	1979–

2 Ambtshalve leden (Ex-officio members)

2.1 *Rijkswaterstaat* (*Public Works Department*)

2.1.1 Hoofdingenieur-directeur van de Algemene Dienst (Director of the General Service)

Ir. R. H. Gockinga	1911–13
Ir. D. J. Steyn Parvé	1914–17
Ir. W. F. Stoel	1917–33
Ir. J. C. Scharp	1933–35 1937–46
Ir. V. J. P. de Blocq van Kuffeler	1935–37
Ir. F. Volker	1946–55
Dr. Ir. J. van Veen	1955–59

2.1.2 Hoofd van de Meetkundige Dienst (Head of the Survey Department)

Prof. Ir. A. J. van der Weele	1959–63
Ir. S. Rienstra	1963–74
Ir. A. Waalewijn	1974–

2.2 *Chef der Hydrografie (Chief of the Hydrographic Department of the Navy)*

Schout-bij-nacht (Rear-admiral)	
C. J. de Jong	1911–14
Kapitein-ter-zee tit. (Captain)	
J. M. Phaff	1914–20
Kapitein-ter-zee (Captain)	
J. L. H. Luymes	1920–35
Schout-bij-nacht	
J. C. F. Hooykaas	1935–40
Kapitein-ter-zee R. van Tyen	1940–42
Kapitein-ter-zee C. ter Poorten	1942–45
Schout-bij-nacht	
Th. K. Baron van Asbeck	1945–61
Schout-bij-nacht	
Ir. W. Langeraar	1961–71
Schout-bij-nacht	
H. H. van Weelde	1971–77
Schout-bij-nacht J. C. Kreffer	1977–

2.3 **Ministerie van Defensie (Ministry of Defence)**

2.3.1 *Directeur van de Militaire Verkenningen (Director of the Military Reconnaissance)*

Kapitein A. Copes van Hasselt	1911–12
Majoor H. C. Fontanier	1912–19
Majoor I. H. Reynders	1919–26
Majoor C. P. Brückel	1926–32

2.3.2 *Directeur van de Topografische Dienst (Director of the Topographic Service)*

A. van Hengel	1932–46
C. A. J. von Frijtag Drabbe	1946–54
J. H. Bramlage	1954–60
W. F. den Hengst	1960–70
Ir. J. A. C. E. van Roermund	1970–

2.3.3 *Hoofd van de Triangulatiedienst van de Artillerie (Head of the Triangulation Service of the Artillery)*

Luitenant-kolonel	
P. J. Hamelberg	1937–40

2.3.4 *Hoofd van de Schoolmeetafdeling van de Artillerie (Head of the School of Surveying of the Artillery)*

Kapitein L. Ezerman	1937–42

2.4 **Directeur van het Kadaster (Director of the Cadastral Service)**

Mr. H. Iwema	1937–39
J. H. J. Houben	1939–42
W. F. Stoorvogel	1942–58
Mr. Ir. S. M. Meelker	1958–68
Ir. M. J. te Nuyl	1969–78
Ir. H. A. L. Dekker	1978–

2.5 **Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)**

2.5.1 *Hoofddirecteur (Director-General)*

Prof. Dr. Ir. F. A. Vening Meinesz	1949–51
Ir. C. J. Warners	1951–65
Prof. Dr. W. Bleeker	1965–67
Dr. M. W. F. Schregardus	1967–76
Dr. H. C. Bijvoet	1976–

2.5.2 *Directeur van de 5e afdeling (Director of the Geophysical Department)*

Prof. Dr. J. Veldkamp	1949–61

2.6 Ministerie van Economische Zaken (Ministry of Economic Affairs)

2.6.1 *Vereniging "De gezamenlijke steenkolenmijnen in Limburg" (Association of colliery owners in Limburg)*

S. M. C. M. Drent	1962–69
Ir. J. G. D. Moonen	1969–78

2.6.2 *Staatstoezicht op de Mijnen (State Control of the Mines)*

Ir. J. J. E. Pöttgens	1978–

BESTUURSLEDEN RIJKSCOMMISSIE VOOR GRAADMETING EN WATERPASSING EN RIJKSCOMMISSIE VOOR GEODESIE IN DE PERIODE 1879–1979 (PRESIDENTS AND SECRETARIES NETHERLANDS GEODETIC COMMISSION 1879–1979)

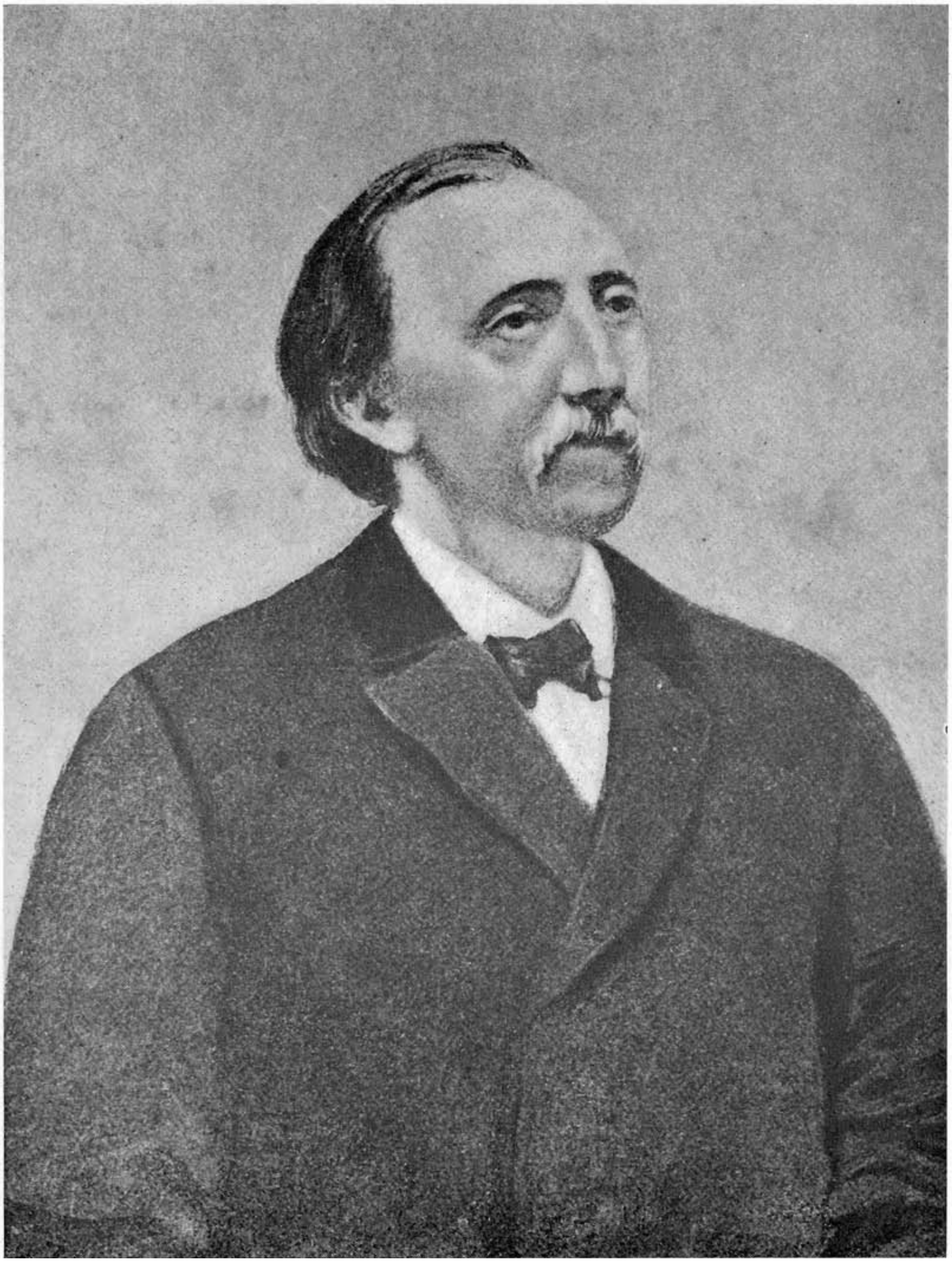
Presidents

Prof. Dr. F. J. Stamkart	1879–82
Prof. Dr. H. G. van de Sande Bakhuyzen	1882–1923
Prof. Dr. J. J. A. Muller	1923–37
Prof. Dr. Ir. F. A. Vening Meinesz	1937–47
Prof. J. M. Tienstra	1947–51
Prof. Dr. Ir. F. A. Vening Meinesz	1952–57
Prof. R. Roelofs	1952–73
Prof. Ir. G. J. Bruins	1973–

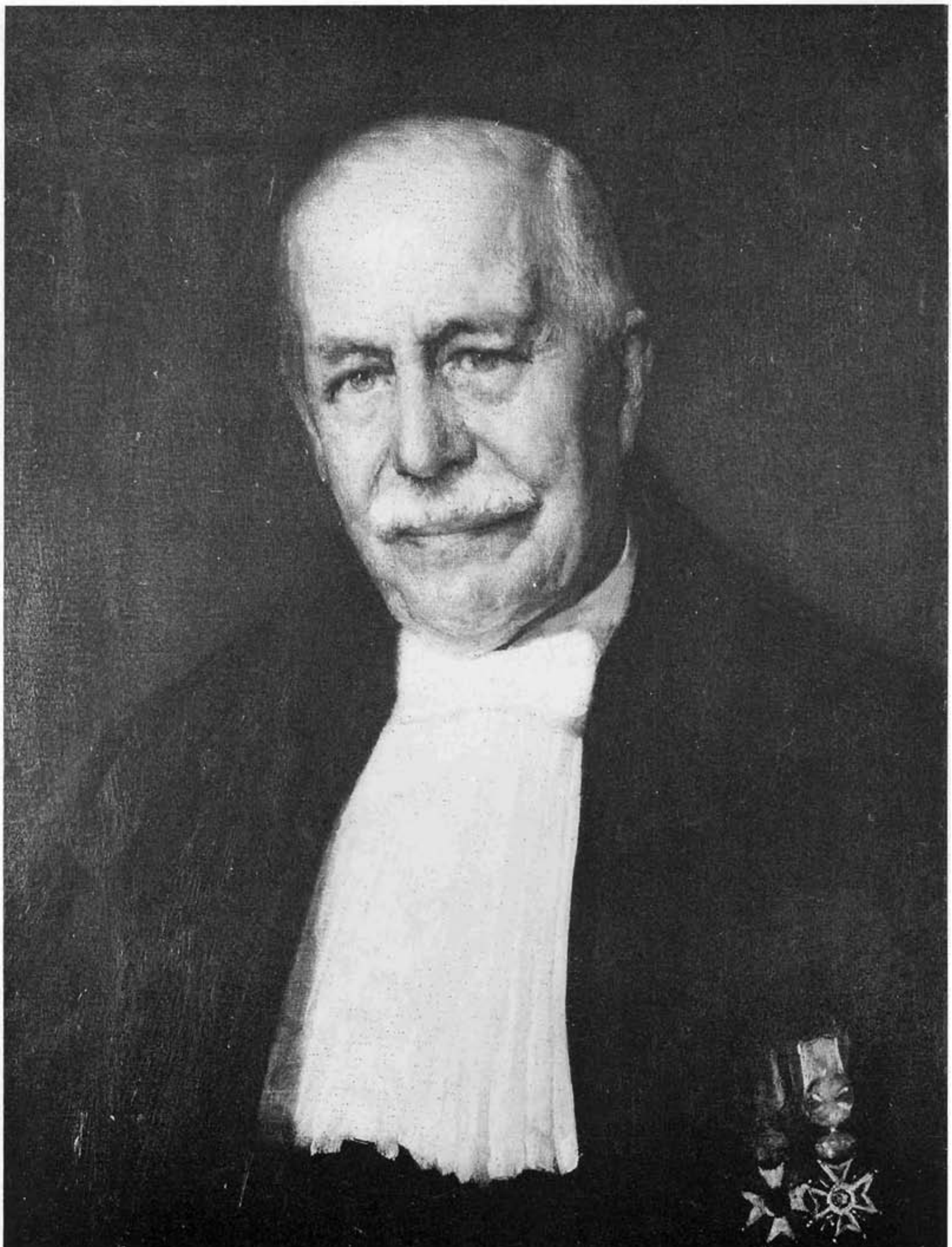
Secretaries

Prof. Dr. J. Bosscha	1879–81
Prof. Dr. Ch. M. Schols	1881–97
Dr. Ir. G. van Diesen	1897–1900
Prof. Ir. Hk. J. Heuvelink	1900–37
Prof. Ir. W. Schermerhorn	1937–46
Prof. J. M. Tienstra	1946–47
Prof. R. Roelofs	1947–57
Prof. Ir. W. Baarda	1957–

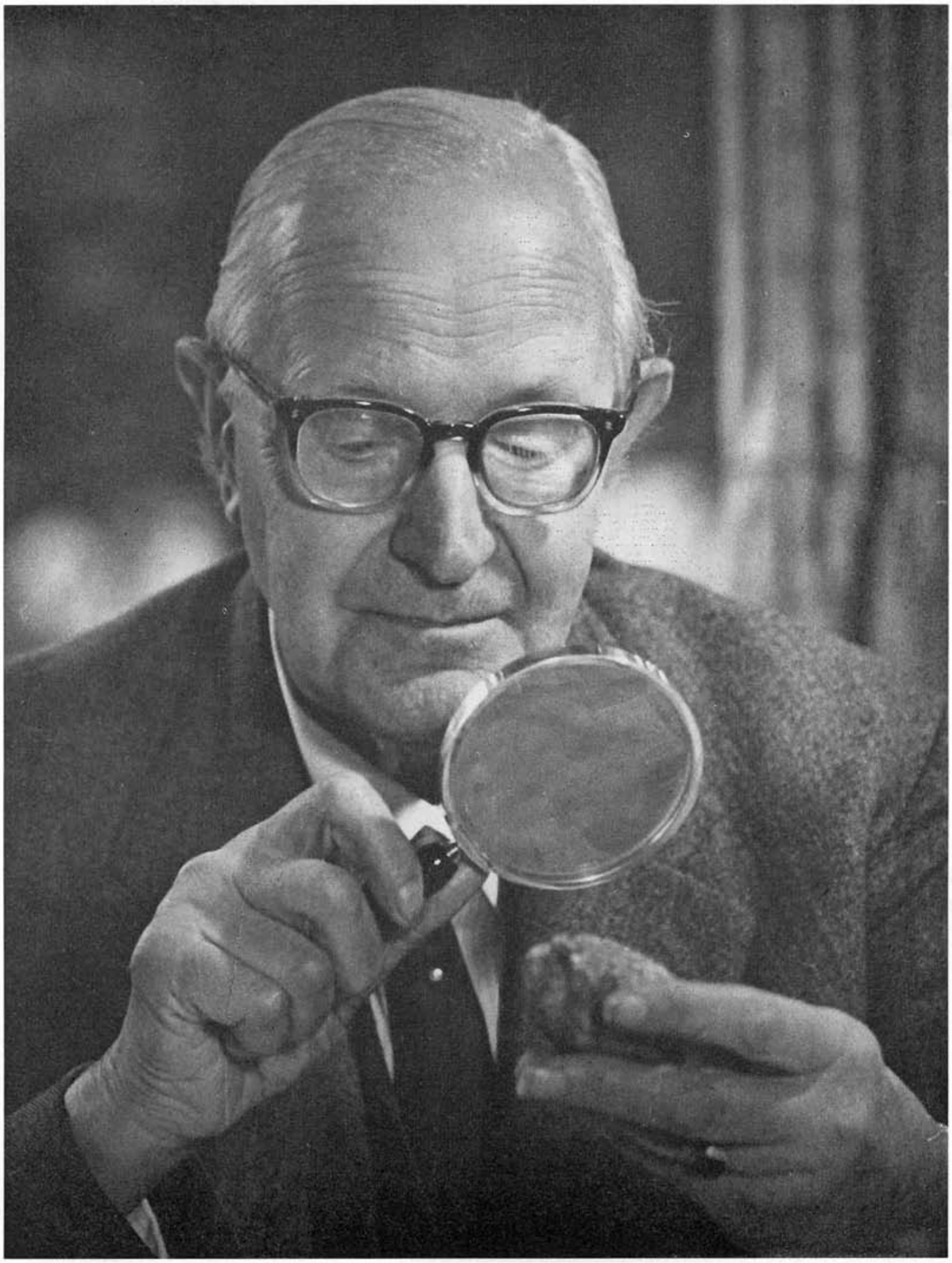
Prof Dr. F. J. Stamkart
President 1879–82



Prof. Dr. H. G. van de Sande Bakhuyzen
President 1882–1923



Prof. Dr. J. J. A. Muller
President 1923–37

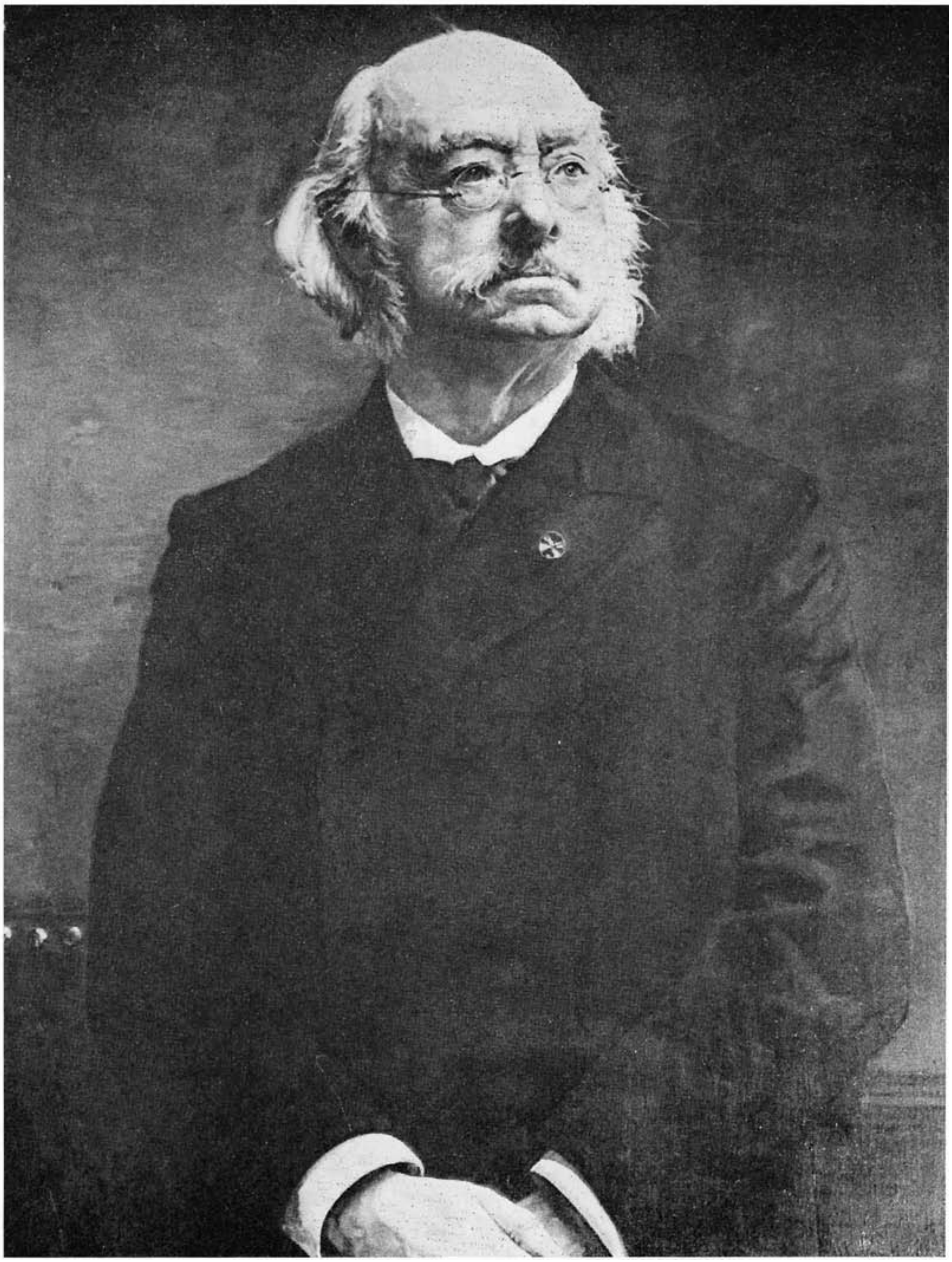


Prof. Dr. Ir. F. A. Vening Meinesz
President 1937–47 and 1952–57

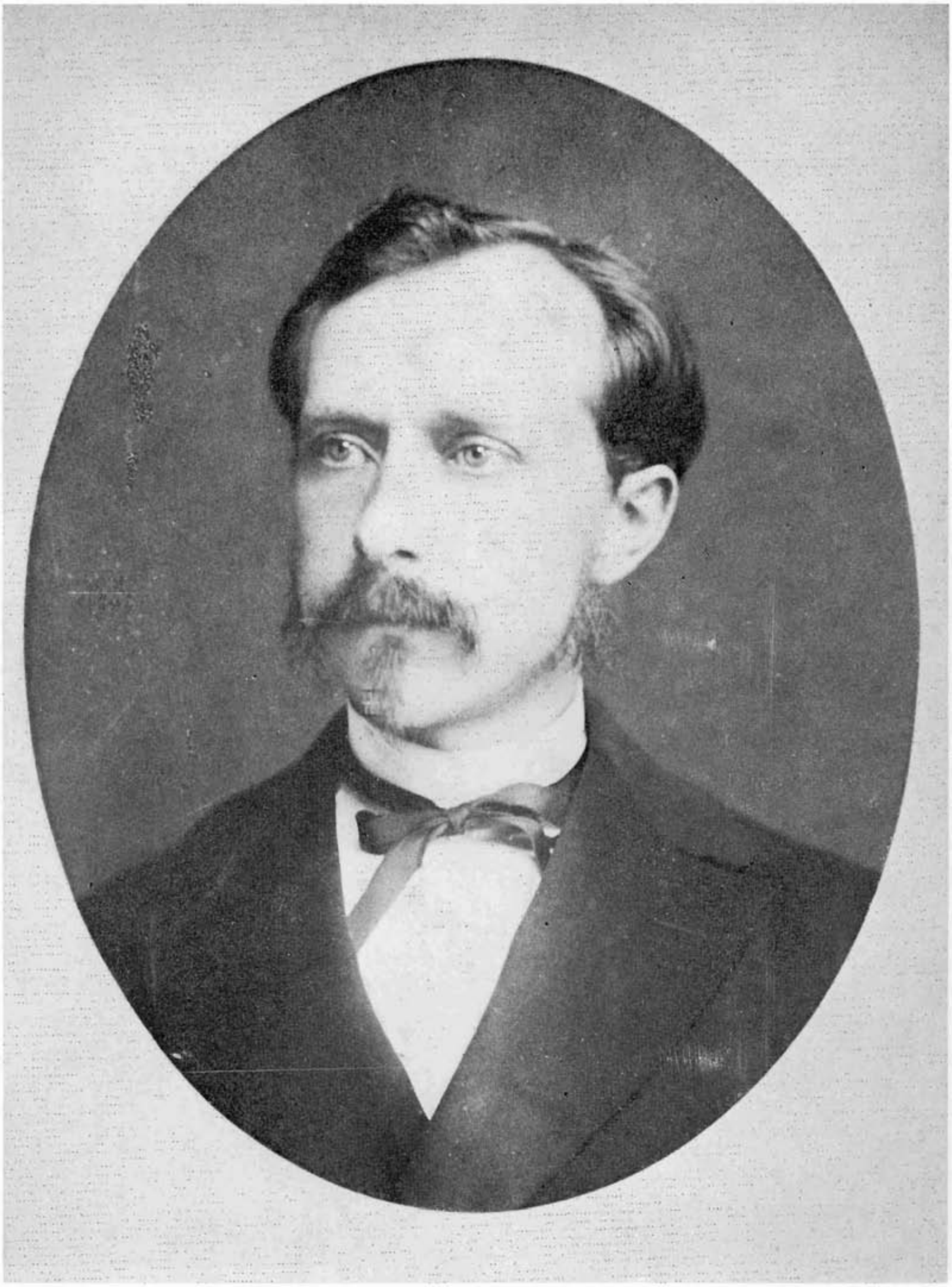
Prof. J. M. Tienstra
Secretary 1946–47, President 1947–51

Prof. R. Roelofs
Secretary 1947–57, President 1957–73

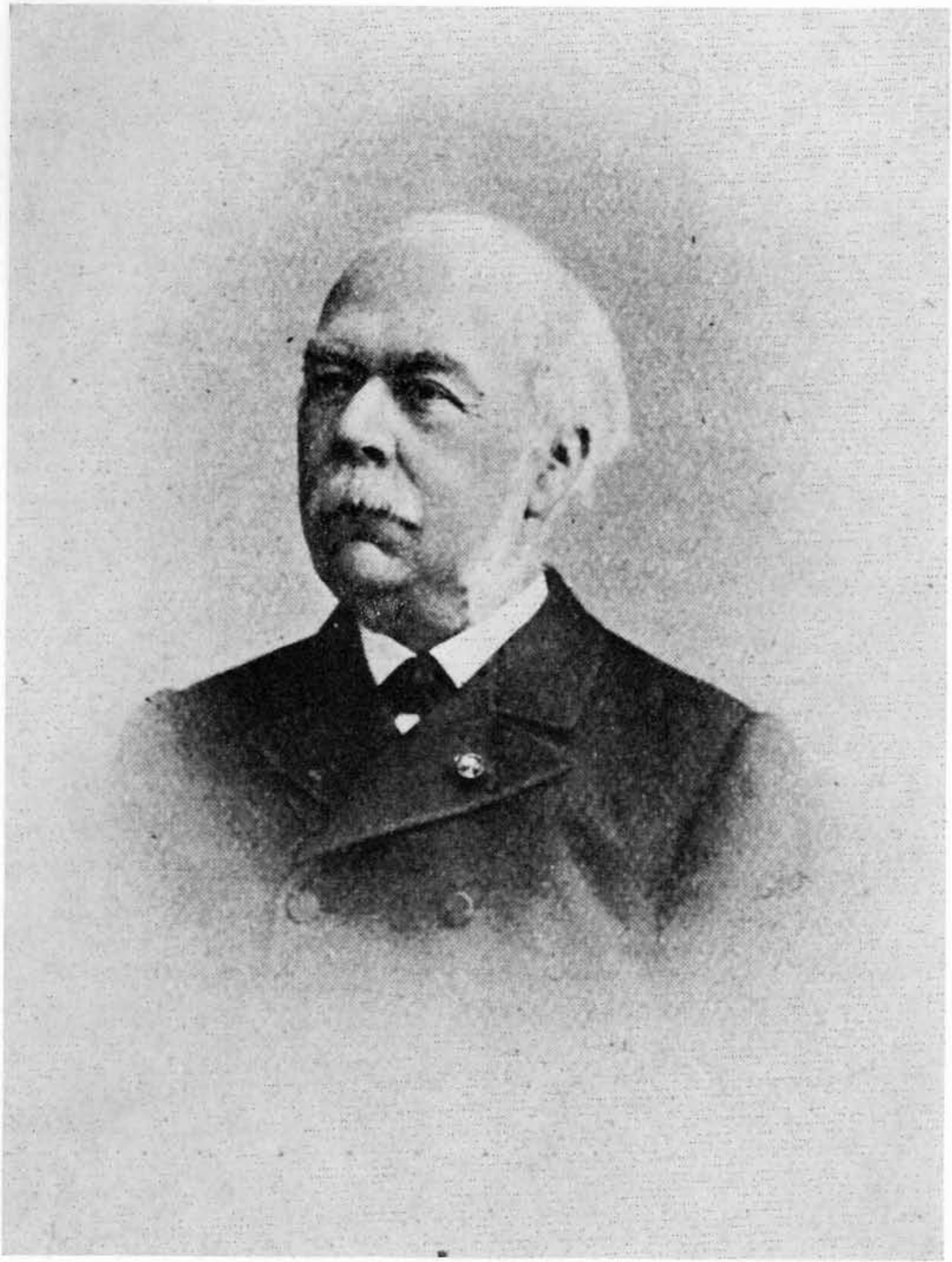
Prof. Ir. G. J. Bruins
President 1973–



Prof. Dr. J. Bosscha
Secretary 1879–81



Prof. Dr. Ch. M. Schols
Secretary 1881–97



Dr. Ir. G. van Diesen
Secretary 1897–1900

Prof. Ir. Hk. J. Heuvelink
Secretary 1900–37

Prof. Dr. Ir. W. Schermerhorn
Secretary 1937–46

Prof. Ir. W. Baarda
Secretary 1957–

Appendix II

PUBLICATIONS ISSUED BY THE NETHERLANDS GEODETIC COMMISSION, DURING THE PERIOD 1879–1979

A General

J. A. C. OUDEMANS – Détermination, à Utrecht, de l'azimut d'Amersfoort, 1881.
H. G. VAN DE SANDE BAKHUYZEN and G. VAN DIESEN – Uitkomsten der Rijkswaterpassing, 1875–1885. Ontworpen en aangevangen door L. Cohen Stuart, voortgezet door H. G. van de Sande Bakhuyzen en G. van Diesen (Results of the State Levelling, 1875–1885. Planned and started by L. Cohen Stuart and completed by H. G. van de Sande Bakhuyzen and G. van Diesen), 1888.
H. G. VAN DE SANDE BAKHUYZEN et BASSOT – Détermination de la différence de longitude entre Leyde et Paris. Paris, 1889.
H. G. et E. F. VAN DE SANDE BAKHUYZEN – Détermination de la différence de longitude Leyde-Greenwich, exécutée en 1880 et 1881. In: Annalen der Sternwarte in Leiden, Siebter Band, pp. 245–335. Martinus Nijhoff, The Hague, 1897.
HK. J. HEUVELINK – Formules en tafels voor de berekening van de geografische breedten en lengten der hoekpunten en van de azimuths der zijden van het driehoeksnet. (Formulas and tables for the computation of latitudes and longitudes of the stations and the azimuths of the sides of the triangulation). Delft, 1903.
HK. J. HEUVELINK – Triangulation du Royaume des Pays-Bas. Tome premier. Delft, 1903.
J. A. C. OUDEMANS – Détermination de la latitude et d'un azimut aux stations Oirschot, Utrecht, Sambeek, Wolberg, Harikerberg Sleen, Schoorl, Zierikzee, Terschelling (phare Brandaris), Ameland, Leeuwarden, Urk et Groningue. Delft, 1904.
H. G. VAN DE SANDE BAKHUYZEN, J. H. WILTERDINK and J. WEEDER – Déterminations de la différence de longitude Leyde-Ubagsberg, de l'azimut de la direction Ubagsberg-Sittard et de la latitude d'Ubagsberg par la mesure des distances zénitales et d'après la méthode Horrebow-Talcott en 1893. Delft, 1905.
HK. J. HEUVELINK – Rechthoekige coordinaten I, Hoofddriehoeksnet (Rectangular Coordinates I, Primary Network). Delft, 1909.
HK. J. HEUVELINK – De stereografische kaartprojectie in hare toepassing bij de Rijksdriehoeksmeting (The stereographic map projection and its application to the State Triangulation). Delft, 1918.
H. J. ZWIERS – Untersuchungen über die Deklinationen und Eigenbewegungen von 163 Sternen, welche 1899–1906 am Zenitteleskop in Leiden beobachtet worden sind. Delft, 1918.
HK. J. HEUVELINK – Topografische kaart en Rijksdriehoeksmeting (Topographical Map and the State Triangulation). Delft, 1920.
HK. J. HEUVELINK – Triangulation du Royaume des Pays-Bas. Tome second. Delft, 1921.
F. A. VENING MEINESZ – Observations de pendule sur la mer pendant un voyage en sous-marin de Hollande à Java. Publication provisoire, Delft, 1923.
F. A. VENING MEINESZ – Observations de pendule dans les Pays-Bas. Delft, 1923.
HK. J. HEUVELINK – Rijksdriehoeksmeting 1885–1928. Rechthoekige coordinaten (State Triangulation 1885–1928. Rectangular Coordinates). Delft, 1928.

HK. J. HEUVELINK – Rijksdriehoeksmeting 1885–1928. Staten van waarnemingen en uitkomsten (Lists of observations and results). Delft, 1929

F. A. VENING MEINESZ – Theory and Practice of Pendulum Observations at Sea, Part I. Delft, 1929.

HK. J. HEUVELINK – Rijksdriehoeksmeting 1885–1928. Basis by Stroe 1913 (State Triangulation 1885–1928. Base near Stroe, 1913). Delft, 1932.

F. A. VENING MEINESZ – Gravity Expeditions at Sea, 1923–1940. Vol. I. (The expeditions, the computations and the results). Delft, 1932.

F. A. VENING MEINESZ (with the collaboration of J. H. F. UMBGROVE and PH. KUENEN) – Gravity Expeditions at Sea, 1923–1932, Vol. II. (Report of the Gravity Expeditions in the Atlantic of 1932 and interpretation of the results). Delft, 1934.

F. A. VENING MEINESZ – Gravity Expeditions at Sea, 1934–1939, Vol. III. (The expeditions, the computations and the results). Delft, 1941.

F. A. VENING MEINESZ – Theory and Practice of Pendulum Observations at Sea, Part II. (Second order corrections, terms of Brown and miscellaneous subjects). Delft, 1941.

F. A. VENING MEINESZ – Tables for Regional and Local Isostatic Reduction (Airy System) for Gravity Values. Delft, 1941.

J. E. DE VOS VAN STEENWIJK – Plumb-line Deflections and Geoid in Eastern Indonesia as Derived from Gravity. Delft, 1946.

F. A. VENING MEINESZ – Gravity Expeditions at Sea, 1923–1938, Vol. IV. (Complete results with isostatic reduction, interpretation of the results). Delft, 1948.

N. D. HAASBROEK – Investigation of the Accuracy of Plotting and Scaling-off. Delft, 1955.

G. J. BRUINS (ed.) – Gravity Expeditions, 1948–1958, Vol. V. (Complete results with isostatic reduction). Delft, 1960.

D. DE GROOT – Goniometrische tafels in tien decimalen voor de sexagesimale en de decimale verdeling.
Ten-place Trigonometric Tables in the Sexagesimal and the Decimal System.
Tablas trigonométricas en diez decimales para las divisiones sexagesimal y décimal.
Tables trigonométriques à dix décimales pour les divisions sexagésimale et décimal.
Zehnstellige trigonometrische Tafeln für die Sexagesimal- und die Dezimalteilung. Delft, 1961.

G. J. BRUINS (ed.) – Standard Base "Loenermark". Delft, 1964.

N. D. HAASBROEK – Gemma Frisius, Tycho Brahe and Snellius and Their Triangulations. Delft, 1968.

P. I. VAN DER WEELE – De geschiedenis van het N.A.P. Delft, 1971.

N. D. HAASBROEK – Investigation of the Accuracy of Krayenhoff's Triangulation (1802–1811) in Belgium, The Netherlands and a Part of North Western Germany. Delft, 1972.

T. J. POELSTRA – A New Satellite Observatory at Kootwijk. Delft, 1974.

N. D. HAASBROEK – Investigation of the Accuracy of Stamkart's Triangulation (1886–1881) in The Netherlands. Delft, 1974.

Survey Department Rijkswaterstaat – Height of Bench Marks in The Netherlands in the NWELL-System. Delft, 1975.

H. L. ROGGE – Register op landmeetkundige literatuur in Nederland, 1961–1970. (Register of surveying literature, published in The Netherlands, 1961–1970). Delft, 1975.

N. D. HAASBROEK – Prof. F. Kaiser en S. H. de Lange in hun relatie tot de astronomische plaatsbepalingen van omstreeks 1850 in het voormalige Ned. Indië (Prof. F. Kaiser and S. H. de Lange and Their Connection with Astronomical Position Fixings of about 1850 in the former Dutch East Indies). Delft, 1977.

P. RICHARDUS (ed.) – Proceedings of the International Symposium on Electromagnetic Distance Measurement and the Influence of Atmospheric Refraction. Delft, 1978.

B Publications on geodesy – New Series

J. E. ALBERDA – Vertical Angles, Deviations of the Vertical and Adjustment. Volume 1, No.1. Delft, 1961.

J. E. ALBERDA – Report on the Adjustment of the United European Leveling Net and Related Computation. Volume 1, No. 2. Delft, 1963.

N. D. HAASBROEK – Stereo Nomograms. Volume 1, No. 3. Delft, 1962.

A. C. SCHEEPMAKER – Analyse van de waarnemingsresultaten verkregen op het geodetisch-astronomisch station op Curaçao tijdens het Internationaal Geofysische Jaar 1957–1958 en een onderzoek van het astrolabium A. Danjon (with a résumé in French: Analyse des résultats des observations faites à Curaçao pendant l'Année Géophysique Internationale 1957–1958 et recherches effectuées sur l'astrolabe A. Danjon). Volume 1, No. 4. Delft, 1963.

F. A. VENING MEINESZ – Interpretation of Gravity Anomalies on the Westcoast of South America and in the Caribbean; The Puerto Rico Trench and Two types of Deep Ocean Trenches. Volume 2, No. 1. Delft, 1964.

R. ROELOFS – Selection of Stars for the Determination of Time, Azimuth and Laplace Quantity by Meridian Transits. Volume 2, No. 2. Delft, 1966.

G. J. HUSTI – Simultaneous Determination of Latitude, Longitude and Azimuth by Horizontal Directions at the Sun. Volume 2, No. 3. Delft, 1966.

W. BAARDA – Statistical Concepts in Geodesy. Volume 2, No. 4. Delft, 1967.

W. BAARDA – A Testing Procedure for Use in Geodetic Networks. Volume 2, No. 5. Delft, 1968.

M. J. M. BOGAERTS – A Self-Reducing Range-Finder with an Automatic Registration System. Volume 3, No. 1. Delft, 1969.

G. BAKKER – The Adjustment of Primary Direction Measurements with Special Reference to Circle Testing Methods. Volume 3, No. 2. Delft, 1970.

J. VELDKAMP – Gravity Surveys in Surinam and The Netherlands Leeward Islands Area, 1958–1965. Volume 3, No. 3. Delft, 1969.

J. C. DE MUNCK – The Theory of Dispersion Applied to Electro-Optical Distance Measurement and Angle Measurement. Volume 3, No. 4. Delft, 1970.

G. J. HUSTI – The Twin Laplace Point Ubachsberg-Tongeren, Applying the Black Method. Volume 4, No. 1. Delft, 1971.

T. HONKASALO – Remeasurement of the Standard Base Line Loenermark. Volume 4, No. 2. Delft, 1971.

G. H. LIGTERINK – The Precision of Photogrammetric Models. Volume 4, No. 3. Delft, 1972.

G. BAKKER, M. HAARSMA, B. G. K. KRIJGER and J. C. DE MUNCK – Measurement of the Base and Base Extension Net "Afsluitdijk". Volume 4, No. 4. Delft, 1972.

W. BAARDA – S-Transformations and Criterion Matrices. Volume 5, No. 1. Delft, 1973.

L. AARDOOM – On a Geodetic Application of Multiple-Station Very Long Baseline Interferometry. Volume 5, No. 2, Delft, 1972.
T. J. POELSTRA and F. W. ZEEMAN – Delft University Equipment for Photographic Satellite Observations. Volume 5, No. 3. Delft, 1974.
L. AARDOOM, D. L. F. VAN LOON and T. J. POELSTRA – The Astrometric Procedure of Satellite Plate Reduction as Applied at the Delft Geodetic Institute. Volume 5, No. 4. Delft, 1975.
G. J. HUSTI – Geodetic-Astronomical Observations in The Netherlands, 1947–1973. Volume 6, No. 1. Delft, 1975.
D. L. F.VAN LOON and T. J. POELSTRA – The Modified Astronometric Procedure of Satellite Plate Reduction as Applied at the Kootwijk Observatory of the Delft Geodetic Institute. Volume 6, No. 2. Delft, 1976.
G. J. HUSTI – Deviations of the Vertical in The Netherlands from Geodetic-Astronomical Observations. Volume 6, No. 3. Delft, 1978.

Appendix III

DUTCH TEXT OF THE REPORT ON STAMKART'S TRIANGULATION

RIJKSCOMMISSIE
voor
Graadmeting en Waterpassing.

Leiden – Delft, 21 April 1884

No. 162

Aan Zijne Excellentie den Heer Minister van Binnenlandsche Zaken te 's-Gravenhage,

In antwoord op de Missive van Uwe Excellentie van 13 Maart 1884 No. 660 Afd. K. W. betreffende het schrijven van de Rijkscommissie voor Graadmeting en Waterpassing van 29 Febr. l.l. no. 156 hebben wij de eer hierbij aan Uwe Excellentie te doen toekomen het verslag over de driehoeksmeting door den heer STAMKART uitgevoerd.

Zooals uit dat verslag blijkt zijn de resultaten van die meting van dien aard, dat zij als eene eenigszins bruikbare bijdrage tot de Europeesche graadmeting in het geheel niet kunnen in aanmerking komen. Van de geheele voor dezen internationalen arbeid bestemde Nederlandsche driehoeksmeting, waarvan het plan in overleg met den Luitenant-Generaal BAEYER ontworpen is en door den toenmaligen Minister van Binnenlandsche Zaken volgens zijn schrijven van 30 April 1886 No. 346 afd. 5 is goedgekeurd, moet dus geacht worden nog niets gedaan te zijn.

Die driehoeksmeting thans achterwege te laten, daaraan kan niet gedacht worden. Tegenover de verschillende staten van Europa, die, blijkens het hierbij gevoegde verslag van den kolonel FERRERO in ruime mate hun aandeel aan de noodige driehoeksmetingen leveren, kunnen wij, wegens de voor twintig jaren gedane toezegging, ons niet terugtrekken. Na de mislukte driehoeksmeting van den heer STAMKART kan dit te minder, omdat wij daardoor zouden te kennen geven dat men in Nederland, waar de driehoeksmeting haren oorsprong genomen heeft, niet meer in staat is eene behoorlijke driehoeksmeting uit te voeren.

Wij moeten hierbij doen opmerken, dat de uit te voeren driehoeksmeting niet alleen ten goede komt van de Europeesche Graadmeting, maar dat daarvan, evenals zulks in ruime mate reeds met de Nauwkeurigheids Waterpassing het geval is, in zeer vele gevallen door den Waterstaat, het kadaster, de genie en den generalen staf een nuttig gebruik zal te maken zijn. Zooals in het overgelegde verslag uitvoerig is uiteengezet bestaat er zelfs dringende behoefte aan eene dergelijke driehoeksmeting. Het is daarom, dat wij, voorstellende de driehoeksmeting voor de Europeesche graadmeting ter hand te nemen, tevens in overweging geven dezen arbeid door eene betrekkelijk kleine uitbreiding zoodanig in te richten, dat hij voor ons geheele vaderland al die praktische resultaten zal opleveren, welke van een goed vastgesteld driehoeksnet verwacht kunnen worden. Wij doen dat met te meer aandrang omdat wij ervan overtuigd zijn, dat de noodzakelijkheid van eene goede volledige driehoeksmeting zich hier te lande meer en meer zal doen gevoelen en men dus binnen een betrekkelijk kort tijdsverloop genoodzaakt zou zijn om met opoffering van meer kosten dan waarmede dit thans mogelijk is, eene driehoeksmeting welke zich zou bepalen tot het voor de graadmeting strikt noodige, uit te breiden tot een volledig net.

Ten einde deze meting voor te bereiden, dient er op zijn laatst in den loop van 1885 het noodige gedaan te worden zoo voor het aanschaffen van de instrumenten als voor de verkenning van het net en voor het verkrijgen en oefenen van het personeel voor de meting. Met de verkenning van een gedeelte van het net dient intusschen reeds dit jaar begonnen te worden. De driehoeksmeting in Pruisen is namelijk zoo ver gevorderd dat in dit en in het volgende jaar de metingen in de nabijheid van onze noordelijke grenzen zullen worden uitgevoerd, waarbij tevens op eenige binnen ons grondgebied gelegen punten zal gericht worden, ten einde de aansluiting met onze driehoeksketen te verkrijgen. Daartoe is het echter noodig dat wij de punten op ons grondgebied aangeven, waarop van Pruisische zijde moet gericht worden. Laten wij die gunstige gelegenheid voorbijgaan, dan zal later de aansluiting aan Pruisen op moeilijkheden stuiten en geheel op onze kosten moeten worden uitgevoerd. Blijkens den in afschrift hierbij gevoegde brief van den chef der Trigonometrische afdeeling van de Landes Aufnahme, den Overste SCHREIBER, van 19 Febr. j.l. is men bereid de metingen zoodanig in te richten, dat de aansluiting nog in 1885 zal kunnen plaats hebben. Een uitstel in deze zaak is dus niet mogelijk en daarom nemen wij de vrijheid aan Uwe Excellentie ten dringendste te verzoeken ons alsnog de daarvoor over dit jaar aangevraagde gelden toe te staan.

Aangaande de nauwkeurigheids waterpassing moeten wij, met verwijzing naar ons schrijven van 28 Februari 1883 no. 117 doen opmerken, dat een inkrimpen van het daarin voorgestelde plan niet mogelijk is zonder de resultaten daarvan in de waagschaal te stellen; want daardoor zou de sluiting van de verschillende veelhoeken, die voor de contrôle hoogst noodzakelijk is, gemist worden en zou de aansluiting aan verscheidene peilschalen aan zee, het hoofddoel der meting, niet bereikt worden. Of het mogelijk is die metingen dit jaar te doen afloopen kan niet met volstrekte zekerheid worden gezegd. Ten eerste is nog niet te bepalen of men over het noodige personeel zal kunnen beschikken. Mocht uit dien hoofde de waterpassing dit jaar met minder kracht worden voortgezet dan wij wenschen en verwachten, dan zou dit tengevolge hebben, dat een deel der uitgaven, waarvoor de gelden reeds door Uwe Excellentie zijn toegestaan eerst in het volgende jaar behoeft gedaan te worden, zoodat de hierdoor veroorzaakte langere duur tot geen grootere kosten zou leiden. Ten tweede kan eerst na afloop van de berekeningen blijken of ook enkele van de in dit jaar gewaterpaste lijnen eene hernieuwde opmeting in 1885 vorderen.

In alle geval is het te voorzien dat in het volgende jaar voor de waterpassing slechts eene betrekkelijke geringe uitgaaf zal noodig zijn. Kan de Commissie in 1885 beschikken over een bedrag van *f* 15000 dan kunnen hieruit tevens de kosten der werktuigen voor de triangulatie en voor de verkenning bestreden worden. Een jaarlijksch bedrag van *f* 10000 voor de driehoeksmeting zal daarna vermoedelijk de Commissie in staat stellen de taak ten einde te brengen, welke door het waardeloos blijken van den arbeid van den heer Stamkart eene ook voor de Commissie zoo onverwachte en ongehoopte uitbreiding moet ondergaan.

De Commissie zou er prijs op stellen om, indien bij Uwe Excellentie na kennisneming der hierbij gaande bescheiden, twijfel mocht overblijven omtrent de noodzakelijkheid om de triangulatie ten spoedigste uit te voeren, aan Uwe Excellentie in een mondeling onderhoud de zaak nader te mogen toelichten.

Het hierbij overgelegde verslag van den Kolonel FERRERO ontvingen wij gaarne na gemaakt gebruik terug.

De Rijkscommissie voor Graadmeting en Waterpassing
Voorzitter Secretaris

VERSLAG OMTRENT DE DRIEHOEKSMETING TEN DIENSTE DER EUROPEESCHE GRAADMETING

Toen na het overlijden van den heer Dr. F. J. STAMKART in den aanvang van het jaar 1882 de verschillende stukken betreffende de driehoeksmeting waren overgenomen, bleek het dat op 46 punten, hoekmetingen waren uitgevoerd en dat voor 42 van die punten, de berekeningen, zoo verre die op het hoekpunt betrekking hebben, waren afgeloopen. Voor de 4 laatste punten was die berekening ook reeds uitgevoerd, maar nog niet onder zoodanigen vorm gebracht, dat daarvan onmiddellijk gebruik kon worden gemaakt.

Eene nadere inzage dier stukken deed echter twijfel ontstaan omtrent de juistheid der berekeningen en de nauwkeurigheid der waarnemingen. De commissie achtte zich daarom niet verantwoord met de berekeningen te laten voortgaan noch om de ontbrekende hoekmetingen te laten uitvoeren, alvorens zij een grondig onderzoek omtrent de bruikbaarheid der gedane berekeningen en metingen had ingesteld.

Het resultaat van dat onderzoek was verre van bevredigend, zoodat de Commissie zich genoodzaakt zag, de verdere bewerking der metingen voorloopig te staken, aan Uwe Excellentie uitvoerig mededeeling te doen van den toestand dier metingen en de noodige maatregelen in overwging te geven om in dien toestand te voorzien.

Vooraf zij het de commissie vergund er op te wijzen, dat toen in 1865 besloten werd om ten dienste der Europeesche Graadmeting een gedeelte van de driehoeksmeting van den generaal KRAYENHOFF te herhalen, de uitvoering daarvan werd opgedragen aan den heer Dr. F. J. STAMKART destijds arrondissements-ijker te Amsterdam. De heer STAMKART bleef geheel zelfstandig met de uitvoering dier meting belast tot in 1879 de Rijkscommissie voor Graadmeting en Waterpassing werd ingesteld, en de heer STAMKART zelf tot lid daarvan benoemd werd. De overige leden der commissie oordeelden het in de eerste plaats noodzakelijk zich er van te overtuigen, dat de uitkomsten der gedane metingen op behoorlijke wijze waren opgeteekend en bewaard werden, ten einde ook na een eventueel overlijden van den heer STAMKART, die metingen te kunnen berekenen. De registers bevattende de copie der waarnemingen werden daartoe overgelegd en daaruit bleek dat voor het verloren gaan van de gedane waarnemingen geen vrees behoefde te bestaan.

Uit de verdere mededeelingen van den heer STAMKART bleek dat de hoekmetingen bijna ten einde gebracht waren, en dat het dus voor de eenheid van de uitvoering wenschelijk was met de weinige nog te volbrengen metingen op de zelfde wijze voort te gaan. Een vermoeden dat de metingen op onvoldoende wijze werden uitgevoerd, kon bij de commissie, waarvan de heer STAMKART zelf lid was, moeilijke opkomen, daar de heer Stamkart, die gedurende zoovele jaren de metingen persoonlijk had uitgevoerd, en dus geacht moet worden volkomen daarvan op de hoogte te zijn, niet den minsten twijfel koesterde omtrent de doelmatigheid van de door hem gevolgde wijze van meten. Eerst toen zij na het overlijden van den heer STAMKART al de aanteekeningen in handen kreeg, kwam zij tot de overtuiging dat de gedane metingen den toets der kritiek niet konden doorstaan. Maar al had de commissie reeds vroeger wantrouwen omtrent de metingen gekoesterd, zou het haar toch niet mogelijk zijn geweest iets aan de in de 13 afgeloopen jaren uitgevoerde metingen te verbeteren, nog om, in de in het reeds ingetreden jaar uit te voeren metingen, afdoende verbeteringen aan te brengen.

Wat de uitgevoerde berekeningen betreft kunnen wij kort zijn. Bij het onderzoek bleek dat daarin niet alleen eene groote menigte rekenfouten voorkwamen, maar dat ook de wijze van berekening op vele punten te wenschen overliet. Wel was daarbij, zooals noodig is, de methode der kleinste vierkanten gevolgd, maar in zeer vele details was daarvan zoo zeer afgeweken, dat eene geheele nieuwe berekening noodig bleek. Wanneer de metingen zelven goed waren, zou dit geen groot bezwaar hebben opgeleverd, maar zij bleken van dien aard te zijn, dat eene nieuwe berekening onmogelijk goede resultaten kon opleveren. Wij zullen daarom bij die berekening niet langer blijven stilstaan, maar onmiddellijk tot de metingen zelven overgaan.

Deze metingen bezitten niet den graad van nauwkeurigheid, die tegenwoordig van een dergelijken arbeid gevorderd wordt, en die noodig is om mede te werken aan de groote internationale onderneming van de Europeesche Graadmeting.

De oorzaken van de weinig bevredigende uitkomsten welke de metingen hebben opgeleverd moeten gezocht worden, eensdeels in de geringe hulpmiddelen waarmede de heer STAMKART meende ze te kunnen uitvoeren, anderdeels in de omstandigheid, dat daarmede iemand belast werd, die, hoeveel verdiensten hij in andere opzichten ook moge bezeten hebben, voor deze taak niet berekend was en niet op de hoogte bleek te zijn van de groote vorderingen, die de geodesische wetenschap in al hare onderdeelen in de laatste 50 jaren gemaakt heeft.

Een eerste gevolg van de geringe middelen waarmede de metingen verricht werden, was dat de heer STAMKART zich geen vast personeel kon verschaffen, maar steeds moest werken met een adsistent, die na een paar jaar naar een betere betrekking moest omzien en dus door een ander moest vervangen worden. Het natuurlijke gevolg hiervan was, dat hij steeds werkte met iemand, die niet op de hoogte van de zaak was; die wanneer iets verkeerds bij de metingen of de berekeningen plaats had, daarop niet opmerkzaam kon maken, en die ook niet geschikt was om bij de berekeningen eenigszins zelfstandig te werk te gaan.

Een ander gevolg daarvan was, dat slechts bij uitzondering gebruik gemaakt werd van heliotrooplicht, het hulpmiddel dat tegenwoordig bij alle driehoeksmetingen van den eersten rang gebruikt wordt. Inplaats daarvan werd steeds op de torens zelven gericht, hetgeen, vooral in ons land, waar men maar zelden een toren aantreft die volkomen te lood staat en waar de lucht meestal niet zoo helder is, dat het toppunt van de toren op grooten afstand duidelijk onderscheiden kan worden, aanleiding geeft tot groote fouten, die later niet verholpen kunnen worden.

Bij de metingen komt in de eerste plaats het instrument waarmede gewerkt werd ter sprake, alsmede de wijze waarop dat instrument behandeld werd. De hoekmetingen werden verricht met een theodoliet van Pistor en Martins te Berlijn, die speciaal voor deze metingen besteld werd. Deze theodoliet die in Maart 1866 ontvangen werd, werd eerst in September van het volgende jaar aan een onderzoek onderworpen, een onderzoek dat echter zoo onvoldoende was, dat daaruit niets kon worden afgeleid. Het voornaamste deel van het instrument, de cirkelrand werd niet onderzocht en eerst na het overlijden van den heer STAMKART toen men behalve de uitkomsten der metingen, ook het instrument aan een onderzoek onderwierp bleek het, dat die cirkel veel te wenschen overliet.

De microscopen waarop het bij de aflezing van de verdeeling vooral aankomt, bleken bij het door ons ingestelde onderzoek geheel onbruikbaar te zijn. In 1867 waren zij door den heer STAMKART onderzocht, maar op geheel onvoldoende wijze. Tijdens de metingen vertoonden zij meermalen ernstige gebreken; inplaats echter van daarna de microscopen te laten herstellen of door andere te laten vervangen werd daarmede voortgewerkt, niet alleen gedurende het verdere gedeelte van het jaar waarin zich die gebreken vertoonden, maar ook gedurende het daarop volgende jaar; zonder dat in den winter iets gedaan werd om de fouten op te sporen of te verbeteren. Bij de waarnemingen werd dan eene methode van meten toegepast, die geheel en al streed tegen de eerste beginselen van eene nauwkeurige meting.

Met de overige deelen van het instrument, het behoeft nauwelijks gezegd te worden, werd op gelijke wijze gehandeld. Onder anderen werd het instrument nooit geregeld, en bij de metingen werd ook nooit gebruik gemaakt van de methoden van meten waardoor de fouten die daarvan het gevolg zijn, geëlimineerd worden.

Met den kleineren theodoliet, die gebruikt werd voor de menigvuldige metingen, noodig voor de herleiding der hoekmetingen, werd op gelijke wijze gehandeld. Ook dit instrument bleek bij onderzoek in vele opzichten zeer gebrekkig te zijn.

De methode van meten die werd toegepast is in hoofdzaak de methode van Bessel, maar gewijzigd op een zeer onoordeelkundige wijze. Deze methode, die in vele landen voor deze metingen gebruikt wordt, is echter wegens de bijzondere toestanden waarin wij hier te lande verkeeren, voor ons minder aan te bevelen. De daarin gebrachte wijzigingen maken ze voor de metingen in Nederland nog minder doelmatig. In Pruisen waar men in sommige streken met dezelfde bezwaren als hier te lande te kampen heeft, heeft men bij de Landesaufnahme, die methode dan ook reeds sedert tal van jaren door eene andere vervangen, die ook voor ons land als van zelve wordt aangewezen.

Bij de methode van Bessel wordt, op al de in den omtrek gelegen punten, die opgenomen moeten worden, achtereenvolgens gericht, eerst rondgaande bijvoorbeeld van links naar rechts en dan in omgekeerde volgorde van rechts naar links. Er verloopt geruime tijd voordat eene dergelijke meting is afgeloopen; gedurende dien tijd moet het instrument onveranderd vast blijven staan. Is deze vaste stand nu op vele plaatsen, waar het instrument op een steenen pijler, die onmiddelijk op den vaste grond steunt, te verkrijgen, op onze hooge kerktorens is dat geenszins het geval. Deze torens zijn voortdurend in beweging; zij ondergaan veelal eene merkbare draaiing, die in een kort tijdsverloop wel zeer gering is, maar in den tijd van enkele uren zeer belangrijk kan zijn. Het zou dus zaak geweest zijn om iedere serie metingen in den kortst mogelijken tijd af te doen, ten einde den invloed van die draaiing zoo klein mogelijk te maken. Inplaats daarvan heeft men, door op ieder punt niet eenmaal maar driemaal te richten, den tijd voor iedere serie aanmerkelijk vergroot. Het geval heeft zich dan ook meermalen voorgedaan, dat het instrument bij het eindigen van eene serie van metingen tot 20 secunden toe verdraaid was; terwijl verdraaiingen van 10 secunden op vele standplaatsen herhaaldelijk voorkwamen. Er bestaat wel een middel om deze draaiing in rekening te brengen en daardoor zich voor een groot deel er van onafhankelijk te maken; te weten het gebruik van een verzekeringskijker. Deze was dan ook werkelijk aanwezig, maar behalve dat hij op verkeerde wijze gebruikt werd, kon wegens zijn slechte bevestiging daarop niet vertrouwd worden. Ofschoon deze laatste omstandigheid zeer goed bekend was, heeft men geen poging gedaan om de wijze van bevestiging te laten veranderen of eene andere wijze van meten te volgen, waarbij die kijker overbodig is.

Het hierboven behandelde is niet het eenige waarin de bij de metingen gevolgde handelingen te kort schieten; vele andere tekortkomingen doen zich herhaaldelijk voor. Wij meenen echter dat het bovenstaande reeds voldoende is om den geleverden arbeid te beoordeelen en zullen thans met een enkel woord de verkregen resultaten toelichten.

Vooraf herinneren wij eraan, dat in de in 1862 te Berlijn gehouden vergadering, besloten werd, om, – niet tegenstaande de nieuwere driehoeksmetingen een veel grooteren graad van nauwkeurigheid bezitten dan de oudere, maar uit overweging dat het niet wel mogelijk is om alle oude driehoeksmetingen te vernieuwen, – ook zoodanige oudere driehoeksmetingen voor de Europeesche Graadmeting toe te laten, waarbij de fout in de som van de drie hoeken van iederen driehoek, niet of slechts bij uitzondering de waarde van 3 secunden overschrijdt.

Aan dezen eisch, voor oudere driehoeksmetingen gesteld, kan de boven behandelde nieuwe meting niet voldoen. Bij de 148 driehoeken, waarvoor de berekening volledig is uitgevoerd, zijn er niet minder dan 15 waarbij de grens van 3 secunden overschreden wordt en bij 2 daarvan klimt de fout zelfs tot boven de 7 secunden.

Toen in het jaar 1861 onze Regeering door de Pruisische regeering uitgenodigd werd tot deelneming aan de door den Luitenant Generaal BAEYER ontworpene graadmeting van Midden Europa, was men algemeen van gevoelen, dat wat het geodesische gedeelte daarvan betrof, de driehoeksmeting van den generaal KRAYENHOFF slechts gebruikt behoefde te worden, om zoo volledig mogelijk aan die onderneming mede te werken. Een critisch onderzoek ingesteld door wijlen Dr. L. COHEN STUART, niet alleen omtrent de gegevens voorkomende in het *Précis historique* van den generaal KRAYENHOFF, maar tevens omtrent die, welke voorkomen in de oorspronkelijke handschriften van de metingen (welk onderzoek uitvoerig beschreven is in de verhandeling van de heren F. KAISER en L. COHEN STUART (*De eischen der medewerking aan de ontworpen graadmeting in Midden Europa voor het Koningrijk der Nederlanden Amsterdam* 1864) leidde tot het resultaat, dat de metingen van den generaal KRAYENHOFF niet de nauwkeurigheid bezitten, die vroeger daaraan algemeen werd toegekend en dat eene hernieuwde berekening dier metingen niet toereikend zoude zijn, om ons vaderland op eene eervolle wijze, aan de graadmeting in Midden Europa te doen medewerken.

Er werd toen tot eene nieuwe driehoeksmeting besloten en de uitvoering daarvan werd aan den heer STAMKART opgedragen. De uitkomsten welke die meting heeft opgeleverd, hebben wij hier boven geschetst; zij staan nog verre ten achter bij de uitkomsten door KRAYENHOFF in het begin van deze eeuw verkregen. Met die metingen kunnen wij onmogelijk voor den dag komen bij de overige geodeten die aan de Europeesche Graadmeting deel nemen, zonder in hun oog den wetenschappelijken naam van ons vaderland aanmerkelijk te doen dalen.

Ten einde aan de op ons genomen internationale verplichting voor de Europeesche Graadmeting op eene eervolle wijze te voldoen, blijft ons niets over, dan de driehoeksmeting met betere hulpmiddelen en volgens betere methoden te herhalen. Maar niet alleen voor de Europeesche Graadmeting is eene nieuwe driehoeksmeting van den eersten rang in ons vaderland noodig; ook om andere redenen bestaat daaraan dringend behoefte. Het is sedert lang algemeen erkend, dat geene deugdelijke opmeting mogelijk is, zoo die niet steunt op een nauwkeurige opgemeten driehoeksnet. Zoowel voor kaarten op groote, als voor die op kleine schaal is dit eene noodzakelijkheid. Overal waar men kaarten gemaakt heeft, die niet op een goed driehoeksnet steunen, heeft men zich genoodzaakt gezien de geheele meting op betere grondslagen gesteund te herhalen. De meeste groote driehoeksmetingen, die thans in Europa ten uitvoer gebracht worden, dienen niet uitsluitend voor de Europeesche Graadmeting, maar beoogen daarneven dit ander praktisch doel.

Ook in ons land is dat beginsel reeds sedert lang erkend. De groote driehoeksmeting van den generaal KRAYENHOFF is daarvan het duidelijke bewijs. Toen men overging tot het maken van de *Groote Topografische Kaart van het Koningrijk der Nederlanden*, was men ervan overtuigd, dat dit tot geen goed resultaat zou leiden indien het niet steunde op eene uitgebreide driehoeksmeting. De driehoeksmeting vervat in de *Meetkunstige beschrijving van het Koningrijk der Nederlanden 's-Gravenhage 1861* was daarvan het gevolg. Deze driehoeksmeting van KRAYENHOFF, omvat een duizendtal punten over ons geheele vaderland verspreid. Ontworpen en uitgevoerd met het oog op de topografische kaart (eene kaart op de schaal van 1 à 50000) bezit deze driehoeksmeting voor dat doel eene voldoende nauwkeurigheid; maar voor kaarten op grooter schaal, zoo als die van het Kadaster is zij onvoldoende. Gelijktijdig met deze driehoeksmeting werd nog eene dergelijke uitgevoerd door de Ingenieurs van den Waterstaat om tot grondslag te strekken voor de rivierkaarten. Zij is beschreven in het *Verslag van de Werkzaamheden tot zamenstelling der Groote Kaart van de Hoofdrivieren in Nederland 's-Gravenhage 1885.*

Het Kadaster, de opmeting op de grootste schaal, die uit den aard der zaak met de meest mogelijke nauwkeurigheid moet worden uitgevoerd, is in ons land tot stand gekomen zonder den steun van eene uitgebreide driehoeksmeting. Evenals in andere landen, waar men op dezelfde wijze is te werk gegaan, heeft men zich ook hier sedert lang genoodzaakt gezien sommige gedeelten daarvan te vernieuwen. Bij deze hermetingen heeft men begrepen dat daaraan den steun van eene groote driehoeksmeting gegeven moest worden en men heeft daarom voorgeschreven dat bij de hermetingen, de nieuwe metingen moesten worden aangesloten aan de driehoeksmeting van de "Meetkunstige Beschrijving". Daar de driehoeksmeting van de "Meetkunstige Beschrijving" voor het Kadaster echter de noodige nauwkeurigheid mist, kon men niet anders dan onvoldoende resultaten verkrijgen; in de *Algemeene Instructie voor de ambtenaren van het Kadaster* die op 1 Januari 1878 in werking is getreden, heeft men dat voorschrift dan ook weer weggelaten. Niettemin blijft men voortgaan met de hermetingen aan te sluiten aan de driehoeksmeting van de "Meetkunstige Beschrijving", waardoor men niet anders dan gebrekkige resultaten verkrijgt.

Dat de driehoeksmeting van de "Meetkunstige Beschrijving" voor het Kadaster de noodige nauwkeurigheid mist, kan uit het volgende blijken. Vergelijkt men de twee bovengenoemde secundaire driehoeksmetingen, die van de "*Meetkunstige Beschrijving*" en die van de *Rivierkaart* welke ongeveer gelijktijdig zijn uitgevoerd, op dezelfde primaire driehoeksmeting steunen en volgens dezelfde beginselen bewerkt zijn, dan vindt men desniettegenstaande tusschen de coordinaten van de punten die in beide metingen voorkomen meermalen verschillen die van 5 tot 10 meters, bij sommige punten zelfs tot 20 en meer meters opklimmen. Bij den dienst van den Waterstaat, bij de herziening van de rivierkaart heeft men verschillende secundaire punten opnieuw moeten bepalen, omdat die punten noch in de driehoeksmeting vroeger voor de rivierkaart uitgevoerd noch in die van de "Meetkunstige Beschrijving" nauwkeurig genoeg bepaald waren. Bij de opmeting van het terrein van het Oude Maasje heeft men zich genoodzaakt gezien aldaar nieuwe secundaire punten te bepalen ofschoon in de "Meetkunstige Beschrijving" een genoegzaam aantal punten in die streek voorkomen, om daarop de verdere meting te kunnen steunen. Waar het net van de "Meetkunstige Beschrijving" de noodige juistheid mist voor de Rivierkaarten op de schaal van 1 à 10000 is dit in nog veel hoogere mate het geval voor de kadastrale kaarten op de schaal van 1 à 2000.

Eene nieuwe secundaire driehoeksmeting is voor den dienst van het Kadaster eene groote noodzakelijkheid, en deze kon niet tot stand komen zonder eene goede primaire driehoeksmeting. De driehoeksmeting van Krayenhoff kan daarvoor niet meer dienen, ook al bezat zij de noodige nauwkeurigheid, omdat vele van de hoekpunten dier meting verloren zijn gegaan en van vele andere de juiste plaats niet meer met de noodige zekerheid kan worden aangewezen.

Nu wij op het punt staan om ter voldoening aan de op ons genomen internationale verplichting, de driehoeksmeting van den eersten rang gedeeltelijk te vernieuwen meenen wij, dat het zaak is om het bovenstaande in ernstige overweging te nemen. De driehoeksmeting voor de Europeesche Graadmeting en de driehoeksmeting als steun voor alle verdere metingen vereischen volkomen dezelfde metingen, alleen heeft de laatste zich over een eenigszins grooter terrein uit te strekken.

Het van den beginne af in het oog houden van beide doeleinden, kan niet anders dan bevorderlijk zijn aan beiden. Wordt alleen de driehoeksmeting ondernomen ten dienste van de graadmeting, dan zal men zich na een betrekkelijk kort tijdsverloop genoodzaakt zien om de driehoeksmeting ook uit te breiden over de overige deelen van het rijk, en in dat geval zal de geheele driehoeksmeting veel langer duren en veel meer kosten dan wanneer van den beginne af die uitbreiding in het oog gehouden wordt. De reden hiervan is hoofdzakelijk gelegen in de omstandigheid dat men bij een latere uitbreiding van het net, op vele van de punten, waar reeds hoeken gemeten zijn, opnieuw hoeken zal moeten meten. Wordt echter van den beginne af die uitbreiding in het oog gehouden dan kan men de metingen zoodanig inrichten, dat die nieuwe metingen op dezelfde punten niet noodig zijn, waardoor eene groote besparing zoowel in den tijd als in de kosten verkregen wordt.

Eene juiste raming van den tijd die voor de meting vereischt wordt is niet wel mogelijk, omdat men niet kan weten met welke ongunstige omstandigheden, vooral wat het weder betreft, men te doen zal hebben. Afgaande op den tijd die in andere landen aan dergelijken arbeid besteed is en aannemende dat zes maanden per jaar aan de metingen besteed kunnen worden, komt men tot het resultaat dat voor de opmeting van het driehoeksnet uitgebreid over het geheele rijk 6 jaren gevorderd worden. Wordt daarentegen de driehoeksmeting alleen uitgevoerd voor de graadmeting dan zal men daarvoor 4 jaren noodig hebben; en gaat men er dan later toe over om die meting over het geheele rijk uit te breiden, dan zullen nog eens 4 jaren noodig zijn, dus tezamen 8 jaren, om de geheele meting te voltooien. Door dus van den beginne af, die uitbreiding in het oog te houden, zal den voor de meting gevorderden tijd aanmerkelijk bekort worden, hetgeen natuurlijk gepaard gaat, met eene vermindering van de onkosten.

Dit is echter niet het eenige voordeel dat aan het samenvatten van beide metingen verbonden is. Een ander niet gering te schatten voordeel is daarin gelegen dat men in zoodanig geval veeleer in de gelegenheid zal zijn om een geschikt personeel te verkrijgen voor de metingen en dat wanneer men later tot de secundaire meting zal overgaan men over een personeel zal kunnen beschikken, dat op de hoogte van die taak is en waaraan men met vertrouwen die meting kan opdragen.

Wat aangaat de kosten voor de uitvoering benoodigd, daarvoor kan evenmin als voor den tijd eene juiste opgave gedaan worden. Afgaande op eene globale raming gemaakt naar een voorlopig plan voor de meting, meenen wij dat voor het aanschaffen van de noodige instrumenten en voor andere onkosten ter voorbereiding van de meting eene som van *f* 4500,– voldoende zal zijn; terwijl voor de eigenlijke metingen per jaar de som van 10.000 gulden gevorderd zal worden.

De Rijkscommissie voor
Graadmeting en Waterpassing

Voorzitter

Secretaris

PART III

PAPERS SUBMITTED BY MEMBERS AND FORMER MEMBERS

1. TECHNIQUES OF PRECISE SATELLITE POSITIONING FOR GEODESY AND RELATED APPLICATIONS; AN ACCOUNT OF WORK IN THE NETHERLANDS

by L. AARDOOM*)

1 Introduction

It is difficult to judge whether the past two or three decades saw a development in the field of geodesy unprecedented in the past century. Undoubtedly however this development was fast, man's leap into space probably having the greatest impact on it. Space flight straightforwardly added the third dimension geodesists for many years had been trying to add along less direct or less practical lines. Potential uses of artificial earth satellites for geodesy were recognized even before the launching of the first of such satellites in 1957 and 1958. It took however until about 1960 before the various conceptual approaches crystalized into the new field of what was called satellite geodesy.

By its very nature satellite geodesy was predestined to provide solutions for the large scale, the global problems of geodesy. Therefore in its application satellite geodesy called for international cooperation even in the pioneering large space-going countries: the USA and the USSR. Such cooperation is probably a more stringent demand for satellite geodesy than for any of the other scientific uses of artificial satellites. This simply is so because the earth itself is in fact the subject of investigation and to make sense, satellite-positioned points on the earth should be locally, thus nationally surveyed.

For a small country, like The Netherlands, practical satellite geodesy cannot be but a contribution to an international effort. Although theoretical aspects of satellite geodesy have never been overlooked in The Netherlands, the emphasis of its involvement in satellite geodesy has over the years been on practical aspects and in particular on the tracking of satellites as part of internationally coordinated geodetic programmes. This somewhat one-sided development could be criticized from a national viewpoint, it is certaintly acceptable when looked upon in the international context in which satellite geodesy should be considered. In any cooperation, whether on a national or on an international level, facilities and capabilities, scientific and technical, should be complementary rather than competing or duplicating. It has turned out, that also from a financial point of view satellite geodesy can be quite demanding and thus its application only feasible on an international level, even for financially strong nations.

This is in particular true for Europe encompassing a relatively large number, geographically speaking, of relatively small countries with limited political and economic potentialities. Individually only the larger of these countries could endeavour to go out on an integrated satellite geodetic programme, the smaller will have to restrict themselves to

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certain aspects of the field as far as practical realization is concerned. Integrating the expertise available in the individual European countries into a long-term programme of satellite geodesy could lead to valuable results to which each of the participating nations would have its own, possibly unique, contribution. It is gratifying that on the eve of potential uses of satellite geodetic results for geophysical investigations such integration was in 1971 initiated in Western Europe under the auspices of the Council of Europe [1] and that the European Space Agency (ESA) currently studies the feasibility of supporting a European level programme in which satellite geodesy would play an essential role [2]. Within this European context and beyond, the expertise developed in The Netherlands over the years holds out a promise that The Netherlands can offer a useful contribution.

How this expertise was built up and how it is planned to be made effective in future will be reviewed in the subsequent sections against the background of international developments in the field of satellite geodesy. The main share of the satellite geodetic effort in The Netherlands was taken by the Department of Geodesy at the Delft University of Technology. This part of the work has however almost from its outset been very substantially supported by an annual funding granted to the Department's Working Group for Satellite Geodesy upon recommendation of the Netherlands Committee for Geophysics and Space Research (GROC) of the Royal Netherlands Academy of Arts and Sciences. The progress of this work is reported on to COSPAR*) annually.

2 Photographic satellite tracking, the technique developed

As long ago as 1961 the idea arose of attempting to contribute to satellite geodesy by ground-based observations of satellites. The only technique then conceivable of yielding accuracies meaningful for geodesy was the photographic one for obtaining station-to-satellite directions referred to a stellar night-sky background. The Department of Geodesy, then still a Subdepartment, of the Delft University of Technology decided to try and gain experience with that technique by developing the necessary equipment and by using it. The development stage had to be part of the undertaking because suitable equipment was not commercially available. What was available was a prototype aerial reconnaissance camera (TA–120) of Bouwers-Maksutov design which the Optische Industrie "De Oude Delft" of Delft was kind enough to lend out at no cost. Later on this camera was purchased from the factory. The main development items were a timing device and a stable mount. Timing was to be achieved by a focal plane chopper and it was found most practical to adopt a parallactic type of mounting. Based on mainly in-house design both concepts were realized at the mechanical workshop of the subdepartment. Although early attempts to observe satellites [3] were not successful, most photographic satellite observations by the Delft-group in later years (see [4], [5]) were obtained by means of this basic set-up.

*) COSPAR was established by the International Council of Scientific Unions in October 1958 to continue the cooperative programmes of rocket and satellite research successfully undertaken during the International Geophysical Year of 1957–1958. The ICSU resolution creating COSPAR stated that the primary purpose of COSPAR was to "provide the world scientific community with the means whereby it may exploit the possibilities of satellites and space probes of all kinds for scientific purposes, and exchange the resulting data on a cooperative basis".

Some drawbacks however of this set-up became apparent already in the first years of operation from early 1966 and on. This led to the design of a new camera system. This design drew heavily on previous experience and the new K-50 system featured an upgraded focal plane chopper and a parallactic mount constructed at Rademakers N.V. in Rotterdam. The essential difference with the TA-120 system was that the K-50 exposes on glass plates, whereas the TA-120 does so on film. The use of glass plates called for a mechanical plate advancing device which was again designed and constructed at the subdepartment's workshops. Unfortunately the new camera system could not be put to satisfactory operation before 1974 and by then the photographic technique of precise satellite tracking had been superseded by other techniques. Both camera systems have been described in considerable technical detail in [6].

3 The photographic technique applied

In the course of time three geodetic camera sites (see Figs. 1, 2 and 3) have been in use in The Netherlands:

period	site description	indentification	numbering
Aug. 1962–Dec. 1969	roof-top, University building for Mechanical Engineering and Naval Architecture, Delft	Wippolder Delft	4123 (COSPAR) 8009 (NASA) 9001 (WEST)
Dec. 1969–Dec. 1973	Ypenburg Airfield near Delft	Ypenburg	4199 (COSPAR) 8034 (NASA) 9002 (WEST)
from Dec. 1973 onwards	East dome, Kootwijk Observatory	Kootwijk	

GEOS-1 (1965–89 A) in its flashing mode was the first satellite to be observed successfully on January 19, 1966. The first satellite to be observed successfully in the passive mode was PAGEOS (1966-56 A), on September 16, 1966. Thus, despite the rather long period of preparation from 1961 to 1966 the camera system was already able to contribute to the early phases of the U.S. National Geodetic Satellite Program (NGSP) and the Western European Satellite Triangulation (WEST), the latter under the auspices of the IAG. Later programmes contributed to were the 1971 International Satellite Geodesy Experiment (ISAGEX) and the European Short Arc Observation Programme (SAOP) [7], the observations being made from the sites occupied at the times the observational stages of these programmes were under way. More than 500 useful frames were taken, all by the TA-120 camera. Satellites observed were ECHO-1 (1960-iota 1), ECHO-2 (1964-4A), GEOS-1 (only in flashing mode), PAGEOS and GEOS-2 (1968-2A; only in flashing mode).

Many frames were measured on the ZEISS/JENA ASCORECORD comparator kindly made available by the International Training Centre for Aerial Surveying (ITC), then at Delft. Since August 1970 the frames were measured on a MANN 422-F comparator. Publications [4] and [5] provide a catalogue of photographic observations covering the

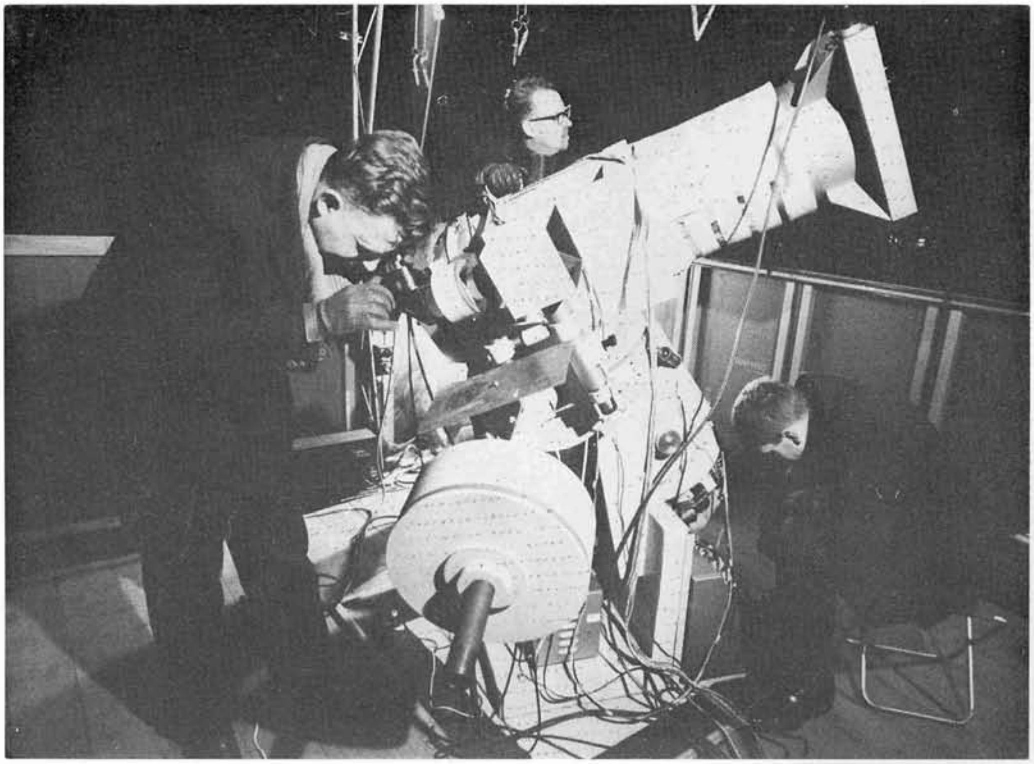

Fig. 1. The TA-120 camera at the Wippolder site

Fig. 2. The TA-120 and K-50 cameras at the Ypenburg station

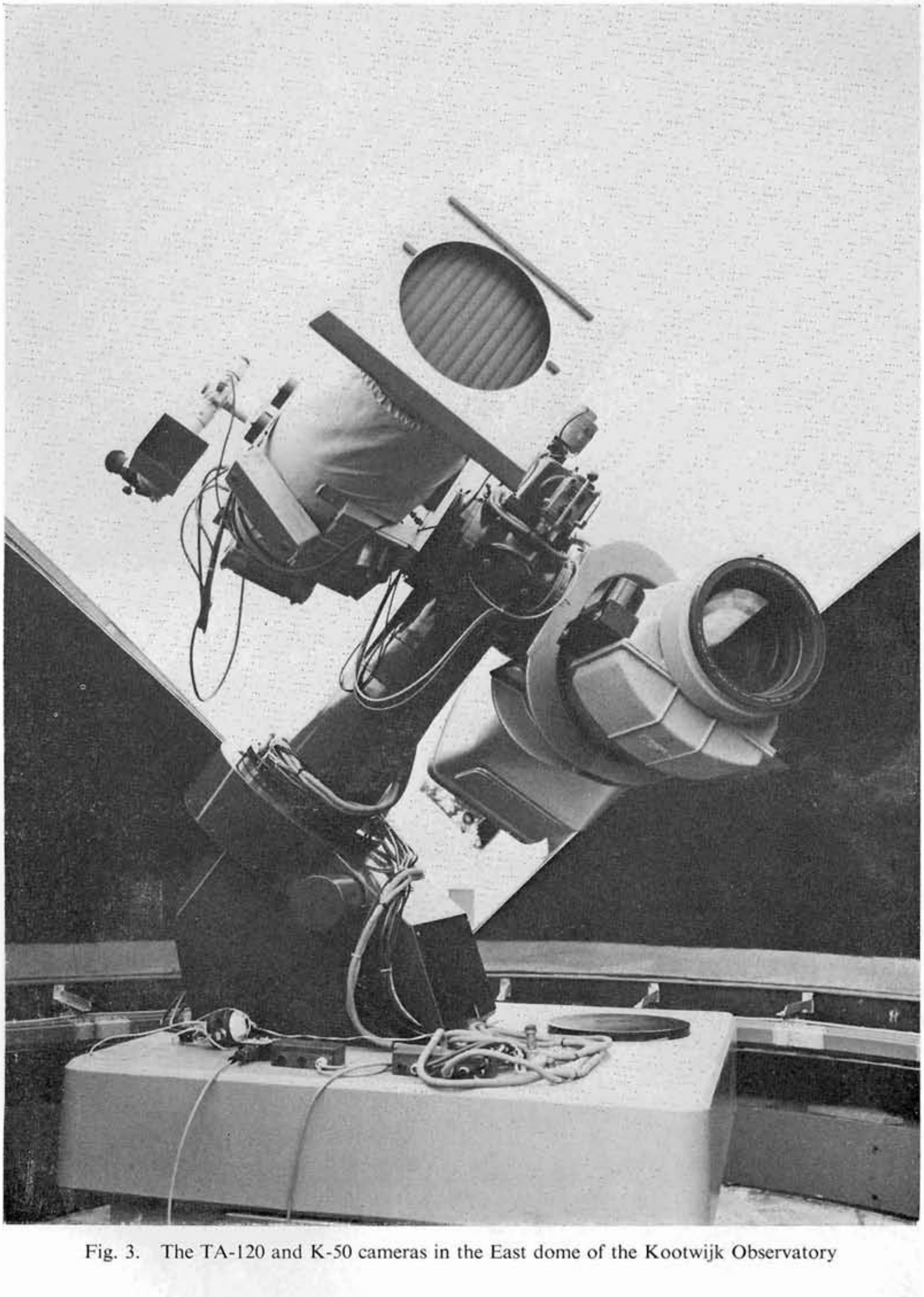

Fig. 3. The TA-120 and K-50 cameras in the East dome of the Kootwijk Observatory

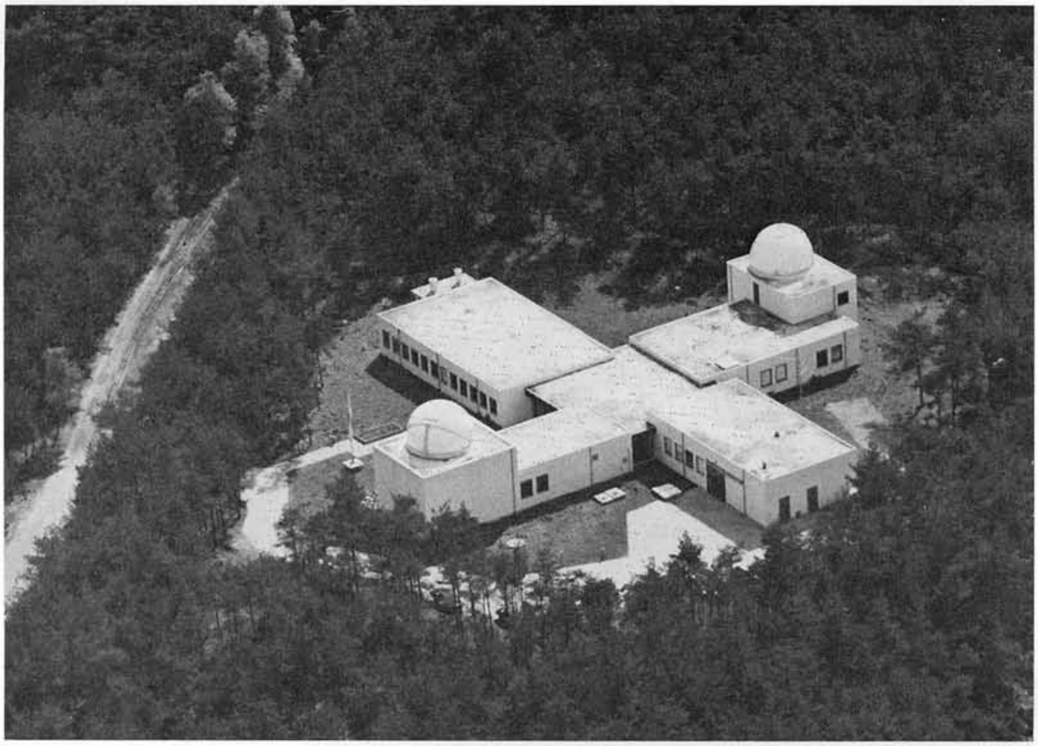

Fig. 4. Bird's-eye view of the Kootwijk Satellite Geodetic Observatory

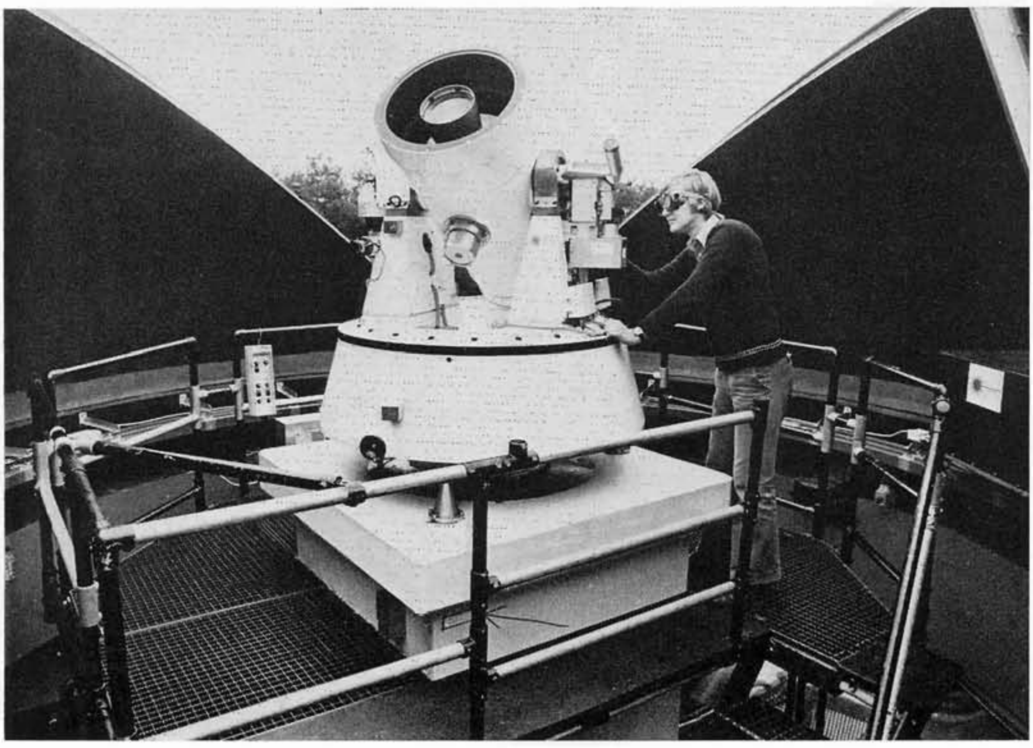

Fig. 5. The Kootwijk laser ranging system in the West dome of the Observatory

period up to April 1, 1974, together with a description of reduction procedures applied. The utilization of these data has e.g. been reported on in: [8], [9], [10], [11].

4 Laser ranging system development

The utilization of laser techniques for geodetic satellite tracking was considered in The Netherlands as long ago as 1968. Early plans aimed at using such techniques for both ranging and illumination for photographic tracking purposes. In view of the rapid progress in laser ranging precision and the ensuing potentialities of this technique to contribute to studies of the dynamic behaviour of the earth, it was decided by 1970 to refrain from a first generation system with conservative design specifications and rather aim for more advanced equipment working at a 25 cm precision level. It was realized that such equipment as a unit would not be commercially available and in 1973 GROC-funding allowed the Institute of Applied Physics (TPD) of Delft to make a design study. From this, noting the overall financial constraints, it became apparent that the ranging concept could be materialized provided the illumination facility was abandoned. Early 1974 again GROC-funding allowed a contract to be signed with TPD for the design and partial construction of a laser ranging system, the technical specifications of which would be summarized in outline as follows: 25 cm single shot precision, both day and night at near earth orbiting retroreflector satellites, maximum repetition rate at least 15 pulses per minute. Such a device was considered a valuable complement to the newly established Satellite Geodetic Observatory at Kootwijk [12], see Fig. 4. Although the extensive experience which the Smithsonian Astrophysical Observatory (SAO) at Cambridge, Massachusetts, USA kindly made available contributed substantially to the overall design, many original concepts were incorporated. The Working Group for Satellite Geodesy at Kootwijk itself took care of the partial design and construction of the electronic items involved. An advance description of the system can be found in [13]. The close cooperation between the Working Group for Satellite Geodesy at Kootwijk and TPD led to the final integration of the various items of the system in the observatory's West Dome Section by the end of 1975 and in the first half of 1976 (Fig. 5). The ruby laser itself had already been installed there in spring of 1975. First measurements and analysis of the data in the summer of 1976 indicated that the system came amply up to its principal specifications. This and further experience has been reported on several occasions: [14]. The laser ranging system in its geodetic context will be described in detail in [15].

Meanwhile SAO provided the AIMLASER computer programme to generate prepass instrument settings from mean orbital elements to be provided subsequently by SAO on a weekly basis. The Delft University Department of Aerospace Engineering gave considerable and efficient support by implementing this programme on the IBM 370/158 computer at the University Computing Centre. This work has been documented in [16].

5 Laser ranging at work

The first laser returns were obtained from GEOS-3 (1975-27A) on July 18, 1976. Since then until July 1, 1978 the following satellites have been successfully ranged at:

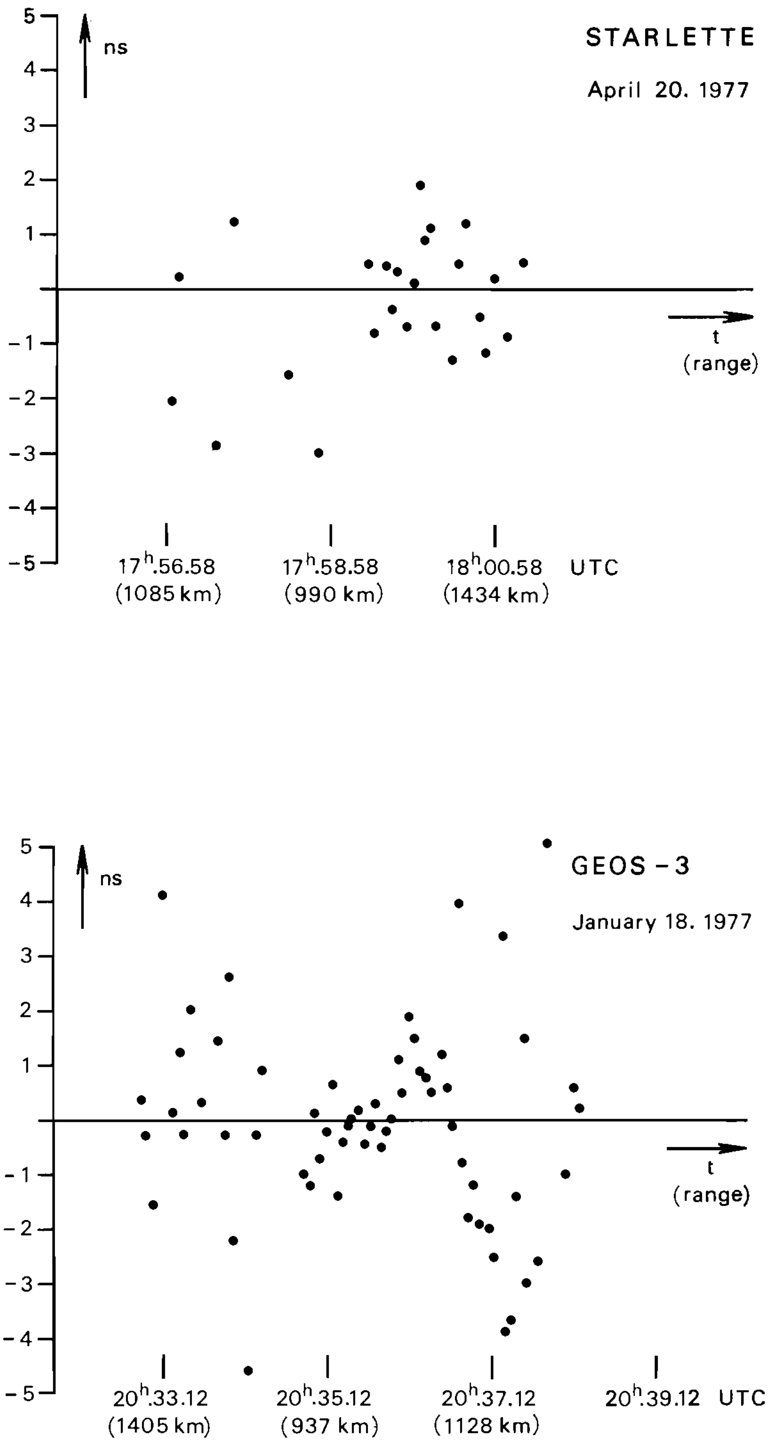

Fig. 6. Single-pass, single-station screening applied to early Kootwijk laser data. Shown are results of STARLETTE and GEOS-3 passes, indicating a single shot equivalent distance standard deviation of about 25 cm.

BE-C (1965-32A):	4 passes
GEOS-1 (1965-89A):	83 passes
GEOS-2 (1968-02A):	9 passes
STARLETTE (1975-10A):	175 passes
GEOS-3 (1975-27A):	158 passes
LAGEOS (1976-39A):	91 passes

LAGEOS could however only be ranged at in darkness.

To assist in updating satellite ephemerides, unprocessed quick look ranging data are on a weekly basis submitted to SAO, which designated the Kootwijk laser site by number 7833. In return SAO, also on a weekly basis, then provides updated mean orbital elements as an input to the AIMLASER-programme referred to in the previous section.

Observation epoch timing to better than 10 μs relative to UTC is obtained by courtesy of the Van Swinden Laboratory (VSL), The Hague, which maintains the national time and frequency standard of The Netherlands.

Calibration, timing, satellite ranging and pre-processing procedures have been documented in [15]. Fig. 6 shows samples of single pass, single station data screening results as part of the pre-processing. Experience has shown that a single shot ranging standard deviation of about 20 cm as estimated from such single pass data screening holds for all satellites observed, independent of orbital height and time of the day. Global 2–5 day's arc fits of early STARLETTE, GEOS-3 and LAGEOS data from Kootwijk suggest an average standard deviation of the same order of magnitude [17].

The first internationally coordinated satellite laser ranging effort contributed to was the Co-ordinated Satellite Laser Ranging (CSLR) as called for by COSPAR in its decision No. 2/76. From August 1 to November 1, 1977, the station ranged at STARLETTE and GEOS-3 in priority as a contribution to the first European Range Observations to Satellites Campaign (EROS-1) agreed on during a conference on European cooperation in this field, held at the Kootwijk Observatory January 17–18, 1977, under the auspices of the Working Party on Geodynamics of the Council of Europe. The Prediction Centre for this campaign was established at Kootwijk. This Centre continued its function in support of coordinated European laser ranging activities after EROS-1. A note on the planned EROS-cooperation can be found in [18].

6 Doppler positioning

The first non-military and non-commercial attempt of practical Doppler-positioning in The Netherlands was made at the Department of Surveying of the Agricultural University at Wageningen using a ship-borne type ITT 4007 receiver, donated by the Royal Dutch Shell Oil Company. To investigate the conditions for Doppler-reception at the Kootwijk Observatory the Institut für Angewandte Geodäsie at Frankfurt (IfAG), German Federal Republic, kindly performed a GEOS-3 (162/324 MHz) tracking session at Kootwijk from July 15 till July 23, 1976, using a Canadian Marcony CMA-725 positioning set. This investigation seemed in order because of the proximity of the General Post Office's Kootwijk radio-transmitting station; the results proved quite encouraging however.

In order to promote cooperation in geodetic Doppler positioning among governmental, commercial and scientific users and investigators in the country, The Netherlands Geodetic Commission succeeded by the end of 1976 in setting up a working group for this purpose.

With a CMA-722B receiver on loan at station 415 in Leeuwarden the Department of Geodesy in a joint venture with the Netherlands Triangulation Service took part in the second European Doppler Observation Campaign (EDOC-2) from April 23 to May 7, 1977 [19]. In the early summer of that same year, Dutch observers gained experience by participating in the German-Austrian Doppler Observation Campaign (DÖDOC) [20]. With the antenna at a well surveyed location close to the Kootwijk laser site, the Department of Geodesy took part in the EROS-Doppler Observation Campaign (EROS-DOC) from December 2 till December 16, 1977. The instrument was again a CMA-722B on loan from the factory because a CMA-751 set ordered in the meantime had yet not been delivered. The aim of EROS-DOC was to Doppler-position the 8 potential EROS laser sites in a relative sense [21]; see also previous section. A location on the observing platform on the roof of the new building, holding the Department of Geodesy in Delft, was, together with the Belgian triangulation station Arlon, Doppler-connected to the EDOC-2 sites Wettzell (German Federal Republic) and Uccle (Belgium). This took place in the second half of April 1978 using the newly acquired CMA-751 set. During phase 1 (June 23 till July 4, 1978) of the SEASAT-1 North Sea experiment (see next section), this equipment occupied the Kootwijk Doppler location. Aim of this campaign was to obtain coordinates in an unified conceptually geocentric reference frame for all European stations to take part in precise SEASAT-1 tracking. All these campaigns, except the GEOS-3 test session of July 1976, were based on the Navy Navigation Satellite System (NNSS) operating on 150/400 MHz.

Through IfAG the Department of Geodesy obtained a version of the PREDOP/GEODOP geodetic analysis programme package, kindly made available by the Geodetic Survey of Canada. The Kootwijk group made this programme work on the IBM 370/158 computer of the Delft University Computing Centre. First computations have been performed.

7 Current work

The five preceding sections reviewed the observation segment of satellite geodesy as it evolved in The Netherlands over the past years. The present section is to concentrate on activities going on at the time of this writing (July 1978). These will be presented in the context of current scientific interests and ensuing satellite missions.

Several European groups maintain their view that photographic observations of directions to satellites by means of some of the more powerful camera-systems can still play a significant role in satellite geodesy, although almost all camera-work, including that in Europe, has been abandoned. Reference is made to [22] and to several private communications. In view of this, despite the fact that the main interest at the Kootwijk Observatory has in recent years been directed towards the development of the laser ranging technique, the photographic method never lost attention. The existing camera-system was considered as a useful complement to the laser ranging system and it was therefore tried to have satellite laser returns recorded by the cameras but these attempts have not been successful. In fact it can be estimated that the chances of success are indeed marginal. It should be remarked that in order not to degrade the precision of the ranging, long pulse mode lasing can unfortunately not be considered. The current line of thinking is that some activity of the camera-system should be maintained in conjunction with the laser ranging, unless convincing arguments prove that directions to satellites precisely determined in this way do not meaningfully serve any scientific purpose.

Much of the world's satellite geodetic interest in these days is focussed on SEASAT-1 (1978-64A), placed in orbit on June 26, 1978. The geodesist's prime interest is evoked by the radar altimeter, the effective use of which calls for vertical SEASAT orbit determination at an accuracy level which will tax the existing tracking capabilities. The prime area of interest for European investigators united in SURGE (SEASAT Users Research Group of Europe) is the North Sea [23]. Partly due to its unique geographic position with respect to this area, the Kootwijk laser station is expected to yield an essential contribution to phase 2 of the precise orbit determination programme. For best effectiveness in a European contribution to this programme the existing EDOC- and EROS-organizations were joined and the Kootwijk group will function again as Prediction Centre for European laser ranging The group also assumed specific tasks in collection and dissemination of global laser tracking data. Kootwijk obtained Europe's first SEASAT laser returns on July 11, 1978, only days after the first laser acquisition of the satellite. This laser tracking is expected to continue until the end of the SEASAT-1 mission which may be well beyond the end of 1979.

Meanwhile the Kootwijk group is intensively involved in upgrading the laser system. Return pulse digitizing and analysis will soon improve the ranging precision by an estimated factor of 2. A further improvement of the measurement precision is expected from shortening the transmitted pulses. System efficiency will be improved by applying multi-stop techniques for travel-timing. A Hewlett Packard 21 MX-E minicomputer currently in the process of being interfaced with the laser system will, partly in conjunction with the other modifications, add to its efficiency of operation. For more details, see [15].

As regards Doppler positioning the Department of Surveying and Photogrammetry of the Agriculture University at Wageningen and the Survey Department of the Department of Public Works (Rijkswaterstaat) at Delft collaborated by ordening jointly an additional CMA-751 set which is planned to be used by the Dutch team taking part in a Pamir-Himalaya Geophysical Project expedition for deep seismic sounding to take place in September 1978. At about the same time the Department of Geodesy CMA-751 will take part in phase 3 of the SEASAT-1 North Sea experiment. Using NNSS satellites ten to fifteen tide gauges selected on the North Sea perimeter will then be mutually controlled in the vertical sense and determined in a common geocentric reference. Most probably one gauge on the Dutch coast will be included.

8 Into the future

This speculation on the future will be restricted to the laser ranging work at the Kootwijk Observatory. One objective of the upgrading of the laser system referred to in the preceding section, is to extend the system's capability to range at more remote satellites: LAGEOS in daytime and NTS-2 (1977-53A) at least at nighttime. Being an experimental satellite in connection with the forthcoming U.S. NAVSTAR Global Positioning System (GPS). NTS-2 provides uniquely referenced time on a worldwide basis to the 100 ns level. For time tagging of laser range observations such timing precision is of interest if the ranging precision approaches a few centimetres. Ranging precision on that level may be attainable at Kootwijk within the next five years, say, provided funding required to execute further substantial upgrading of the laser system is granted. Access to NTS-2 time transmissions requires a special receiver. Via the existing T.V.-timing link [15] between VSL and Kootwijk the laser work there could thus profit from an eventual installation of such a receiver at VSL.

There is currently a tendency which may reverse these timing procedures in the sense that that laser ranging is no longer time tagged through the international timing network as maintained by the Bureau Internationale de l'Heure (BIH), but rather that station-to-satellite laser transmission and ranging becomes a new and powerful method of global time transfer to the 0.1 to 10 ns precision level. This method is based on a concept [24] which was recently proposed for feasibility testing on a European space mission to be flown by the end of 1980 [25]. The Kootwijk laser station is a candidate participant in this LASSO-experiment. Full participation however requires the capability to range to the geostationary orbit and a Kootwijk-VSL timing link improved to 10 ns or better over a 110 km ground path. This latter improvement seems feasible and has already been prepared. If finally approved by ESA, the LASSO-experiment in case of Dutch participation would call for a closer cooperation between the Kootwijk group and VSL. This type of work would become more global and long term in nature if indeed some of the operational GPS satellites would be equipped with laser retroreflectors and laser pulse detection and timing devices.

To take part in such worldwide time comparisons could become a long term objective of the EROS cooperation. In addition, and apart from the ongoing contribution to the SEASAT-1 programme (see preceding section), EROS objectives foreseen are to help monitor earth rotation and platetectonics. These are among the objectives of an integrated European programme of space oceanography, navigation and geodynamics as recently recommended [2]. In which context the laser ranging work in Europe and at the Kootwijk station in particular is continued in the long run will depend on whether these recommendations are followed.

As yet the pulsed laser ranging to satellites technique is thought of as the only technique ultimately capable of reaching the critical 1–3 cm precision level required for the majority of geodynamic investigations. If on the other hand an all-weather technique would reach that level operationally, then such technique would certainly replace the weather conditioned laser technique and the programme at the Kootwijk Observatory should then be adjusted in time accordingly.

9 Concluding remarks

The satellite observing work reviewed in this article has over the years yielded contributions to a sequence of internationally organized campaigns, which in their turn form part of a broader programme of global geodesy spanning many years in time. In the course of time the precision of satellite geodetic techniques in general has improved considerably. Because of this, the objectives of satellite geodesy were made to evolve to studies of the dynamic behaviour of the Earth as a deformable body. Parallel to this course of events, considerations of cost-effectiveness of potential techniques to reach such objectives have become more customary than before. In continuing ongoing work and in adopting further work, scientific and application-oriented institutes have to be restrictive in view of their financial constraints. So in The Netherlands, and future developments in the field of geodetic satellite observations will probably have to be incorporated in a programme at least partly and convincingly aimed at obtaining national benefits. Because of the interdisciplinary nature of the work, involving certain branches of earth sciences and astronomy, represented in the Netherlands Geodetic Commission, this Commission could play a unique role in establishing such a programme.

Kootwijk, July 1978

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2. MATHEMATICAL GEODESY IN RELATION TO THE NETHERLANDS GEODETIC COMMISSION

by W. BAARDA *

1 The past

The Netherlands Geodetic Commission owes its birth – in a different organizational form – to the 19th century interest in the determination of the figure of the earth. Around 1860 this interest gave rise to an effort to realize this in international cooperation under the leadership of German geodesists. The junction of regional or national triangulations was of necessity the first objective and so our country was actually involved in this international project. Of course, the necessary funds could only be obtained if national interests could also be served: the country needed a good control network for mapping as well as a national levelling network for the unification of heights.

Thus, in the first fifty years of the Commission's existence, the Netherlands' triangulation evolved, since then faithfully maintained and densified. Several levelling surveys succeeded each other, carefully connected by benchmarks deemed identical. Only at a later stage gravity networks were added, mainly through the activities of VENING MEINESZ. Astronomical observations formed part of the triangulation, but they were a separate category. It was along these lines that the work of the Commission was split up into compartments apparently having little cohesion; they are reflected in the arrangement of the chapters of the annual reports. Until some years ago, the International Association of Geodesy had a corresponding division into Sections, with a fifth section for the determination of the geoid, to which – apart of course from Vening Meinesz' theoretical work – The Netherlands have contributed relatively little on account of the flatness of the country.

Leaving apart the fields of work of the International Federation of Surveyors, the International Society for Photogrammetry and the International Cartographic Association, to which the Commission has repeatedly turned its attention, one feels rather amazed at the static character of geodetic problems over the last hundred years.

Every national triangulation was computed on its own reference ellipsoid, somewhat like an embroidery on a canvas providing spatial rigidity, the threads of the embroidery following geodesics. An impressive body of literature treated difficulties encountered; the discipline of ellipsoidal computations, connected with the flourishing theory of map projections came into being. The third dimension, however, interpreted as height above the ellipsoid, has always given rise to problems. Astronomical, levelling and gravity measurements proved necessary, but the many publications hardly seemed to converge towards a generally accepted solution. The height definition itself was not the only issue: the dispute between "translative" and "projective" ellipsoidal computations has not been settled to the present day, and auxiliary surfaces, meant to save the ellipsoid, such as geoid, quasi-geoid and telluroid continued to have a mystical strain.

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After the Second World War, the approach to terrestrial geodetic computations has essentially remained the same, even if it was universally tried to unify national triangulation and trilateration measurements to form subcontinental terrestrial networks. As to the methods applied, there seems to be an analogy with the situation in adjustment theory, where in the thirties the remark was heard: "Why delve into the theory of least squares when it has all been sorted out already?"

2 From past to present

But now it seems that the development has definitely broken through this static character of geodesy. Satellite techniques, developing since the sixties, brought the insight that spatial geodetic methods are not essentially different from the already existing spatial photogrammetric methods, be it that there are complications because celestial mechanics is involved in the orbit computation of a satellite. But, curiously, the computer first produced a series of "improved" reference ellipsoids, and then an equally impressive series of geoids. A new complication is that the definition of the geoid has also become less certain on account of the finding that the mean sea level possibly differs up to a few metres from an equipotential surface. This certainly affects the satellite altimetry now emerging, even if some are trying to maintain the geoid by using filtering methods of mathematical physics to eliminate this difference.

It cannot be denied that in satellite geodesy truly spatial Cartesian coordinates are computed as well, but it appears time and again that the historically conditioned ties with the ellipsoidal computing system are too close to permit a consistently new course. For example: the base of geoid computations remains the gravity anomaly, being the difference between measured gravity and the theoretical (approximate) value computed from an ellipsoidal normal gravity field in which more or less dubious height definitions play a part. Even more curious is the use of deflections of the vertical, which cannot be defined without an ellipsoid, if they can be sharply defined at all.

3 Present-day problems

It can hardly be doubted that cartographic purposes will always necessitate the use of an ellipsoidal coordinate system with its possibility for the application of map projections; but then it should be a unique and universal ellipsoidal system covering the whole earth. Satellite methods have already given an important contribution to the unification of national or subcontinental networks, but there remain problems to be solved.

Firstly, there is doubt whether the orientation and length-scale of spatial measuring systems have a precision and a reliability which is equivalent to the precision and the reliability with which the relative positions of coordinate points have been fixed. One may in this respect think of different satellite- and VLBI-systems and also of the problem of centring with respect to the centre of mass of the earth in dynamic satellite systems. This doubt is expressed in the analysis of ten years of the USA's National Geodetic Satellite Program [S. W. HENRIKSEN, ed. (1977)] and in several publications analysing Doppler measurements. The doubt is made explicit in the dissertation of B. H. W. VAN GELDER (1978) and supported by the VLBI-study by F. J. J. BROUWER and P. VISSER (1978). The consequence would be that a description for the relative positions of coordinate points has to be found which largely eliminates uncertainty in the centring, the orientation and the length-scale. This indicates the necessity to use division algebras, implying for three-dimensional spatial systems the use of quaternion algebra. The application of the theory of S-transformations then leads to the description of the relative positions of coordinate points by form elements, formulated by quaternion theory in the framework of three-dimensional Euclidean geometry. Spatial sub-systems deemed homogeneous can then be connected via form elements which are invariant with respect to a (differential) similarity transformation. The relevant homogeneity means that evasive residual effects of reductions, translations, orientations and length-scale factors can be eliminated to a sufficient degree by the introduction of form elements, provided that the method and period of measurement are adapted to this approach. This approach is more cautious than the way which is usually followed in the American computations, and it offers better possibilities for testing. It is essential that the definition of form elements, and hence all further computation, is made in terms of spatial Cartesian coordinates.

Secondly, it follows that every national or sub-continental ellipsoidal coordinate system has to be transformed to a Cartesian coordinate system, before the junction to spatial systems via form elements can be effected. The critical point here is the height of terrain points with respect to the ellipsoid used, whose centre will not in general coincide with the centre of gravity of the earth. In [BAARDA (1979)] it is shown that for a complementary height computation one needs both levelling and gravity observations. The Stokes-like integral equations developed admit – contrary to the customary theory – a regional application, which in this case is certainly necessary because an ellipsoidal system is always limited to a part of the earth. The difficulty which still has to be overcome is that the unambiguous height concept introduced is centric, i.e. defined with respect to the centre of mass of the earth, whereas the ellipsoidal coordinate system is non-centric. The publication does offer a possibility to estimate the non-centricity, but the domain of integration of the integral formulas concerned is the whole surface of the earth, so that regional application is not realistic.

Thirdly, the ellipsoidal partial systems show internal shortcomings, mainly where the consistency of the computing model is concerned. This has become clear from further elaboration of formulas in [BAARDA(1957)]; a sharper treatment was given in [E. W. GRAFAREND (1972)]. To the author's knowledge, this matter has never been worked out further, so that there is no appraisal of the effect on computed ellipsoidal coordinates. Now that the problem of the junction of spatial and ellipsoidal systems is becoming a practical one, this inconsistency should be investigated at short notice. A second problem is the inclusion of distance measurements in the ellipsoidal computing model. This introduces two types of difficulties, the reduction of measured distances to the ellipsoid connected with the uncertainty of the height [P. MEISSL (1972)] and the ignorance about the precise ratio of length-scales in distance measurement and the reference ellipsoid used. Both difficulties seem to be avoidable by considering distance measurements from one terrestrial point as a series of distance measures, but the consequences for the ellipsoidal computations have not yet been solved in a satisfactory way. An implication would be that, when mapping onto a plane by a map projection, the computation would in principle also have to be executed with distance measures. When distance measurements cause problems, one can also expect difficulties with azimuth measurements. For this, reference can be made to [BAARDA (1957)], to which G. L. STRANG VAN HEES (1977) has given an interesting extension. Of course, all these difficulties would vanish if terrestrial networks would be computed spatially as well, as has been elaborated in the quaternion theory. But this requires the measurement of vertical angles, which usually has been and is omitted on account of the influence of vertical refraction. For the time being it is therefore more realistic to aim further research at the properties of the ellipsoidal computations. The urgency of such research is shown by the discrepancies actually found for the first time in the re-adjustment of the European triangulations. Before and after the first phase of this adjustment, which only concerned angle- or direction measurements, none of the observations in the Netherlands' triangulation had to be rejected. After a recent computation of the second phase, now also including distances and azimuths, some observations accepted in the first phase were rejected; moreover, a distinct and probably unacceptable distortion of the national network was established.

Fourthly, one should draw the consequences of network junction via form elements in the framework of Cartesian coordinates. This means that for cartographic purposes it should be considered how the transition to a uniquely defined ellipsoidal coordinate system could be made (i.e. sufficiently unique for practice). And also, how one should establish the connection between this system and the earlier national or sub-continental ellipsoidal partial systems.

4 Possible consequences

From the preceding it appears that the many techniques of measurement and computation are interwoven to an extent that has hardly been evident before. It is therefore meaningless to divide the Commission's field of work into the old compartments. The same applies to new compartments that one might wish to add for spatial methods, marine techniques and possibly even the areas touching geophysics and oceanography [BAARDA (1979)]. But likewise it is to be expected that the line dividing the members of the Commission according to practical or theoretical interest will gradually become more vague. For Doppler techniques confront practice already now with the contrast between the spatial and the ellipsoidal approach; the concept of height and the significance and the weakness of levelling are being discussed generally; a practical solution to geodetic problems at sea is becoming more and more urgent. This also implies that in the near future of the Commission's work, areas which are now considered theoretical, will be partly taken over by the national services: gravity measurement on land by the Survey Department of the Department of Public Works, which takes care of the levelling; gravity measurement at sea by the Hydrographic Service of the Royal Netherlands Navy; parts of spatial methods by the Netherlands Triangulation Service (a department of the Cadastral Service) and/or the Hydrographic or Topographic Services. These are only examples of a prediction which may seem weakly founded, but they deserve discussion when the Commission's field of work for the coming decades is considered. This would make the coordinating task of the Commission more important and its discussions even more interesting.

5 The deformable earth

Although one has so far hardly achieved the description of the earth as a rigid body, the problem of the deformable earth already presents itself. There are changes without hysteresis, such as tidal effects, and changes with hysteresis, such as deformations of the earth's crust. One speaks of deformation measurements, although it may be reflected that alterations with time will be the rule rather than an exception. Fortunately, in a limited time-span the order of magnitude of such changes is usually small as compared to the precision and reliability of measurements, so that existing principles of measurement remain applicable. Therefore one will, also here, establish deformation by comparing form elements pertaining to the same physical points, as derived from measurements made at different times; each of these measurements should be performed within a relatively short period [BAARDA (1975)]. Here, the theory of precision and reliability is essential if one wishes to make realistic statements. And realistic statements are needed because in this field there is already now a development from theory to practice [NASA (1978)].

6 A period of reflection

The consciousness of a changing earth marks the decade in which the Netherlands Geodetic Commission celebrates its centenary, and it marks the beginning of a period of reflection after a strong development of measuring and computing methods in the past twenty years. Several lines of thought are seen to converge: general matrix inverses [A. BJERHAMMAR (1973)], inner precision [P. MEISSL (1962)], inner adjustment constraints [G. BLAHA (1971)], solution space [A. J. POPE (1973)], singular adjustment problems [H. PELZER (1974)], estimable quantities [E. W. GRAFAREND, B. SCHAFFRIN (1976)] shed a new light on the theory of S-transformations (essentially developed already in 1944) as shown in [J. VAN MIERLO (1978) and internal reports by this author]. The idea of criterion matrices is deepened from different points of view, the research being devoted, in particular, to the form of the covariance functions to be used [BAARDA (1977)], [K. BORRE (1978) and his references]. The idea of the reliability of a network begins to be taken up [W. FÖRSTNER (1978)] and will certainly lead to interesting discussions. A brilliant survey of new approaches to the geodetic boundary value problem was given in [H. MORITZ (1977)] whereas the same author deepened the background of collocation theory in a number of publications culminating in [H. MORITZ (1978)]. Important results may be expected from the application of new ideas from mathematical geometry, where authors like E. W. GRAFAREND and N. GROSSMAN continue the development of A. Marussi's ideas. Finally, one of the most fascinating future problems of geodesy seems to be the interaction with geophysics and oceanography; [I. I. MUELLER (1975, 1978)] and [U. A. UOTILA (1977)] are notable publications in this area, where a convergence of ideas is hardly noticeable so far.

7 The need of main lines in reasoning

It is evident that we witness an enormous deepening of the ancient field of geodesy, following and accompanying the widening that was already noted before. This tends to make the single person feel modest, as it is hardly possible for him to survey the whole field and at the same time have insight into all its parts. Even more than in previous periods it will therefore be necessary to trace the main lines in geodetic reasoning; the author's own experience has taught him how laborious and time-consuming this is and will be [BAARDA (1978)].

Also in other aspects modesty is fitting. If, after a long struggle with the subject, one has arrived at the insight that the form elements referred to are the base for the description and junction of networks of different types, then one must conclude that this is essentially nothing but a sharper formulation of statements in existing discussions on the admissibility of the junction of spatial networks by a (complete) similarity transformation. And if this struggle leads to a rejection of the ellipsoidal computing model, then practical considerations again necessitate the introduction of a reference ellipsoid, as was argued before.

But all the same such an individual struggle with the subject-matter on one's discipline is necessary and useful because in this way practical points of view can be imbedded in a theoretical, logically consistent model. Experience shows that along this path new methods for practice can be found, either with or without the extension and re-interpretation of existing methods.

8 The Commission

It is exactly this exchange between theory and practice which makes the work in the Netherlands Geodetic Commission so fascinating. The significance of this Commission indeed resides in the mutual fertilization of ideas by the practically or theoretically inclined members and the services or institutes they represent. Much of this comes to the fore in the many subcommissions and working groups established by the Commission; the actual execution of operations is only a rather weak reflection of all the considerations. In order to make explicit this nucleus of the Commission's work it would be good to publish, along with the fascinating historical survey of the Commission's activities, an extract from the minutes of meetings and from preparatory reports. Lack of time and space made this impossible, and one is obliged to refer to the Communications of the Commission in which it is tried to record the activities of the last decades.

May the work of the centennial Commission – and not in the last place in this sense – be continued in the period to come.

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3. LAND INFORMATION SYSTEMS

by M. J. M. BOGAERTS *

1 Introduction

In September 1974 a new curriculum was introduced at the Department of Geodesy of the Delft University of Technology. One of the main aspects in the new course for geodesists is that more attention is now being paid to the planning and administrative side of the profession. This refers to collecting, processing and supplying administrative information linked to technical data obtained from surveying. This information refers to the entire field of relations between men and the land, the main aspects of which are: levying of taxes, legal position of the land, supervision, land and town renewal, physical planning. Planning and administrative geodesy includes also introducing and guiding changes in the relation between men and land in town and country planning. An important aspect of planning and administrative geodesy is the juridical-administrative framework in which it operates.

For proper education and research in planning and administrative geodesy it was considered necessary to establish a new chair in the Department of Geodesy, realized in 1976, called "Land Information Systems".

The following short description of this professional field is taken from a lecture I delivered on the occasion of the opening of the Seventh European Symposium on "Urban Data Management", The Hague, April 23–27, 1979.

Land information systems refer to land and spatial units and to the activities of the authorities and of private persons which are closely connected with them. These spatial units can be defined as follows:
- *administrative* areas, e.g. countries, parishes, tax districts;
- *functional* areas, e.g. school districts, medical districts;
- *networks*, e.g. roads, rivers, pipelines, transmission cables;
- *objects*, e.g. buildings, land parcels, monuments, all objects above, in, or under the surface of the earth.

Although land information systems can be used for a wide range of objectives, we concentrate here on five of the more important:

a. *Tax levy*
Because land parcels have a fixed place on the surface of the earth and because they are visible to everyone, they are suitable objects for levying of taxes. From ancient times there have been land information systems for land tax. The problem attaching to these information systems is that they have mostly been based on data from other information systems. In such a set-up, in many countries the problem arises that, for a variety of reasons the

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exchange of data between the different land information systems is very difficult. Moreover, there is also the problem of large gaps in the reflection of reality. A well-ordered record of the use to which it is put is sadly lacking.

b. *Protection of the legal system in real estate (commerce)*
There are landtitle recording systems or cadastres in almost every country. A cadastre is mostly set up to ensure a fair levy of the land tax. Experience has shown that registration of titles to land is an important instrument in the protection of the legal system in real estate. The registration refers to persons and land and their mutual relationships which consist of commercial rights. In these days it does not only concern the situation of private law; more and more restrictions are imposed by the government on property and the use of real estate. In most countries the registration of these aspects of public law is seldom effected systematically. An automated cadastre is one of the largest databanks of a country.

c. *Management/supervision*
The supervision of land and real estate may be described as efficient maintenance and functioning. Supervision breaks down by the kind of immovables and the objectives such as agricultural management, supervision of buildings, roads, waterways, nature, landscape, etc. This complicated situation is one of the reasons that most information systems were created for the management and supervision of immovables.

The land information systems that serve for management and supervision are characterized by an intensive decentralization. Underground and aboveground wiring and pipeline systems are a good example of this. Almost every pipe line and wiring system supervisor has a relevant information system.

The opportunity of an efficient exchange of information between these systems is very important to a country, for instance, for safeguarding the connections and for town and country planning. Unfortunately this exchange of data seems to be a very complicated affair for countries.

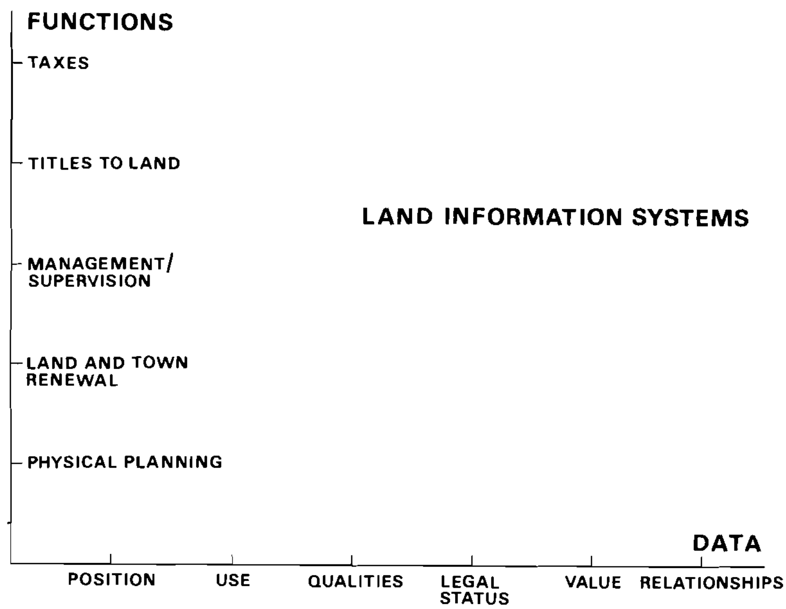
d. *Renewal*
Renewal means the renewal of urban and country areas, including large civil engineering projects. Examples are the reallotments in Western Europe that started about seventy years ago. As the areas now vary up to 200 km^2, large land information systems are needed and must be kept up to date for a period of 12 to 15 years. In urban areas there are many information systems for various functions. Most town planners have to make do with the existing undynamic land information systems, so that the information required is often not available, or is out of date, or incomplete. New ideas with respect to urban renewal call for dynamic information systems.

e. *Planning*
Since 1967 we have seen a great upsurge in the volume of planning research. New designing methods call for up-to-date information. The information systems for the purpose of town and country planning are mainly statistical data systems, as there is no need for identified objects.

Although land information systems deal with enormous quantities of data, they can rather easily be divided into six sections. The *position* of the spatial objects with respect to the surface of the earth. This is in fact the only point the objects have in common. Therefore, it is precisely the point which is important for the exchange of data between different land information systems.

The *use* that is made of the spatial objects may consist of the very many activities that are carried out in a modern complicated community. The *qualities* of the objects are, for instance, the dimensions and the material of which they are made. The *legal status* deals with the question of who is the owner, who is the user, what other commercial rights there are and what are the limitations in respect of property and use from the standpoint of public law. One of the most complicated kinds of information is that relating to *value*, because there are so many different kinds of values. The last section of the information concerns the *relationships* between the use of spatial objects and other economic and social activities.

If we combine the objective of the land information systems with the data stored in them, the result shown in the following diagram is obtained.



2 Organizational problems with land information systems

The many big and small land information systems each supply a small part of the information for all private and governmental activities with land and spatial objects. To ensure efficient functioning of the governmental apparatus the information exchange must be optimal. Unfortunately this is generally not the case.

For a variety of reasons, the coordination between the various data systems gives rise to difficulties in practice. Some reasons for the problems in respect of coordination are:

- too many different kinds of identifiers are used which have little or no connection with each other;

- it often happens that no use is made of the national coordinate system in assessing the location of spatial objects;
- the size of the objects to which the information is connected is not uniform;
- the registration times of the information are different. The periods of updating show much variation;
- it is often difficult to gain access to information systems, in addition to which they are inefficiently structured.

Since in land information systems much use is made of maps, the coordination up to now has proved to be better than was expected. The onward march of automation, however, will more than likely give rise to many new problems in the short term.

Organizational problems can be overcome by new technical facilities and consultation should culminate in actual cooperation between the various public authorities. This should result in new legal provisions. In the field of land and land use there are hundreds of laws in our country which show little coherence. I expect the situation in other countries is similar.

In all these laws there is little or no mention of the information supply. It is strange that this important and costly activity has hardly any legal status. An attempt is being made in The Netherlands to coordinate the complete administrative legislation in respect of land and land use. This opportunity should be used also to make legal arrangements for the information supply. At the same time the disadvantages of large information systems could be dealt with. Land information systems too may be a threat to privacy. Automation gives the government a lead on democratic opposition, for instance.

3 Technical aspects of land information systems

The technical aspects of land information systems refer to the collection, processing and supply of information. Some aspects of data collection are: identification, structuring, classification, accuracy, analysis, study of measuring techniques, selection of data. I shall now dwell briefly on two of these aspects, i.e. structuring and classification.

The *structuring* of data means the investigation of their logical coherence. Therefore, it is not only a question of determining what data are to be stored, but, in addition, their relationship has to be investigated, in addition to which it must be determined which of these relationships has to be registered, not to mention the relationship between the various relationships which may also be very important. For the structuring of data and their relationships there are different techniques which are described in the informatica manuals. The fact that informatica experts write about this subject, shows that the problems are looked at the basis of the tool (computer), whereas this should be done with reference to the problems themselves.

A remarkable development in structuring on the basis of the problems themselves takes place with the map-encoding databanks, which usually form part of the land information systems. The data structure of the geographical part of a land information system is usually rather simple. It is formed by a description of the objects and the coordinates which indicate the location. Generally one important piece of data is missing, viz. the relative location of the geographical unit, i.e. the location of the unit with respect of the surrounding units. The structures in which this relative location is indicated, are called the topological data structures. The initiation to describe map-encoding elements in a topological way with the aid of polygons, segments and junctions is undeniably attributable to the start of the DIME project in 1967 (DIME = Dual Independent Map Encoding) on behalf of the processing of American censuses. The DIME-structure has a number of drawbacks which have been avoided in the development of other topological data structures.

Classification may be seen as an aid to a survey of the complicated quantity of objects or data; it is, in other words, the regulation of a seemingly chaotic situation. If one wishes to have a suitable system for the exchange of data between different land information systems, or if one desires to aggregate, couple, etc. it will be necessary to arrive at well-founded agreements with respect to the coding of data and particularly to classification. This classification is also necessary to get suitable series of data. When mixing up, in a data collection, the properties which are fundamental and can be split, then the applicability decreases and the costs for the updating of data increase. Therefore, it is essential that the properties of the data be separated as well as possible. Where in a data bank different objects are connected indissolubly and one of the properties is unknown, the other properties will also be lost. In various countries attempts have been made to arrive at an efficient classification of data on immovables.

Data processing takes us to the field informatica. Database technology is of particular interest for the development of land data systems. It enables us to make the large collections of data on immovables with their structured contents suitable for further processing. A databank contains all data of importance for a certain field of application, together with their interrelationships. The most important demand made on such a data collection is that the users' programmes are independent of the way in which the data are stored. The advantage of such independence is that the users' programme need not be changed each time that the classification of the data is altered. Nowadays there are very expensive databank systems which do give satisfying results. These systems, however, require so much more money and manpower, that it is often doubtful if their introduction in a certain land data system is really profitable.

Land information systems have to deal with many new ideas on the processing and supply of information, such as decentralization, related databanks, working with interactive graphical systems etc.

4 Working group "Uniformity"

An important connection between the Netherlands Geodetic Commission and the field covered by land information systems is the working group "Uniformity", established by the Commission in 1974. The task of this working group is to develop such a system of classification and location indication of topographically identifiable units that it will be possible to interchange data stored in various information systems in the best way. After being set up the working group contacted the "Bestuurlijke Overlegcommissie Overheidsautomatisering (BOCO)"* of the Ministry of the Interior and it was agreed that the result of the studies carried out by the working group would be made available to BOCO.

In consultation with BOCO the working group is presently investigating the criteria with

* Governmental consultative committee studying the application of automation in public agencies.

which detailed topographical data collections and if possible details of land information data collections (such as underground cables and pipelines, buildings, cadastral parcels) should comply so that data on the location of land information units can be supplied automatically in a suitable and effective way using topological basic information. This investigation includes, in particular, classification, precision, reliability, structuring of data and location indication, the accessibility of databanks and conversion problems. In order not to make the investigation too complicated and too time-consuming the working group concentrates itself first on large scale maps. Of course this investigation of the working group Uniformity concerns only a part of the problems associated with land information systems.

4. ON SOME ADVANCEMENTS RECENTLY MADE IN ASTROMETRY

by G. VAN HERK *

Astrometry is of importance to geodesy for more than one reason. This explains why close ties have always existed between the two sciences. Investigations on the movement of the coordinate systems and on the positions of the stars have had common interests. The actual determination of the positions of the stars has belonged more to the domain of the astronomers, geodesists confining themselves, usually, to the role of consumers of the astronomers' results. It is obvious that geodesists have wondered why astrometrists could not offer more accurate results. Here, "*accurate*" means less influenced by systematic errors.

A very striking example of these systematic errors was given a few years ago by those who were responsible for correcting the orbits of space probes. An adjustment of such an orbit requires the knowledge of precise time. It turned out that the clock corrections were depending on the latitude of the station where the PZT observations of time were made. This dependency was a consequence of each station using different stars; different groups of stars have their own, different, systematic errors in right ascension.

For a long time astrometrists have been aware of the existence of systematic differences in their results and they have detected over the years a number of parameters which may play a part in producing these systematic differences. The person who performs the observation is, in some instances, responsible. The brightness of the star can have some influence, as well as the speed with which the star crosses the field of the meridian circle. It can always be argued that our atmosphere may have a detrimental effect. In some cases it became obvious that instruments, turned out by a specific workshop were behaving in a systematically different way than those from other sources. Astrometrists have, for a long time, tried to turn systematic errors into random ones by changing their methods of observing and by asking the cooperation of more observatories, hoping that a combination of more different systematic errors might cancel them on the average. Many have been the efforts to combine different results into a mean that would be less affected by systematic errors than each individual contributing source. We owe to these efforts several "fundamental catalogues", of which the Fourth Fundamental Catalogue (FK4) of the German school of composers, now at Heidelberg, is the one which is adopted as the international standard. The fact that this catalogue contains only 1535 stars, or one per about 24 square degrees, tells us how much is still to be desired.

As stars have their own – though small – motions (when measured in angular size per century), a compiler of a fundamental catalogue has to determine, next to a best mean position of a star, the time derivatives of these positions. In other words, he has to deduce the motion of the coordinate system and the motion peculiar to each star, which means he has at his disposal fewer condition equations than he needs. It has become the practice for a long time to accept the motion of the coordinate system in order to deal

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with fewer unknowns than in the general problem. We are now, after about 80 years, turning over to the precessional constants of W. FRICKE. Modern technological knowledge may help speed up the improvement of these constants. Ever since interferometric radio techniques claim an accuracy in the determination of an absolute declination of the order of 0.″01, can we hope that the precession may be found more accurately and sooner than with the old-fashioned observations – mainly performed with visual meridian circles.

There exist several signs that the meridian circles conceived in the last decade give improved results compared with observations made 40 or 30 years ago. So far as we can tell now, the improvement is certain with respect to random errors, and this may help better to detect where systematic errors occur. A few examples are the following. The reading of a graduated circle used to have an uncertainty of a few tenths of a second of arc. An automatic circle scanning device developed at the Copenhagen Observatory reads a circle with a repeatability of 0.″04. The same accuracy is obtained in Washington with an electronic angular positions transducer. In the Copenhagen instrument it is still necessary to know the errors in the division of the circle. Fifty years ago, the determination of the division errors kept a couple of astronomers busy for the better part of a year. With the new device this takes less than nine hours. It means that all sort of troubles that might occur during the determination have less chance of happening. The Copenhagen results claim $\pm 0.''02$ as a standard deviation for a division error.

Modern micrometers have improved considerably the accuracy with which a transit is observed. The Washington micrometer registers the position of the travelling wire (on which the star-image is kept) every fourth second. Some uncertainties, previously incorporated in the results are now better eliminated, the main improvement being that after four seconds the "settings" are far more independent than the five or seven positions during the same number of contacts with the old micrometer – the latter are too close together. A very precisely working travelling micrometer, guided photo-electrically, designed at Bordeaux, has given very accurate results. So has the photo-electric micrometer, working as a pulse counting photometer, developed at Bergedorf and extensively used during the Hamburg expedition to Perth. The results came close to what can be expected as the minimal error due to atmospheric behaviour. For the asymptotic mean errors the values $\pm 0.''023$ and $\pm 0.''14$ were found for the right ascension and declination observations respectively. The random errors were of the order of $0.''17(\cos z)^{-0.5}$ and $0.''27(\cos z)^{-0.5}$ for these coordinates. Meridian observations remain the most popular ones to be performed, and quite a few astronomers try hard to improve the designs of the meridian transit circles. Already 20 years ago, R. d'E. ATKINSON worked on "horizontal" meridian circles: two fixed telescopes, mounted horizontally with their optical axes aligned in the plane of the same meridian face each other at such a minimum distance that a flat mirror is allowed to rotate, perpendicular to the meridian, between the objectives. Each telescope allows the observation of roughly half the sky with an overlap at the zenith. Several advantages can be mentioned for this particular design but the difficulties encountered are by no means to be underestimated. Work along these lines is now in progress in Russia, Denmark, Portugal as well as in other countries. The last few years have seen an extension of studies of the influence of the atmosphere. More realistic atmospherical models are introduced and more investigations, using modern equipment, on local conditions are carried out. In this work groups of astronomers headed by G. TELEKI, work closely together with groups of geodesists. However, to solve the difficulties caused by our atmosphere, there is only one way out which settles this problem completely: to observe above the atmosphere. Two schemes are being studied, one set up by NASA, the other conceived by P. LACROUTE. The accuracies claimed so far would help solving several problems in a time lapse, possibly a factor of a hundred smaller than with ground-based observations. Of course such outer-space observations put different strains on the instruments to be used, but at the moment no insurmountable problems seem to have been encountered. This is a promising improvement for the future, but what has been already established with respect to the determination of the lunar orbit is astonishing. The lunar laser-ranging technique, applied since 1969, aims at measuring the range three times daily with an absolute accuracy of a few centimetres. The work done, especially at the MacDonald Observatory, has already given improved results compared with the old-time angular measurement approach, and it is hoped to use the results in telling how fast the earth rotates, to pinpoint the position of the pole at any moment and to detect continental movements.

As not all aspects can be covered here, however superficially, only one, of less interest to geodesists may be mentioned. The new Flagstaff mirror telescope, designed by K. AA STRAND, measures parallaxes of stars down to the 18th magnitude, which helps greatly in increasing our knowledge of the nearby population of the Milky Way.

5. GEODESY, CRUSTAL DYNAMICS AND EARTHQUAKE PREDICTION

by A. R. RITSEMA *)

1 Introduction

GEODESY has entered a new era with the ascertainment of the non-steady-state of earth. Apart from the geometric coordinates, factor time is going to play an increasing role in geodesy. The step from the recently found kinematic phenomena on earth to the dynamic considerations of cause and effect is a small one. This also will bring geodesy more within the realm of geophysics.

It is only recently that the consequences of a non-steady-state earth for geodesy are really understood and appreciated. The dynamic character of the earth's outer shell is well documented in the form of gradual, periodic or transient displacements of the surface in both vertical and horizontal directions. Geodetic measurements have contributed significantly to this new insight.

Geodesy supplies data that bear on geodynamic processes of vastly different scale. The range includes the periodic changes, the secular or quasi-periodic changes on a planetary scale such as the polar wobble, variations in the earth's rotation or the length of the day; zero-frequency changes such as plate-tectonic movements on a global scale, glacial rebound and sediment loading effects on a regional scale; the secular, pre-, co- and post-seismic creep on a regional to local scale; the transient effects on a very localised scale such as the man-made subsidence caused by withdrawal of water from the underground and the periodic or semi-periodic loading effects by marine tides, storm surges and air-pressure variations.

Several of these types of data have a direct impact on human society. The foremost practical applications of time-dependent geodesy lie in the field of crustal dynamics and of earthquakes and their prediction.

EARTHQUAKES accompanied by ground breakage and faulting of the landscape cause distortion of geodetic networks around the line of rupture. This was realised already long ago. In fact, the very earliest example of geodetically determined horizontal displacements of first and second order triangulation points was that in Sumatra after the great Tapanuli earthquake of 1892 (Fig. 1). It was found by MULLER, later a member and president of the Netherlands Geodetic Commission.

The cause of such motions remained obscure for many decades, and it is only in the last 15 years that a global process of motion and flow in the earth's mantle and crust was suggested, giving a satisfactory explanation of both the position of the zones where earthquakes occur and the type and direction of movement that is found in the earthquake foci. This was done in the theory of plate tectonics [LE PICHON e.a. 1973], which says that the earth's lithosphere is divided into a limited number of internally rigid plates moving with respect to each other and causing the relatively narrow zones in which earthquakes are concentrated. Processes of crustal dynamics are now being studied to find the driving forces for these observed plate kinematics.

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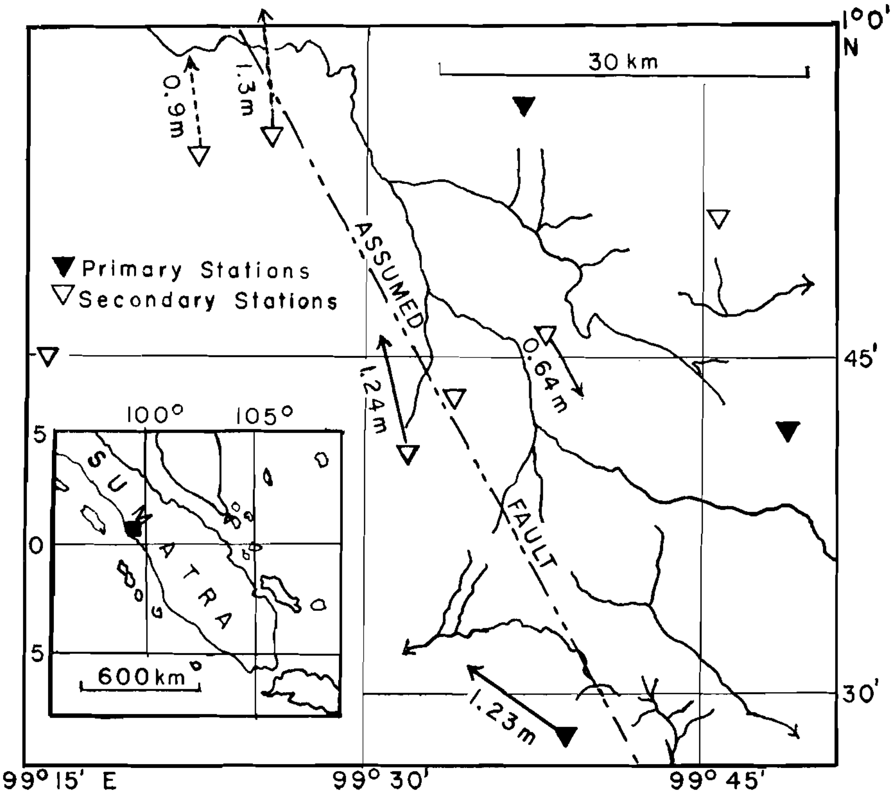

Fig. 1. Displacement of triangulation monuments by the earthquake of May 17, 1892 in Tapanuli, Western Sumatra, and the inferred line of faulting (after MULLER, 1895). Estimated dextral fault displacement of 3.5–4 m.

On the other hand it is only in the past 5 years that some mechanism has been found that could explain the more immediate effects before, during and after earthquakes and which is of direct importance in the problem of earthquake prediction. This so-called theory of dilatancy [see for example RIKITAKE, 1976] explains, how by a process of micro-jointing under the regime of a growing stress, the fault rock for certain periods prior to the earthquake increases in volume, resulting in a sometimes measurable bulging of the landscape.

Geodesy can contribute significantly to the solving of both these problems of crustal dynamics and of the prediction of earthquakes.

2 Crustal dynamics

Long-term average rates of plate motions are determined from the geological record. Magnetic anomalies connected with mid-oceanic ridges and transform faults give velocity averages over a period of 10 million years. For the control of instantaneous plate motions continuous, or at least regular, geodetic observations are needed. Quantification of instantaneous crustal plate movements is supposed to be possible with a number of 30 to 40 stations distributed over the main plates of the earth. The accuracy of the relative positions of these stations ultimately should be of the order of 1 cm, if we note that the distance changes caused by the process of plate tectonics maximally are 10 to 20 cm/year, but mostly are of the order of a few cm/year only.

For an effective checking of contemporary plate kinematics a satellite positioning system is the most obvious choice. Optimally, the system should be of the type of a Spaceborne Ranging System in which a satellite regularly and automatically ranges a number of strategically distributed passive landmarkers equipped with retroreflectors. The orbit of the satellite has to be kept under control by a number of fixed and well spread terrestrial observatories. At each passing of the satellite over a marker-point, the ranging data are to be processed in terms of the relative position of the point with respect to the orbit-positioning observatories. If such a system could reach an accuracy of 1 centimetre it would be ideally suited for the quantification and the control of instantaneous global plate tectonic movement patterns (Fig. 2). Any accumulation of regional strain could then be detected by the differences between the observed and the expected displacements. The important question could also be solved as to how far the plates are stable throughout and without distortion, or as to how far internal motions within plates do occur.

At plate boundaries where earthquakes are concentrated, the density of observation points has to be a factor 10^3 to 10^5 greater than that for the delineation of the global plate motions;

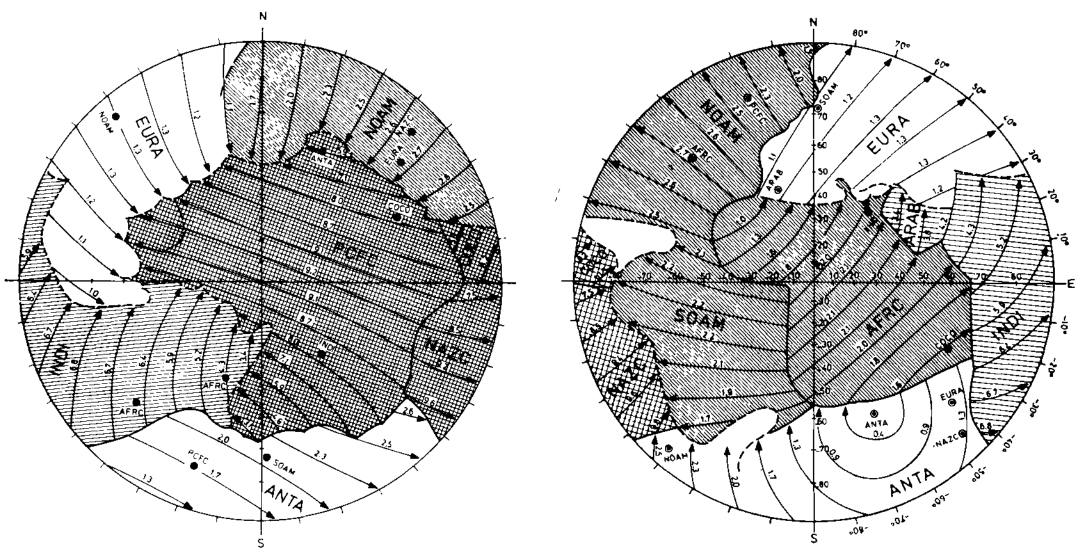

Fig. 2. Instantaneous crustal kinematics in stereographic (WULFF) projection according to the model of Minster et al. (1974), based upon mid-ocean spreading rates, fracture trends, earthquake slip vectors and hot spot locations. Lithospheric plates are assumed to be rigid and their kinematics to be determined by motion around a rotational axis. The rate of motion is indicated in cm/year. The low displacements of Eurasia and of Antarctica are the least reliable in value and direction. The figure gives a general idea of the order and type of displacements for which geophysicists seek confirmation from advanced geodetic techniques. Plates and rotation-poles are indicated as follows: EURA-Eurasia, AFRC-Africa, SOAM-S. America, NOAM-N. America, ARAB-Arabia, ANTA-Antarctica, INDI-Indiaustralia, PCFC-Pacific, NAZC-Nazca, COCO-Cocos.

Note added in printing:
A more recent calculation by Minster & Jordan (J. Geoph. Res. **83**, B11: 5331–5354, 1978), based on an expanded data-set, gives significantly different positions for the rotation-poles of the Eurasian and the Antarctica plates, namely 1°N 23°W and 22°N 76°E respectively. In both cases the angular velocities are even lower than those of the earlier model indicated on the figure.

distances between stations should be of the order of 10–1000 m. Moreover, the rate of measurements for the detection of appreciable displacements has to be a factor 10^1 to 10^2 greater. In these regions monthly changes equalling yearly or 10-yearly relative motions between the interior of the plates can locally be expected.

For an effective control of focal processes and horizontal and vertical premonitory ground movements incidental VLBI and satellite or lunar ranging are of use, but the classical land-based repeat or continuous strain measurements in earthquake-prone regions are still to be favoured when it comes to a dense network.

It is realised that the accuracy of the terrestrial measuring techniques necessarily deteriorates with distance and that centimetre accuracy can only be reached for relative positions at distances of the order of a few to a few tens of kilometres. For a dense regional network this attainable accuracy is acceptable, especially if controlled at a limited number of base stations by other techniques such as VLBI and lunar ranging with an accuracy of 20 cm regardless of the distance. This compares favourably with the accuracy of the classical triangulation methods of 10, 50 and 250 cm at 10, 100 and 1000 km distance respectively, and that of levelling measurements at the same distance of 1, 5 and 25 cm respectively [SONG, 1978].

The regions that should be kept under control are not restricted to the places where in historical time earthquakes have occurred. In regions with a well-known geology and seismological history it has been shown that the potentially catastrophic earthquakes of magnitude 6 and higher all are located on or near Quarternary fault lines. This means that not only the fault sectors with known epicenters should be monitored, but the complete fault zones as determined by geologists.

Seismologists in earthquake-prone regions such as California use continually recording strain, tilt and creep meters for monitoring purposes. Arrays of these instruments needed for an areal coverage, however, are very expensive. The standard geodetic positioning techniques nowadays require less investment and therefore are still invaluable.

3 Earthquake prediction

The difficulty here is to distinguish pre-, co- and post-seismic phenomena in the background of secular movements. Along certain prominent fault zones, the background creep, quasi continuous and at constant rate, can amount, as we have seen, to 10 to 20 cm/year, but on the average the movement does not amount to more than some centimetres annually.

Premonitory movements, indications for future earthquakes, mostly are in the form of a bulging of the landscape around the places where the earthquake will occur. This is in accordance with the dilatancy theory as enunciated earlier.

Pre-seismic creep is more rapid than the secular motions at the place, up to one order of magnitude faster, but is mostly concentrated on particular sectors of the fault zone only. In certain cases premonitory uplifts of 5 to 8 cm in a few months time have been observed and there are indications for still more rapid motions in advance of some earthquakes. That until now such fast rates have not been reported more often is due to the paucity of the observation records and the normally accepted repeat-interval of 1 year or more between geodetic measurements.

Co-seismic slip along faults is very rapid, with propagating velocities of up to 4 km/sec and extreme values of instant displacements of about 10 metres. In depth fault displacements may be twice or more than that observed in the field. Post-seismic creep following earthquakes, mostly is less rapid than the pre-seismic motions. Its rate is of the order of a decimetre per year.

It is clear that for a reliable discrimination between pre- and post-seismic creep motions the seismic history of the region has to be known. It should also be realised that precursors in the form of anomalous uplifts may occur years in advance of an earthquake. In general the precursor time for heavy earthquakes is longer than that for smaller shocks. For an earthquake of magnitude 4 the precursor time is of the order of 10 to 20 days, for a magnitude 6: 1–2 years, and for $m = 8$ it could be tens of years. Also the areal extent over which anomalous uplifts are found is greater for the heavier shocks than for the smaller ones.

Geodetic measurements by no means are the exclusive tools in the practice of earthquake prediction. In fact, it is only one of the many kinds of observations that are needed for a reasonably reliable earthquake warning. Among the other basic data used for prediction purposes are the seismic history of the region and the level of local micro-shocks activity which clearly fluctuates with the occurrence of heavy earthquakes in between. But also earth magnetic data; water level changes in wells and radon emanation data; velocity changes of seismic waves; and tilt, strain and creep measurements can give significant information about imminent earthquakes.

It should be realised, however, that all these observations, including the geodetic anomalies, are of local consequence only. It will never be possible thus to extend the area for which the predictions are made beyond that of the immediate region for which direct data are available. Moreoever, even with the most complete information available, there is no law which says that an earthquake will follow. Sometimes, anomalies of the kinds just described are observed without any accompanying earthquake in the region. Such for example was the case with the propagating ground uplifts between 1969 and 1977 on Izu peninsula, Japan, where a growing bump of originally a few centimetres only and a few tens of kilometres in diameter, spread out with a velocity of about 2 km/month. In September 1976 the maximum uplift was already 15 cm in amplitude and the location of its centre was displaced tens of kilometres to the southwest from the original position. Japanese seismologists (1977) are of the opinion that this is a case where geodetic anomalies are not indicative of an ensuing earthquake.

Another puzzling case is the Palmdale bulge in California just north of Los Angeles (Fig. 3). This uplift is now monitored as a test-case for future movements. It extends for about 575 km from the Pacific coast well into Arizona. Its centre is situated in the Mojave desert. Since 1959 the uplift is estimated to have grown to 35 cm near Palmdale, and even more, around 45 cm, 100 to 200 km farther east. The areal extent of about 80 000 km^2 and the rate of elevation suggest a stored energy that easily could yield an earthquake of magnitude 8. It is possible, however, that the energy will be released in a series of smaller magnitude events spread out over many years and many segments of the faults present in the region. And as set out before, the uplift could even subside without any accompanying earthquake at all. A major project is now under way in the form of an extensive relevelling of the whole area. The measuring has been carried out by more than 300 specialists in spring and summer of 1978. The teams surveyed lines with a total length of about 4 000 km in a network covering the known area of the uplift. The idea behind the project is to be able to determine if possible the likelihood and potential size of future earthquakes in the area.

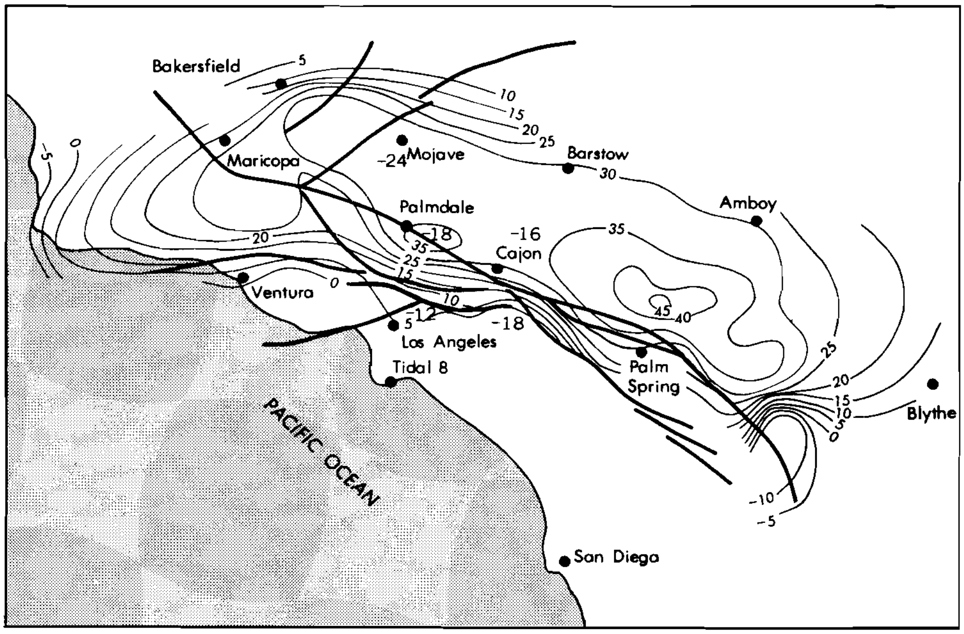

Fig. 3. The Palmdale uplift in southern California, after CASTLE (1978): the site of a future earthquake? The isobase shows elevation changes between 1959 and 1974 with a contour interval of 5 cm. Locally tectonic subsidence did occur since then. At places where this has been established the amount of later subsidence is indicated in centimetres. The largest historical earthquake in the region took place on January 9, 1857. It had a Richter magnitude of about 8.0.

Conclusions

To reach the ultimate goal of predicting earthquakes, and especially the most damaging large earthquakes, will require extensive fundamental studies in understanding earthquakes and their precursors; and extensive long-term programmes in monitoring earthquakes and related activity in diverse tectonic environments.

Observation of crustal movements and deformation in seismic zones are essential to progress in the understanding of earthquake processes, in the prediction of earthquakes and the reduction of hazards induced by earthquakes. It is expected to become standard practice soon in seismic regions all over the world.

Already important funds are now being made available for this purpose in countries like Japan, China, the USSR and USA. In Japan an amount of US M$ 28 was spent in a ten-year programme of earthquake prediction beginning in the year 1965. The annual budget for 1975 was US M$ 7, excluding salaries and expenses for the construction of permanent observatories. In the USA coordinated activity in the form of the Earthquake Hazard Reduction Program started at a later date, but the increase in budget has been substantial since then. In the years 1972–1974 the annual budget doubled twice from an initial US M$ 4.6 to US M$ 19.5 in 1974. In both countries an important part of these funds was spent in geodetic work.

It is not so long ago that the main link between geodesy and geophysics was gravity which in both disciplines was used as an important source of information, either as an expression of the earth's shape or of its internal structure. With the new geodetic techniques and higher accuracies over great distances this role of gravity as the primary link between geodesy and geophysics is taken over by geodynamics being of basic importance for the determination of the physical processes shaping the interior as well as the exterior of the earth.

The general tasks and possibilities of development for geodesists and geophysicists have been summarized in the foregoing. European geophysicists and geodesists more specifically will find a major challenge in the determination of the kinematics of the broad mobile belt of the Mediterranean. For this purpose also observational stations in stable Africa and on the Arabian platform will be needed. The most promising region for such joint measurements is the North Anatolian fault zone in which regularly earthquakes, great and small and accompanied by mainly horizontal displacements, do occur.

Contributions of The Netherlands in the joint field of interest of crustal dynamics may be expected from the Kootwijk satellite station as a monitoring base-point for European plate motions. On a regional scale a study could be made of the internal stability of the European plate by classical repeat measurements over international boundaries, supplemented and increased by satellite ranging, Doppler ranging and VLBI. On the local scale the contemporary tectonics of the country (especially in the southeastern part) should be kept under control by the classical land-based measurements and brought into relation with local seismicity and earthquake mechanisms [AHORNER e.a. 1976].

It is obvious that a growing cooperation between geodesists and geophysicists is imminent, and that the Netherlands Geodetic Commission is going to play an increasing role in national as well as international interunion research efforts such as the International Program of Lithosphere Research that possibly will start in 1980 as the successor to the Geodynamics Project in the seventies and the Upper Mantle Project in the sixties.

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6. GEODESY AND PHOTOGRAMMETRY

by A. J. VAN DER WEELE*

1 Introduction

No intensive statistical investigations are needed for one to be able to say with certainty that the word *photogrammetry* does not occur in the annals of the "Rijkscommissie voor Geodesie" (Netherlands Geodetic Commission) as often as various other terms used when referring to geodetic activities. We may find a possible explanation if we study the way in which photogrammetry has developed. No doubt it will appear that this development, founded as it is on basic sciences such as geometry, optics, chemistry and instrumental engineering, shows a number of similarities with geodesy, which suggests a close relationship. I want to discuss this relationship in some more detail.

The multitude of aspects which for this purpose may be taken into consideration should be arranged into some sort of order, for which the time factor seems to be very important. This is perfectly clear when one is aware of the fast and revolutionary technical progress of the last few decades; the now common use of such key words as computer, astronautics and laser may serve to illustrate this point. It seems therefore appropriate to follow a chronological approach, taking the development of photogrammetry as a point of departure. For the sake of simplicity, I will distinguish three periods, of which the time boundaries, not by chance, are marked by the First and Second World Wars.

2 Before World War I

In this period, photogrammetry developed mainly in two fields of application, i.e. for the drawing of buildings and other monuments (MEYDENBAUER, LAUSSEDAT in the middle of the 19th Century) and for the mapping of mountainous terrain, where access was difficult. The latter application, terrestrial photogrammetry, fits into what is usually called by geodesists *lower geodesy*: measurements in areas of limited extent, which means that the influence of the earth curvature can be neglected. These measurements were tied to points of higher order, wherever possible.

At this point it may be useful to pause for a moment to draw attention to a difference in the basic elements which were at the disposal of geodesists and photogrammetrists in the period considered above. For the geodesist, these were direction measurements, carried out separately for the horizontal and the vertical plane, together with distance measurements. In principle the photogrammetrist uses a photograph, from which only a spatial bundle of rays can be reconstructed. Thus, for the orientation of this bundle in space and for the scaling of maps and drawings, additional measurements are needed. The production of final maps from the images (photogrammetric restitution) was often done by using a combination of graphic and numerical methods, which was very labour intensive. At the

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end of this period (analogue) instruments were developed leading to an improvement of the economy (for example, the autograph of VON OREL 1912, developed from the first stereocomparator of PULFRICH 1901).

3 Between World War I and II

The advancement of the aeroplane, which during the First World War had increasingly proved its usefulness for reconnaissance purposes, stimulated the practical development of aerial photogrammetry. This period is marked by a continous improvement of technical means (lenses, cameras and restitution instruments), thus increasing the measure of competition between the new photogrammetric approach and current terrestrial methods. This concerned costing as well as accuracy of position fixing; numerical methods were hardly ever used in restitution. Apart from a few exceptions, the required accuracy of both photography and restitution was achieved by trying to approach as well as possible the simple mathematical model of a photograph, i.e. the central projection on a plane surface; the *physical* model was adjusted to the *mathematical* model. One exception was, for example, the lens distortion, which was insufficiently mastered; for this reason some instruments were provided with so-called compensation plates. If calculations were inevitable, as for example, in photogrammetric triangulations, this was done by relatively simple means, such as desk computers for the transformation of coordinates, based on an analysis of graphic comparisons between coordinates, obtained from adjacent strips and from terrestrial data.

Two aspects of this period deserve particular attention. Most surveys are carried out by tying one photogrammetric model or groups of models to terrestrially determined points. Initially, the differences between photogrammetric and terrestrial coordinates generally were attributed to errors in the photogrammetric system. By gradual improvements of the photogrammetric procedure such as substituting the dimensionally unstable acetate film for glass plates, this explanation appeared no longer tenable for many cases. The lack of accuracy or rather of homogeneity of the existing local coordinate systems in The Netherlands could thus be demonstrated very clearly. The self confidence of the photogrammetrists as well as the confidence of others in the photogrammetric method thus grew considerably, though not to the same degree for both groups.

According to the "Leerboek der Landmeetkunde" (Textbook for Surveying) by SCHERMERHORN and VAN STEENIS, *lower geodesy* is limited to measurements in areas of about 50 × 50 km, since within these dimensions neglect of the earth's curvature does not lead to unacceptable distortions. In the years between 1936 and 1940, however, a start was made with the application of photogrammetric triangulations over areas which extend far beyond this limit. The geological survey of large areas in what was then called New Guinea offers the first and most spectacular example. This does not mean that photogrammetry entered the domain of *higher geodesy*. On the contrary, the required accuracy, very vaguely defined, in the "Mijnwet" (Mining Act) as 1 pro mille (1×10^{-3}), was so much lower than usual that, applying the criterion used in the book of SCHERMERHORN and VAN STEENIS, the limit of 50 × 50 km could have been doubled. However, this type of work, contrary to the applications in The Netherlands, had already some relation to higher geodesy. The terrestrial data, upon which the photogrammetric triangulation had to be adjusted, consisted of points 80 to 100 km apart, whose coordinates were determined by astronomical observations.

These points were complemented where possible by local networks, thus providing some means for a check on scale and azimuth.

The contradictions, resulting from the connection of the photogrammetric system to the terrestrial data, proved to be of a magnitude which was difficult to explain notwithstanding the rather primitive photogrammetric procedures. Afterwards it could be proved that a much better fit would have been possible if the astronomically determined coordinates could have been corrected for the influence of deflection of the vertical.

This led to the decision that, for an area near the Andes in Latin America, where the topography indicated the high probability of deflections of the vertical, the astronomically determined coordinates should not be used. The internal adjustment of the photogrammetric system was thus based only on the local scale- and azimuth data. The resulting differences in position were rather high, but later gravity observations confirmed that the difference could be attributed to a great extent to the local gravity deviations. The classical idea of starting from a very accurate, wide-mazed, primary network with subsequent densifications was successfully abandoned.

Despite all the misery it brought, the Second World War influenced the development of photogrammetry in The Netherlands in a favourable way, since the interruption of much practical work made it possible quietly to analyse all the experience gained. Of course, first of all attention was paid to the problem of the obtainable accuracy resulting in a much better insight into the propagation of observational errors in a strip; also, the occurrence of rather important systematic errors could to a great extent be explained by instrumental influences, thus providing means for their elimination. The finding of an analogy with the propagation of errors in levelling was an interesting by-product of these studies.

4 After World War II

The fastest and most revolutionary developments in both photogrammetry and geodesy occurred in this period. Their influence cannot yet be fully estimated; certainly they have had and will still have far-reaching effects. In the context of this article I will limit myself to those aspects which are connected with the relationship between photogrammetry and geodesy.

Firstly, the introduction of modern computers brought within reach the possibility of computation and adjustment of large photogrammetric blocks. The introduction of the numerical restitution of photographs based on rectangular coordinates of the points to be determined, measured in the photograph, eliminated the errors inherent in the analogue restitution instruments, while offering the possibility of refining the mathematical model (the central projection) and increasing obtainable accuracy. The development of super wide-angle lenses of excellent optical quality increased the efficiency of photography and restitution, and the modern navigation aids enable the improvement of regularity and homogeneity of the networks to be computed. These improvements are of course most important for areas where a geodetic network of points does not yet exist or where old points cannot be traced.

Determination of the terrestrial control still needed does not pose insurmountable problems any longer, since satellite observations provide precisions within 1 or 2 metres with relatively short observation series and easily transportable instrumentation.

Although not all problems have been solved and although there is still insufficient practical experience under varying circumstances to guarantee that all pitfalls can be avoided, it may be said that photogrammetry has developed as a method of establishing control to such an extent that the time-consuming and expensive terrestrial triangulations are no longer necessary. Indeed, photogrammetry has definitely entered the realm of higher geodesy by its application for the measurement of a global network of points, based on the derivation of directions from photographs of satellites against the background of stars. Although the precision of these directions is limited to about one second of arc, the simplicity of the basic concept and the absence of complicating additional assumptions which often occur in other methods, may well make this procedure a useful complement to these methods for several years to come.

A century ago the word "graadmeting" (arc-measurement) was included in the name of the "Rijkscommissie" as a reference to the aim of providing a contribution to the determination of the figure of the earth as part of an international cooperation. Consequently, the desired accuracy for the triangulation was not derived from any intended practical application, but directed towards the maximal obtainable results. That a similar high accuracy was applied for the densification of the primary network has been an illogical, but at the same time a fortunate decision since many points of lower order could only be determined in an unfavourable way, geometrically speaking. Thanks to the high quality of the measurements the relative position of these points has been sufficient for most practical application.

The conclusion that the execution of very accurate triangulations is no longer required for the determination of the figure of the earth, has as a consequence that there has developed a clear distinction between surveys for scientific and for practical purposes. For scientific purposes an increasing precision should be aimed at, in particular since the study of the dynamic properties of the earth-crust as well as of the surface of the oceans comes within reach.

On the other hand the requirements for practical applications can now be directly related to the purpose, thus contributing to the economy and the efficiency of practical surveying. This is the more important for those vast areas of the world where no good maps exist and where practical demands with emphasis on speed, have the highest priority.

A rational approach lies in the concept that for all practical applications not more is required than a certain degree of relative accuracy on limited distances. BAARDA has developed this concept around 1950 in the "Handleiding voor Technische Werkzaamheden van het Kadaster" (Manual for the Technical Activities of the Cadastral Service). The concept allows for the fact that the networks to which the measured points belong, may have deformations. It also implies that all new measurements must be tied to points of the existing network, of which a certain number must therefore be permanently monumented in the field.

This concept, developed for the Cadastral Service, is generally valid in my opinion. I do not know of any application – at least not in the civilian sphere – for which more than a good relative accuracy is needed.

The photogrammetric method automatically presents a good relative accuracy, so that it is eminently suitable for the requirements which may be formulated in the light of the said concept. At the same time it fits in with the increasing demand for data for planning and management purposes in accessible geo-based data banks. Part of this information can be efficiently derived from the aerial photograph. If one also takes into account the possibility of additional data collection, which is potentially present in the so-called remote sensing techniques, it is clear that an important field for coordinating and advisory activities of the "Netherlands Geodetic Commission" is still open for the future. The relation between photogrammetry and geodesy may thus become much closer than it has been in the past.

7. RESEARCH IN THE DEPARTMENT OF SURVEYING AND PHOTOGRAMMETRY OF THE AGRICULTURAL UNIVERSITY, WAGENINGEN

by G. A. VAN WELY *)

1 Introduction

The programme of research in this Department is determined within the possibilities of personnel and material. The five university-educated staff members are occupied with lecturing and instruction of students for two-thirds of their time. This will not diminish during the coming years and an increase of personnel can not be expected. In addition to instruction and research a certain amount of time must be devoted to administration. For this very reason the programme of research has been restricted. Traditionally and also because of the demands on the Department, both from the University and from external interested parties, the research has been directed towards the introduction and improvement of new instruments and methods in practice. In the following pages a review is given of the more important projects.

One of the most important bodies with which a close cooperation is maintained is the Netherlands Geodetic Commission: It offers possibilities for and stimulates mutual cooperation between scientific institutes and government services. This concerns not only the solution of problems of a practical and organizational nature, but also the initiation and execution of geodetic research. This becomes apparent in two projects of the Agricultural University. Therefore the actual problems in respect of these projects will be treated in more detail.

2 Research programme

The programme deals with two subjects:
- Geodetic Observational Techniques
- Photogrammetry, Processing of Survey Data and Cartographic Aspects.

In each group several projects are carried out.

2.1 *Geodetic Observation Techniques*

2.1.1 Quantitative determination of horizontal refraction
The angle measurement in long traverses and the measurement of distances with electronic equipment are affected by refraction. The knowledge of the magnitude of this refraction is necessary in order to eliminate its influence or to correct for it.

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2.1.2 Development and improvement of geodetic instruments
A need exists to simplify and speed up field measurements without a loss of precision and adapt them to immediate processing in an electronic computer and automatic plotter.

2.1.3 Satellite Doppler Positioning Systems
The positioning (horizontal coordinates and height) by means of the Navy Navigation Satellite System (NNSS) may become a feasible method of replacing the conventional methods of triangulation and trilateration. The investigation into what degree this possibility may eventuate is the subject of research, in cooperation with other geodetic institutes. This research project is combined with the work of the Working Group on Satellite Doppler Positioning of the Netherlands Geodetic Commission.

A fruitful "cross-fertilization" of theory and practical application has been made possible by the institutes determining the course of a research programme. This programme often requires international contacts and international cooperation. The concentration of forces is important, also because of the considerable expenditure on the required equipment. The Agricultural University and the Department of Public Works have a special interest in the accuracy of the height determination with this system. In an appendix the actual problems of this part of the project will be treated in more detail by Dr. P. RICHARDUS of the Agricultural University, chairman of the above-mentioned Working Group.

2.2 *Photogrammetry, Processing of Survey Data and Cartographic Aspects*

2.2.1 Electronic data processing and storage of geodetic information in respect of contour lines, transformation of coordinate systems, digitizing of data from maps and aerial photographs.
Manual handling of data is often time-consuming, expensive or even impossible in special cases. (Semi-) Automatic processing of data would be an efficient tool for several tasks. In addition there is an increasing need for flexibility in the presentation of results (maps, digital data) as well as for a continued processing.

The purpose of this research is (*a*) to contribute to the exploration of simple and efficient methods for semi-automatic processing of geodetic information, and (*b*) to adapt the data acquisition in coherence with this data processing.

2.2.2 Investigation into the introduction and use of large scale photomaps
Photomaps can be produced fast and cheaply. The application in combination with graphical and digital data requires an investigation with regard to photography and reprography in cooperation with government agencies.

2.2.3 Investigation into the introduction and use of a large scale base map of The Netherlands for technical, administrative and planological purposes
Part of the investigation are the activities of the "Central Council of Mapping" for the centralization of uncoordinated surveying and mapping requirements of various agencies in the same region. The compilation of a national base map which is suitable for the widest possible range of users has been centralized.

This research project is the continuation and extension of the work originally initiated by the Netherlands Geodetic Commission and the Netherlands Association of Geodesy in the study group "Large Scale Base Map" (1972–74). In the final report, issued by this Commission, the chaotic situation that exists in respect of the map compilation in The Netherlands has been emphasized. The large differences at present with regard to form, contents and quality of large scale maps are partly due to the strong decentralization of the production and partly to the lack of contacts and cooperation in this field.

The recommendations of the study group have been accepted by the government. As a result, a start has been made with the issue of the large scale base map of The Netherlands. (GBKN) by the Cadastral Service under the aegis of the Ministry of Housing and Planning. This issue concerns planning, compilation and revision of a large scale line map of topographical objects, connected to the national coordinate system (R.D.-system). Permanent agreements have been made with regard to form, size, numbering, accuracy and the minimum contents of the maps.

A *Central Council of Mapping* and eleven *Provincial Mapping Committees* have been established for managing, coordinating and guiding the editing of the maps. In these councils all members of governmental and semi-governmental agencies, centrally and regionally, concerned with the compilation and use of large scale maps, are represented. The map is only made of those areas where a clear demand exists. The costs are shared by the participating services and industries. For this purpose they conclude a contract for each mapping project. For the participants it has the advantage that not only the cost of survey and revision are shared but also that the same map is used by all who work in the same region, be it technically, planologically or administratively. This increases the possibilities of a better communication between the users. After the results of the first investigations had become known, a rapid introduction became necessary in connection with developments in society.

Some questions have not been solved as yet. On the other hand, practical experience should show whether the arrangements and the organization made answer the purpose. Generally this is the case, but a certain number of points require a more detailed investigation. To that end, through close cooperation within the Central Council of Mapping, many contacts exist between the Department of Surveying and the Managing Board of the Cadastral Service.

Some current problems are the following:

- It became apparent that the planning and realization of each project separately led to proliferation and did not satisfy the general need. A regional or countrywise arrangement for the sharing of expenses is required instead of an arrangement per project. The introduction of the proportional map-usage by the participants might result in a more systematical planning of the surveying and mapping. A first step in this direction has been made by the Cadastral Service, who will carry a fixed share of fifty percent of the expenses of all projects in the next three years.
- When defining GBKN, the question of the field reconnaissance for the benefit of photogrammetric maps has been left open. Research should ascertain whether field reconnaissance is necessary (partly or completely). The use and the cost of the map are of a large influence in this respect.
- Very important are the arrangements for the maintenance and revision, especially in

respect of: present interest, tracing and bringing to notice, number of mutations, cost and combination of mutation surveys.
- Various ways of cooperation are possible, both in production and revision.
- The GBKN is a base map. The goal of the users is to have a means for processing their own thematic data, for internal usage as well as for external communication. All facets of the usage of maps and the exchange of information should be studied for an economical production. Automation of the data processing may play an important role.

The Minister of Housing and Planning has agreed with the proposal of the Central Council of Mapping to carry into effect a number of GBKN-projects, financed by the Government, to study the above-mentioned problems in the period 1979–1981.

APPENDIX

DOPPLER SATELLITE POSITIONING SYSTEMS. INVESTIGATION INTO THE ACCURACY, PARTICULARLY THAT OF THE HEIGHT COMPONENT

With the aid of two or more Doppler-satellite receivers translocation between stations by simultaneous observations can be carried out, yielding differences of the horizontal coordinates and the heights of these stations. In regions where the orthometric height differences between these stations are known, the relative position of the ellipsoid and the geoid at these stations can be easily derived. Conversely if the geoid is known (with an accuracy of approximately 0.5 m) at stations of Doppler observations, orthometric heights may be derived that can be used for many practical purposes, especially in remote areas, where no other data are available.

Accuracy of "Doppler" heights

The accuracy of a height obtained by Doppler-satellite observations is considerably lower than that of the simultaneously obtained horizontal position coordinates. The latter coordinates can replace positioning by conventional methods for many purposes, whereas this is not the case with the "Doppler" heights. One of the reasons is that the observation of east-west symmetrical passes of satellites, represented by the directions of the point of "closest approach", eliminates errors in latitude and longitude, but does not do so in height (or height differences for that matter).

The main sources of errors contributing to a *single* determination of a *height difference* between stations 50 km apart and approximately at sea level are in units of metres (one standard deviation) [Kouba, 1976] are (table 1):

Table 1

Instrumentation (receiver)	$0.4\sqrt{2}$ m	independent of altitude
Antenna phase centre	0.1 m	independent of altitude
Orbit uncertainty	0.1 m	independent of altitude
Tropospheric refraction	$0.38\sqrt{2}$	

KOUBA adds to this budget a σ of 0.1 m for mean biases, independent of the number of passes. The total σ then becomes $\sqrt{0.9}$ m for a single pass or $\sqrt{(0.1^2+(0.8)^2/n)}$m for n passes.

There are reasons for assuming that the first source of error will be reduced by a factor 0.5 in the very latest designs of receivers. It is obvious that the tropospheric refraction is the main source of trouble.

Tropospheric Refraction

An investigation into the contribution of this type of refraction seems necessary if the accuracy of "Doppler" heights is to be increased substantially. This is of importance to geodetic control surveys in general; it is particularly important in practice to know as to whether an improvement of the accuracy can make "Doppler" heighting replacing spirit levelling or trigonometric heighting partially or completely (e.g. in control surveys for mapping and technical/agricultural projects in developing countries, control points in photogrammetric surveys, height control at sea etc.).

For the sake of argument, the present estimate of the nominal value of the tropospheric correction of the distance of the satellite to the observation station in a vertical column is given sufficiently by a simplified expression derived from HOPFIELD (1972)

$$\Delta s = \Delta h_d + \Delta h_w = 2.296 \times 10^{-3} P_0 + \Delta h_w \text{ metres} \qquad (1)$$

where P_0 is the pressure in mb; Δh_d the dry component and Δh_w the wet component. The Δh_d is proportional to the pressure (at the observation station); the Δh_w is proportional to the difference $(12000 - h_s)$ metres, where h_s is the orthometric height of the observed station. At sea level at mid-latitudes this represents ($P_0 = 1013.25$ mb):

$$\Delta_s \approx 2.33 + 0.20 \approx 2.53 \text{ metres.}$$

The correction for an inclined distance with an elevation E^0 is obtained by $\Delta r = \Delta S$ cosec E. In "Doppler" counts the equivalent formula becomes

$$\Delta N_{\text{trop}} = N_{\text{vac}} - N_{\text{obs}} = -f_0\,(\Delta r_i - \Delta r_j)/c \qquad (2)$$

where $\Delta r_i = \Delta s_i$ cosec E_i at a particular station, f_0 is the reference frequency (400 MHz), and c the speed of EM waves in vacuo. As an example the ΔN_{trop} are listed in table 2 for satellite passes at sea level, and at 4500 m altitude and maximum elevation of approx 52° at intervals of 2 minutes of time.

Estimates of the accuracy of the tropospheric refraction correction diverge in the literature. The lowest estimate is a "one σ" of $2\frac{1}{2}\%$, the highest of 15% (under special adverse meteorological circumstances) of the nominal correction Δs. Taking the former value for a 30-second Doppler count measurement at sea level, and an average satellite pass of 32 of such counts

Table 2

at sea level			height 4500 m
UT	E	ΔN_{trop}	ΔN_{trop} ($P_0 \approx 600$ mb)
2034	7.6°		
		13	8
36	17.5		
		5	3
38	32.2		
		2	1
40	52.4		
		0	0
42	50.9		
		2	1
44	30.6		
		5	3
46	16.3		
		15	10
48	6.6		

Irregularities shorter than the Doppler interval are reflected in the instrument noise.
(8 two-minute periods) then the value of 0.38 m is obtained for the shortest slant range used earlier in table 1. The latter value of $\sigma = 0.15\,\Delta s$ gives 2.15 m. At present a $\sigma = 0.05\,\Delta s$ is a current estimate.

A physical correlation should exist concerning the tropospheric refraction as measured at two stations simultaneously, depending on their remoteness. This should still be subject to special research.

(Memorandum RICHARDUS, May, 1978).

8. GEODESY FOR PLANNING PURPOSES

by G. F. WITT*)

In planning one can distinguish between national, regional, municipal and town planning. For all these planning purposes the use of maps on different scales is necessary, and geodesists are the suppliers of these tools. In most cases they will also deliver registration data concerning the owners and users of land, the area of parcels and the size of farms, etc. Often these data are used in a statistical way: the total area of industries in a fixed region, the total number of workers in an industry, etc. may be important in future developments. But if activities must be done to realize the plans in the field, as for instance constructing roads, bridges and canals, buildings, etc. the owners and users personally are involved. They have to sell their land or this will be expropriated. Then the relationship between the owners and users (subjects) and the land-parcels (objects) is at issue. At any rate the possibility of creating a new relationship between subject and object is obvious.

Often it is only the task of the geodesist or land surveyor to measure the alterations of the boundaries, to produce new maps, to keep up to date the cadastral registration, but in some cases he will have a part in planning of a new division of the land. He is not only a Registrar of new relationship between subjects and objects, but also a Planner.

In The Netherlands we have the system of re-allocation (in French: remembrement) as a part of land consolidation. In close cooperation with experts in agriculture, forestry, landscape architecture, nature and landscape preservation, and open-air recreation the geodesist has to design a new division of the land. Partially the old boundaries disappear, new ones are designed; sometimes new relations between owners and tenants must be established.

Here the principal role of the geodesist in planning lies neither in providing a cadastral base nor in providing maps and other important field data, though this is necessary for the succesful determination of planning policy, but in designing a new land use pattern! Once the great decisions of national and regional importance have been made, these decisions must be realized on the ground, which is the task of the geodesist-planner.

Not only in agricultural, but also in town planning the geodesist is able to do considerable work, though it may be in another way. In municipal planning, especially town planning, alteration of the planning structure is continuously going on. As in agricultural planning, the realization of a plan in which the destination of land has been designed, takes many years. The activities, which are accompanying the process of transforming agricultural land into building land are rather complicated, and therefore they are performed by a special municipal service, the "land service". To the tasks of this service does not belong drawing up a town-plan, but all the activities, with their financial consequences, related to the

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realization of the plan are managed by the "land service". It plays an important role in acquiring land by expropriation or buying; often the service has its own valuers. The purchase-price and the compensations for users of land and buildings are registered, as well as the estimated costs of all the expected construction to be done. In this way it is possible to estimate the cost of a plan, the estimated "exploitation-cost". When the real cost and the area of land to be sold for building are known, the price of one square metre of land can be fixed. In fixing the selling-price of land, grants given by the authorities must be taken into account. The real exploitation cost can be calculated after all the work has been done; the task of the service is to check the real cost of every part of the work by comparing them with the estimated cost. If the estimated cost is exceeded the service has to warn the executing service.

During the time the municipality owns the land, the land service manages the land: it may be given in tenancy, as long as it is not needed for construction of works. When it is ready for building, parcels of land are sold and the service has also the task of preparing the sale.

A very important job has been assigned to the service after the plan has been made. In general, regulations are in force about the percentage of the area to be occupied by streets, parks and gardens, buildings, etc. The service checks that the plan is in accordance with the existing regulations. To avoid contradictions there will in most cases be a cooperation between the town-planner and the service. This task, which ensures a reasonable design, is growing more important in our time, with the emphasis on the welfare of people. In this respect the influence of the geodesist is increasing.

It is clear that geodesists working in this section of geodesy must have knowledge of the different aspects of this branch of science. Therefore in 1955 a new chair in the Department of Geodesy at the Delft University of Technology was established. Not only the rural and agricultural aspects of planning are a part of the education, but also the urban (municipal) aspects, as far as the geodesist is involved in these activities. The new chair in "Geodesy in Planning" (Dutch: planologische geodesie) finds its principal task in studying the activities and the consequences of altering the relationship between subjects (owners, users, etc.) and objects (real estates) in planning. In this process the geodesist must have his proper share.

Besides the basic geodetic subjects, the geodesist in planning receives schooling in legal aspects related to real estate, i.e. civil and agricultural laws, especially about land consolidation, the technique of reallocation (remembrement), etc. Furthermore he must have some knowledge of the sciences of civil engineering, agriculture, economics and sociology. This broad education enables him adequately to fulfil his role as a planner.

Since its establishment the chair Geodesy in Planning has done some research in various fields. The main items are mentioned below.

1. The automation of the cadastral registration, as used in remembrement, has been investigated, as well as other systems of land information. Nowadays automation of registration of these data is applied in the governmental Remembrement Service.
2. In remembrement, land of different quality is being exchanged. For that reason it is necessary to estimate the exchange value. The valuers thought they could value land with great accuracy. However an investigation has shown that the assumed accuracy was overestimated. This overestimation of the ability in valuation had caused much super-

fluous work in registration and calculation during the whole process; the result of the investigation has led to saving of time.

3. In cooperation with lawyers and agricultural and geodetical officials of the governmental services of land consolidation imperfections in the present law of remembrement have been studied. Proposals for improvement have been made and were discussed in a symposium on that subject.
4. Designing a new pattern for hundreds of owners and tenants is a process prone to mistakes. For that reason it was desirable to search for a method in which automation could be applied. At the moment a method for automatized division into new parcels is being used in practice.
5. Special laws have been introduced, containing a new system of land consolidation. Nowadays the problems about agriculture, forestry, housing, recreation, landscape, etc. are difficult and will be the more so in future. However the existing law for re-allocation does not give enough scope for solving these problems. In the special laws a new procedure with a combination of re-allocation and expropriation has been laid down. The intention is to institute a new *general* law for land consolidation handling the mentioned procedures.
6. A number of investigations have been done on behalf of the municipal land services, which are especially of importance for the development of town-planning in The Netherlands.
7. Much attention has been paid to the problem of obtaining a uniform system for the whole country in making a cadastre for underground cables and mains for water, gas, etc. A report about this subject was prepared and discussed, not only by geodesists but also by a great number of representatives of public utilities. The urgent need for more unification in registration of cables and mains was clear. The main results of the discussion were:
   a. measuring of the different objects should be done in the national coordinate system by all public utilities;
   b. the national Cadastral Service should make maps on the scale 1:2000 for rural areas, the geodetical services of the towns should take care of maps upon the scale 1:1000 or larger. Now the Cadastral Service has begun to make maps of special parts of the country, in many cases in cooperation with other services or private firms;
   c. a working-group should try to compose a bill, containing the first step to registration of cables and mains. This bill is now ready and is awaiting discussion in Parliament.
8. Renovation of towns is a very urgent problem. A start has been made studying the possibility of using the system of re-allocation in urban areas. This system has already been applied in several European countries. In The Netherlands planners and executors of plans are accustomed to use expropriation for obtaining land. Only if re-allocation appears to be a cheaper and faster procedure, will it have a chance to be put in practice. Much study and investigations have still to be done about problems of urban regeneration.

Geodesy in planning, in The Netherlands a substantial science for the last 25 years, strongly connected with current developments in our society, is waiting for more study and research in future. Moreover it will give employment to many geodesists.

9. SERVICE OF CADASTRE AND PUBLIC REGISTERS

by H. A. L. DEKKER *

1 Introduction

The "Dienst van het Kadaster en de Openbare Registers" (Service of Cadastre and Public Registers, usually called Cadastral Service) is in charge of the cadastre and land registration (public or legal register). Cadastre and Land Registration are the two components of one and the same public service. The underlying principle of this cooperation is a combination of *publicity* and *speciality*. In The Netherlands the principle of publicity implies that mutations of the legal position of immovables (land and real estate) *must* be published in the relevant legal registers, the "public registers". Without publication, provisions of the Civil Code will make it impossible to effectuate the legal transfer of the legal rights. By means of this publication all interested parties are able to acquire information on the legal position of an immovable property by consulting the public registers. This enables checking on possible violations of the rights of third parties. For The Netherlands the principle of speciality implies that every immovable property should be identified by means of the cadastral designation i.e. by the name of the municipality, the letter of the cadastral section and the parcel number by which it has been individualized on the cadastral map.

2 Publication of deeds

In The Netherlands the deed in which the change of the legal position of an immovable property has been described is published. The deed must be drawn up by a notary public on an officially prescribed form, a copy of which is inserted in one of the loose-leaf volumes of the public register. It goes without saying that the actual effectuation of the publication of a transfer cannot be obtained before the vendor's and purchaser's identity have been checked, as well as the identity of the object.

3 Cadastre

The cadastre of The Netherlands, introduced in 1832, was originally established for predominantly fiscal purposes. By Imperial Decree of 1811, NAPOLEON I ordered the entire country to be surveyed and registered in order to obtain a basis for a fair levying of the land tax. Cadastral registration implied a complete survey and plotting of all parcels, registration of the owners and their rightful claimants and measurement of areas and valuation of each parcel and lot. Most of the maps, having a size of 100 × 70 cm (about 17,000 in total), were drawn to the scale of 1:2500 (for urban areas 1:1250). On these maps every parcel, house or other construction, every street or road, every footpath and waterway was plotted. The field plan (plan-minute) is a map showing the parcels of the original

* Director-General, Service of Cadastre and Public Registers.

survey and plotting, i.e. the situation of the immovable properties existing at the moment of the introduction of the cadastre, whereas the land register gives a description of the same.

The cadastral registration was put up municipality by municipality as a "personal folio", which means that every number of the ledger shows all the parcels on which the identical owner holds the identical titles. At the top of the folio the owner's name and further relevant personal information are mentioned. For each parcel the folio shows the cadastral designation (referring to the cadastral map), volume and serial number of the relevant deed in the public register, the nature of use (house, yard, forest, etc.), the area and some other data. In addition the land register shows the legal encumbrances resting on the parcel on account of several public laws.

4 Cadastral map and Public Registers

As stated above the Dutch cadastre was originally established as a Government inventory on landed property for a fair and rational levying of taxes. However, from the very start the cadastral map especially has been used as a means of identifying parcels involved in the establishment or the transfer of legal titles to property. It was therefore logical that soon after the introduction of the cadastre in 1832 the designation of parcels in official deeds by means of their cadastral identification – an unambiguous and concise description – was made obligatory by Royal Decree.

The aforementioned fusion of Cadastre and Public Registers achieved that for each parcel the cadastral administration refers in a simple way to the relevant deed in the public registers. On the other hand the combined organization of Public Registers and Cadastre promotes a quick processing of each change of the legal position of a parcel.

5 Updating of the Cadastre

In order to derive a lasting benefit from the results obtained, it is necessary to enter all mutations of the shape of the land or the legal position in the cadastral maps and the registers or, in other words, to keep the cadastre continuously up to date. In The Netherlands this updating of the land registration is rather simple, because each deed of transfer or establishment of legal rights on immovable property contains the relevant cadastral designation and must be presented for registration in the public registers in order to obtain legal force. These deeds (about 300,000 pieces a year), are passed on to the cadastre daily. The result of this closed system is that the scrupulously updated registration shows clearly, incontrovertibly and immediately who holds a legal right to a certain parcel of land or water, to a certain building or apartment, just because the entries in the cadastral registers are derived from these deeds.

The volume of the activities of the cadastre is impressive. The registers contain the names of two and a half million title holders to more than six million parcels, all of which are represented now on a total of 27,000 cadastral maps. Every year one and a half million mutations are introduced in the cadastral data. Like those of the public registers, these cadastral data are open for consultation by anyone, without restriction, for a reasonable fee. This follows from the publicity principle. The increasing need of the public for cadastral information is apparent from the fact that for instance in 1973 written information was given in nearly one million cases.

6 Change of the situation in the field

A transfer of legal rights is often connected with the sale of a part of a parcel. Many deeds concern the creation of new property boundaries, which have to be surveyed by the Cadastral Service. After the survey, the results of which are presented to the interested parties, the newly created parcels are given a separate proper new number, the area of the new parcels are calculated and the resulting new situation is entered in the cadastre registration while the cadastral map is updated. Also important changes of the topography of a site – like for instance building or demolishing of houses, factories, etc. – are regularly checked by the surveyors of the Cadastral Service and entered in the maps and registers.

7 Organization

Civil servants are in charge of all the activities of the Cadastral Service. Apart from the General Directorate, this service consists of 11 directorates in the provinces, each subdivided into the following departments:
a. public registers and cadastre;
b. revision survey;
c. resurvey and land-consolidation projects;
d. survey administration and mapping.

Besides, there is a centralized Photogrammetric Service, a Computing Bureau, a Training Centre, a Triangulation Service and a Bureau for the Cadastral Databank.

Until 1973, the Cadastral Service was under the responsibility of the Ministry of Finance. In 1973 it was transferred to the Ministry of Housing and Physical Planning, mainly because circumstances had changed to such an extent that hardly any correlation was left with the predominantly fiscal objectives of the Ministry of Finance. On the other hand the incorporation of the Cadastral Service in the organizational frame of the Ministry of Housing and Physical Planning has been effected because of the capability of the service to produce all sorts of administrative, cartographic and juridical data concerning landed property.

8 Renewal and land consolidation

Especially in this the most densely populated country in Europe, with a considerable scarcity of land, the importance of town and country planning becomes more and more evident. For this matter, the cadastre is one of the Government's sources of information. In anticipation of the forthcoming developments in the field of town and country planning the Cadastral Service is preparing maps on the scale of 1:1000 and 1:2000 in the coordinate system of the Netherlands Triangulation Service. These maps are made on the basis of resurvey projects and land-consolidation projects. Since 1924, 22% of the entire area of agricultural land in The Netherlands have been consolidated – partly by means of reallotment of parcels – within the frame of a reconstruction scheme for the countryside. In view of the expansion and continuing development of urban and urbanized residential districts, especially after the Second World War, the renewal and remapping activities have been raised to about 50,000 ha a year. The Department of Projects has been charged with the realization of this important work.

Head Office of the Cadastral Service at Apeldoorn.

9 Photogrammetric Service

Aerial survey is applied for suitable renewal projects and for topographical mapping of the land situation prior to the start of the land consolidation activities. Sometimes it is used for parcel mapping after the completion of the consolidation.

10 Computing Bureau

Detail surveys of renewal and consolidation areas is largely realized by means of electro-optical equipment for measuring of directions and distances. Apart from the electronic measurements, detail surveys are also executed by means of tape measurements; the results of these measurements are adjusted and expressed in coordinates of the national grid. The Central Computing Bureau is charged with these computations and the calculation of areas with the aid of computers. The production of new cadastral maps of the aforementioned renewal and consolidation surveys is also the task of this bureau. This work is executed using automatic plotters.

11 Training Centre

At the Cadastral Training Centre, candidates for draughtsman and technician are being trained for two years. After this they are posted to one of the directorates in the provinces.

12 Triangulation Service

The activities of this service, called Netherlands Triangulation Service, mainly consists of the upkeep of the network of fixed points of which the coordinates are known. On the national level this network provides control for lower order measurements by the cadastral survey department and by many surveying departments of other public services. On the international level it is part of the European triangulation network. Besides, the Netherlands Triangulation Service contributes to connecting national stations to the world satellite network.

For use by survey institutions, information sheets and maps are made of all primary, secondary and lower order triangulation points, showing the technical and numerical data of each point. For the last few years automatic data processing has been used for this purpose.

13 Bureau for the Cadastral Databank

The Bureau for the Development of the Automation of the Cadastral Registration is developing a databank. This cadastral databank will contain, for each separate cadastral parcel, not only its cadastral designation with the data now found in the "personal folio", but, a among other things, also street name and house number; the coordinates of the centre of the parcel; if relevant, its location on a reallocation plan, a development plan, etc. and annotations referring to special statutory regulations applying to the parcel. It is expected that this databank will be fully operational before the end of the eighties.

14 Adaptation to changes in society

The rapid changes in society require an adequate adaptation on the part of the Cadastral Service in the field of legislation, organization, techniques and registration. The following facts illustrate that the Cadastral Service is fully aware of this necessity:

1. A Bill going to serve as a legal basis for the Cadastre as a land data information system with the widest possible scope is being drafted.
2. Under supervision of the Cadastral Service the production of a large scale Base Map of The Netherlands is being executed by a combination of several public survey and mapping services. It is a rectangular sheet line map on the scale of 1:1000 or 1:2000, including such basic topographic features as will enable third parties to use it – with supplementary details added by themselves – as a location plan for their own activities.
3. A Bill on the Registration of Administrators of Cables and Pipelines is also being drafted. The ultimate objective is to put in principle the Cadastral Service in charge of the registration of underground pipelines and their administrators. This registration is considered to be of paramount importance for planning authorities and for the prevention of calamities.
4. All sorts of modern techniques will be introduced, such as:
   - the aforementioned application of automatic plotters for the drawing of new cadastral maps;
   - the execution of geodetic calculations with the aid of computers;
   - the automation of the land-consolidation administration;
   - the automation of the allocation procedure in case of land consolidation;
   - the development of a cartographic data base, including a coordinate cadastre, to be established in the future;
   - the development of models for the automation of the entire land registration, resulting in a central cadastral data bank connected with the provincial bureaus by means of terminals on real time basis.

15 Relation between the Netherlands Geodetic Commission and the Cadastral Service

The aforementioned measurements in the 19th century for the introduction of the cadastral registration – and the resulting maps – were executed municipality by municipality. So in every municipality a separate triangulation was designed, measured and calculated and consequently there were differences in origin, scale and orientation between the maps of the various municipalities. Especially the mapping of the areas near the boundaries often caused trouble.

When at the end of the nineteenth century it became apparent that many cadastral maps had to be renewed it was clear that these maps had to be incorporated in a national coordinate system. In 1889 the Minister of Finance, being responsible for the Cadastral Service, requested the Netherlands Geodetic Commission to establish a national triangulation network. The original idea was to determine about 100 stations by primary triangulation only, but finally 3600 stations were determined by primary and secondary triangulation.

After the completion of the triangulation it was decided to entrust the updating of the triangulation to the Netherlands Triangulation Service. This service, founded in 1930, is a department of the Service of Cadastre and Public Registers. The Commission handed over the files and instruments concerning the triangulation to this new service. In the forty years of its existence the Netherlands Triangulation Service has checked, corrected or determined many thousands of stations.

All the data concerning the stations of the net are stored in a computerized data base. From this base the required data can be supplied by a print-out.

In addtion the Netherlands Triangulation Service executes special activities at the request of the Netherlands Geodetic Commission. Among other things the service was involved in:

- the readjustment of the European Triangulation. For that purpose the service carried out first order measurements in the period 1956–62 to improve the connection between the triangulation of our country and those of Belgium and Germany.
- the measurements of a new base line on the "Afsluitdijk", the dam closing the former Zuiderzee.
- the traverse measurements for determining the coordinates of the satellite observation stations.
- a contribution to the international Doppler-campaign in 1977.

16 Other tasks of the Netherlands Triangulation Service

The Netherlands Triangulation Service has filled various needs in the field of a national coordinate system. Its customers were mainly public services, private surveyors and various other geodetic and photogrammetric offices. So far the service has been able to fulfil the actual tasks satisfactorily.

In the future the development of Doppler-techniques applied to triangulation may require further adaptation in the organization of the Netherlands Triangulation Service.

10. THE HISTORY OF THE TOPOGRAPHIC SERVICE AND ITS GEODETIC ACTIVITIES

by E. KOLK*

1 History of the Topographic Service, 1798-1932 [7], [17]

The earliest traces of the development of the Topographic Service date back to 1798. In that year a commission was set up by the Executive of the Batavian Republic with the task of composing a map of the country. In October 1798 general C. R. T. KRAYENHOFF was put in charge of the making of the "Groote Kaart" (Great Map). This map, at a scale of 800 Rhineland roods to the inch (1:115200) was to be compiled from existing maps at various scales, if necessary to be completed by field surveys. The information contained in the existing maps showed such discrepancies that KRAYENHOFF decided to carry out a triangulation in order to get all the maps into the same reference system. During the years 1799 and 1800 KRAYENHOFF himself carried out the angle measurements with a sextant. He also measured a base line and took measurements for the orientation of the geodetic network. Although the sextant measurements were quite sufficient for the compilation of the "Groote Kaart", KRAYENHOFF succeeded in getting permission to carry out a triangulation using a "repetition circle". One of his arguments was that these measurements could serve as an extension and connection of the arc-measurements of DELAMBRE and STRUVE. KRAYENHOFF made the measurements in the period 1801–1811. The results of these measurements served as the geometrical framework of the topographical maps of The Netherlands until 1932.

In 1806 the Batavian Republic was succeeded by the Kingdom Holland under LOUIS NAPOLEON. In that year the Depôt-General of War was established (following the example of France) and KRAYENHOFF was appointed Director. The Topographic Bureau and the Corps Geographic Engineers were set up under the jurisdiction of the Depôt-General. The Topographic Bureau was charged with the drawing and engraving of the maps of the Kingdom, including that of the "Groote Kaart". The Geographic Engineers had to carry out field reconnaissance and field measurements.

After the Napoleonic domination, once again a Topographic Bureau, under the jurisdiction of the Royal Engineers, was set up by Royal Decree of 12th March, 1814 [14]. The following year, 14th January 1815, the structure of the Topographic Bureau was changed, a First and a Second Section were created. The present Topographic Service originates from the Second Section.

The First Section, the former Geographic Engineering Corps, was charged with the task of carrying out triangulations, levelling and mapping. For the "Map of KRAYENHOFF"**), as the "Groote Kaart" has become known, J. ERZEY completed a primary triangulation in

*) At the request of the present Director of the Topographic Service, J. A. C. E. VAN ROERMUND.

**) Very shortly a facsimile edition will be available to the public. The edition will comprise eight map sheets, one title sheet and one index sheet.

the province of Limburg during the years 1816–1819. He also carried out a triangulation in Belgium during the period 1814–1830. These territories became a part of the Kingdom of The Netherlands in 1814 and were only partly measured by KRAYENHOFF. The "Map of KRAYENHOFF", covering only the northern part of the Kingdom, was completed in 1823. The other duties of the First Section were mainly restricted to the Northern Netherlands.

The Second Section was created at the initiative of the General Staff and was also under the command of that body. Originally, the Second Section was in charge of military reconnaissance. "The Military Reconnaissance" – as the Second Section became known was based in the Southern Netherlands (Belgium). In 1815 its task was extended to surveying for mapping purposes. When the Military Reconnaissance was temporarily dissolved because of the Belgian Rebellion in 1830, it had become a fully equipped mapping organization. It even had its own Lithographic Printing Department [3].

The Lithographic Printing Department remained with the Military Reconnaissance until 1841 when the former became a part of the Royal Engineers. From 1848 until 1872 the Lithographic Printing Department was an independent unit of the Ministry of War. In 1848 the name was changed to Topographic Bureau – not to be confused with the earlier mentioned Topographic Bureau, set up on 12th March, 1814. In 1868 the name became "Topographische Inrichting" (Topographic Map-making Establishment). In 1872 the "Topographische Inrichting" was placed under the authority of the General Staff. The duties of the "Topographische Inrichting" and its predecessors were not limited to the production of military maps. Maps were also made for civilian purposes.

The field duties of the Military Reconnaissance were not officially resumed until 1839 when King WILLEM I approved of its topographical mapping activities. The Royal Decree implied that the task, originally assigned to the First Section, had definitely been transferred to the Military Reconnaissance. The surveys, started by the General Staff in the province of Noord-Brabant in 1834, were extended to cover the whole country and were completed in 1859. The topographical surveys were worked out to enable a drawn map to be made at a scale of 1:25 000, which served as the base of the Topographic- and Military Map of the Kingdom of The Netherlands. This map, at a scale of 1:50000, was engraved on stone and printed by the previously mentioned Lithographic Printing Department. The first edition appeared in the period 1843–1864.*) Since 1885 this map has also appeared in colour.

Since 1863 coloured maps at a scale of 1:25000 have appeared. Initially, strips of terrain, important from a military point of view, were mapped. These "STRIP MAPS" developed into the Chromo-Topographic Map which appeared in 1876 and covered ultimately the whole country in 1931 [3]. Since 1894 levelling has been done for representing the height by means of contour lines. Before that time the heights were given by means of individual height spots and by representation of height differences. In this context the methods developed by VAN GORKUM (the Director of the Military Reconnaissance from 1817 until 1841) should be mentioned. Of course other maps were produced as well and the maps already mentioned were continued but within the scope of this article it is only possible to mention some main trends.

In the "Twenties" there was particularly strong criticism of the obsolence and the geo-

*) In 1973 a facsimile edition was published.

metrical accuracy of the maps. In 1924 the General Staff presented an eight-year plan to make up arrears at the Topographische Inrichting. In December 1926 the Minister of Defence installed a commission to investigate the working methods of the Topographische Inrichting [18]. Two years later this so-called "Commission BLOKHUIS" submitted a report in which, among other things, were recommended the reorganization of the Topographische Inrichting and a better distribution of work with the Military Reconnaissance. In the same year the Director of the Military Reconnaissance submitted a report on the reorganization of the Military Reconnaissance [18]. Then in 1929, the Chief of the General Staff submitted a report to the Minister of Defence in which he advised the amalgamation of the Topographische Inrichting and the Military Reconnaissance into one Topographic Service. The Minister agreed to the proposals and ordered the Triangulation Commission (see section 2) to work out directives for this reorganization. On 4th January, 1932, the two services were united.

2 Geodetic activities, 1798–1932 [1], [4], [7], [17]

The primary triangulation by KRAYENHOFF in the period between 1801–1811 and the measurements by J. ERZEY in Limburg between 1816–1819 constitute the geometrical structure of the topographical mapping in The Netherlands until 1932. The triangulation by KRAYENHOFF was connected to the French triangulation by DELAMBRE at the stations Dunkirk and Mont Cassel. The side Dunkirk–Mont Cassel was taken as the base of the network. The orientation of the KRAYENHOFF triangulation was also taken from the French network. The geographical coordinates of Krayenhoff's primary points were established starting from the geographical latitude and longitude of the station Dunkirk. The ellipsoid of the "Commission des Poids et Mesures", with semi-major axis of 6375737 metres and a flattening of 1:334, was adopted for the Krayenhoff map, the Choro-Topographic Map. The "Précis Historique", in which KRAYENHOFF recorded the measurements and calculations, gives no indication as to which map projection had been chosen. However, measurements on the original copper plates, which are kept in the archives of the Topographic Service, have proved that KRAYENHOFF adopted the equirectangular projection [17]. Concerning the choice of the scale, KRAYENHOFF wrote that the geographical latitude of the standard parallel is 52°30′. However, the measurements on the copper plates indicate that the standard parallel coincides with the latitude 51°02′ of the station Dunkirk.

In 1820 King WILLEM I charged a commission with the task of designing a general topographical map of the Kingdom which would be useful for all Services. Five ministries were represented in this commission, and M. J. DE MAN, Director of the Archives of War and the Topographic Bureau (see section 1), acted as a chairman. The commission presented extensive proposals in 1822 and again in 1824 but none of them were realized due to disagreements within that body. The proposals circulated within the ministeries until 1830 when the Belgians rose in revolt. Then the issue was shelved until 1928. The proposals agreed in principal with the proposals of a similar French commission which was installed by King LOUIS XVIII. The Dutch commission proposed that a map should be made of the whole Kingdom, at a scale of 1:10000. This map should also serve as the base for a topographical map at the scale of 1:50000. All ministries concerned would participate while a to-be-established Central Bureau would be put in charge of the operation, and would make the topographical map at the scale of 1:50000. J. E. van Gorkum, Director of the Military Reconnaissance and a member of the commission disagreed with the proposals on major issues. Van Gorkum favoured the scale 1:15000, among other things, and he also did not approve of the arrangement of the work distribution. In accordance with the proposals of the commission the maps were to be made in the projection of Bonne. The First Section of the Topographic Bureau made many calculations for the commission during the years 1822–1825, including calculations for the projection and a design of the sheet division.

The calculations of the First Section were not in vain. When in 1842 it was decided to publish the "Topographic- and Military Map of the Kingdom of The Netherlands", these calculations were adopted. The central point of the projection of Bonne is situated in the region of the village of Chaam on the meridian of the "Westertoren" in Amsterdam and has a geographical latitude 51°30′. This was the central point of the Kingdom prior to 1830. The extensive and time-consuming calculations were considered to be too laborious to carry out once more with a new central point adapted to the new boundaries. The projection of Bonne is an equivalent projection method, which was used in many places at that time, including France, from which country much has been copied. The ellipsoid adopted had the following dimensions: semi-major axis 6376950.4 metres, flattening 1:309.65. These values were calculated by P. J. Ackermans of the First Section in 1822 from the measurements of Delambre. They deviate slightly from the values which Delambre and Puissant calculated from the same measurements.

The primary net of Krayenhoff was densified by the Military Reconnaissance during the years 1836–1838 and 1841–1855. The results of this secondary triangulation were published in the "Meetkunstige Beschrijving van het Koningrijk der Nederlanden" (Geometrical Description of the Kingdom of The Netherlands) in 1861. The positions of 1016 points on Dutch territory were now known: 79 of the first order, 776 of the second order and 161 of the third order [3]. The quality of the densification measurements was sufficient for topographical mapping, however as a secondary triangulation the results were below the standards which might have been expected.

The cadastral plans, which had been made by the Cadastral Service since its establishment in 1811, were used as base for the topographical surveys until 1932. The cadastral plans showed juridical boundaries which, of course, did not have to coincide with the topographical boundaries. Therefore topographical information which was not shown on the cadastral plans had to be surveyed and added separately. At the time, around 1820, this had been one of Van Gorkum's major objections to the proposals of the "Commission De Man". Therefore Van Gorkum advocated a completely new survey at the scale of 1:15000. He wanted this task to be assigned to his own Military Reconnaissance... It should be mentioned that the Military Reconnaissance was the only organization with experience in topographical map-making from cadastral plans.

According to the regulations, each cadastral municipality had to be covered by a local triangulation network that had to be tied to the nets of the surrounding municipalities. These regulations were not always put into practice which meant that in the topographical surveys, not only the ties between bordering municipalities, but also the ties of sheets within one municipality did not always fit the way they should [8]. In this set-up large errors could occur. In 1926 the Military Reconnaissance started to measure polygons in order to improve the geometrical structure.

From 1909 the geometrical structure was also improved by the adoption of the measurements of the "Rijkscommissie voor Graadmeting en Waterpassing" (Netherlands Geodetic Commission). To this end HK. J. HEUVELINK calculated the coordinates of R(ijks) D(riehoeksmeting) stations, the national coordinate system, in the Krayenhoff-system. This was done in such a way that the Krayenhoff-coordinates of points common to both systems were kept fixed [5], [6]. The question arises as to why the R.D.-coordinates in the stereographic projection were not adopted for engraving new map sheets. HEUVELINK writes: "Because of the great extent of such a work and the great costs involved in the design and implementation of a completely new map, it was decided that no changes would be made in the nature of the map according to the projection of Bonne and the existing design of the sheets" [16].

From 1926 tables, designed by H. F. VAN RIEL, were used for the conversion R.D.-Krayenhoff. VAN RIEL had connected both systems by a third degree conformal transformation using 41 points common to both systems [9]. Using his own tables VAN RIEL compared 99 points of the "Meetkunstige Beschrijving" with identical points in the R.D.-system. He found a standard deviation of 2.8 metres. For the first order Krayenhoff-points this value was approximately 1 metre.

In 1925 the Ministeries of Defence and Finance established the Triangulation Commission with the task of coordinating surveys made by the Cadastral Service, the Military Reconnaissance and the newly created Military Survey in order to serve the interests of these organisations [19]. The commission tried to establish some unity in the four coordinate systems which were used by the Army, viz. Krayenhoff, R.D., R.D. converted to Krayenhoff and the map sheet coordinates. In 1925 it was proposed that the Minister of Defence replace the existing coordinate systems by one single system: that of the R.D. but then translated to the origin $X = -155000$ metres and $Y = -463000$ metres. The translation was suggested in order to get positive coordinates for the whole country and also to create northings and eastings which could never be the same. On the advice of the Military Reconnaissance and the Topographische Inrichting the proposal was rejected forp ractical and financial reasons. The Minister was of the opinion that it would better to wait until the introduction of new maps based on the R.D.-system. The translated R.D.-system was introduced in 1931, also on the proposal of the Triangulation Commission (see section 1). This system is still generally in use nowadays.

During the years 1927–30 the Triangulation Commission supervised three experiments regarding topographical mapping from aerial photographs, viz. the experiments "*Hilvarenbeek*", "*Den Hout*" and "*Oosterhout*" [17]. The commission came to the conclusion that the method of restitution of single photographs would be uneconomical but the mapping from stereopairs was preferable to the method then in use. The rejection of the restitution of single photographs was mainly due to the large amount of fieldwork that had to be carried out because of the small photo format (13 × 18 cm), and the need to fix four points per photograph, as well as the time-consuming transference of the topographical features from the rectified photographs to the minute sheet. Also the poor image-quality of the rectified photographs had a negative influence.

The report of the previously mentioned Commission BLOKHUIS, which had to investigate the working methods of the Topographische Inrichting, contained as an appendix an essay entitled "the bases of the official maps of The Netherlands related to the modern requirements". The essay was written by J. VAN ROON, former Chief of the Training Brigade of the Topographic Service in the Dutch East Indies. Echoing the commission DE MAN of 1820, VAN ROON advocated the introduction of the scale 1:10000 and mapping from renewed cadastral plans, and went further, advocating setting up a separate service which would do all the mapping. The ideas of VAN ROON resounded in the recommendations of the Commission BLOKHUIS. The Commission proposed to make the Topographische Inrichting a government agency, independent of any Ministry. The Commission also proposed the establishment of a Mapping Commission with the task of investigating the most efficient ways of surveying and reproducing the official maps of the country. This Commission would have to include representatives of the land and sea forces, the Ministry of Transport and Public Works, the Geological Service, the Cadastral Service, the Association of the Dutch Municipalities and also the Netherlands Geodetic Commission. These ideas were not put into practice. The report of VAN ROON, which was published in an adapted version in the periodical of the Royal Geographic Society [10], was strongly criticised by, amongst others, the Triangulation Commission, the Military Reconnaissance and Prof. W. SCHERMERHORN [11], [18]. VAN ROON was reproached for being out of touch with the current survey practice in The Netherlands and his professional knowledge was also held in rather low esteem. In this period the possibilities of photogrammetry were not yet very clear and this gave rise to vehement discussions on the way in which topographical maps should be produced: by means of cadastral plans or by means of photogrammetry. Again, the map scale 1:10000 did not get off the ground although in surrounding countries topographical maps at the scales 1:5000, 1:10000 or 1:15000 appeared. In a letter to the Director of the Military Reconnaissance in 1929, Prof. SCHERMERHORN criticised the scale 1:10000, quoting a Dutch proverb: "too large to be a napkin and too to small to be a table-cloth".

3 The history of the Topographic Service from 1932 to the present time [15], [17]

The working methods of the united Topographische Inrichting and the Military Reconnaissance were thoroughly altered as a consequence of the introduction of photogrammetry and new methods of reproduction. The new maps which were based on the R.D.-coordinate system appeared in the stereographic projection. The map scales 1:25000, 1:50000 and 1:200000 were maintained and only the sheet division was adjusted. The stone engravings could be replaced only gradually. Also, because of the Second World War, it was not until 1958 that the last "Bonne sheets" could be replaced.

After NATO came into existence, specifications were developed for the military use of maps of the allied countries. Since 1950 the maps for military purposes have been provided with an UTM-grid. The scale of 1:200000 was replaced in 1968 by that of 1:250000, and the new scales of 1:100000 and 1:500000 were introduced in 1954 and 1971 respectively. The 1:100000 map has not been revised since it was finished in 1958.

During the course of the years the military demand for maps has been much reduced while at the same time the civilian demand has greatly increased. All the map scales just mentioned also appeared in a civilian edition. In 1964 the map at 1:25000 was considered to be redundant from a military point of view. This resulted in financial problems for the civilian edition but these were overcome when it became apparent that this version was too important to be abolished. Also the Netherlands Geodetic Commission had recommended the continuation of this map.

The map on a scale of 1:10000, in the past the subject of so many discussions, came into production in 1952. This map is derived from the base-engraving of the 1:12500 map and therefore the production costs are relatively low.

In cooperation with the Survey Department of Rijkswaterstaat (Department of Public Works) the production of the *Altitude-map* at a scale of 1:10000 was started in 1961, and will be completed within a couple of years. Already it has been decided that revisions will be made when the need arises.

In 1960 an important change took place in cartographic work, brought about by the introduction of stable drawing materials and stable photographic film. Instead of drawing with pen and ink on astralon, engraving on stabilene was introduced and the collodium process on glass was replaced by photographic reproduction on stable film. In 1975 a start was made in the automation of engraving maps. This method, which is developing by a process of trial and error, will replace the major part of the manual engraving in the future with the expectation that out-of-date information – the worst enemy of the map maker – can then be combatted more efficiently.

The maps of the Topographic Service are renewed every 5, 7 or 10 years, depending on the kind of area they represent. Besides the maps mentioned above, other types of maps are drawn and printed on a commercial basis.

4 Geodetic activities from 1932 to the present time

Originally, in 1932, the intention was to apply stereo-restitution in photogrammetric mapping, but the capacity of the type of equipment necessary for this was considered to be too small to be economical. As The Netherlands is a country where height differences are small, Prof. SCHERMERHORN was requested to supervise an experiment to produce maps from rectified photographs [12], [13]. This method, which had been applied successfully by the Survey Department of the Rijkswaterstaat for some time, was adopted in 1933. Later on, when the hilly areas had to be mapped, stereo-restitution was introduced too.

The geometrical structure of the photogrammetric maps was obtained by means of field surveys and radial triangulation. In 1964 the method of the block adjustment was introduced. This led to a substantial saving in fieldwork.

After the Second World War a group of German geodesists carried out the Central European Adjustment by order of the US Army Map Service. The separate triangulations of the participating countries were united in one system (UTM, international ellipsoid). Thus, 44 R.D.-points were determined in the system of the Central European Adjustment. In 1950, Prof. J. M. TIENSTRA and Ir. G. J. BRUINS determined the positions of the remaining First Order R.D.-points in this system [2], [17]. Also, they derived a second degree conformal transformation for the conversion R.D. – Central European Adjustment. These formulas are based on an affine transformation within triangles and are valid in an area of limited dimensions. With the transformation formulas thus obtained the positions of the UTM-grid points, which had to be shown on military maps, were determined. As the transformation is neither conformal nor continuous inconvenient errors occurred in neighbouring triangles. Common points with Germany and Belgium showed up errors of several metres although these were only partly due to this transformation. Therefore in 1959 a fourth degree conformal transformation, valid for the whole country, was developed by Prof. G. J. BRUINS and the Topographic Service. The triglist, a military list of coordinates, is based on the latter transformation.

Since 1961 the Topographic Service participates in OEEPE experiments in the field of topographical map production.

The revision of the network of R.D.-points, which started after 1970, caused extra work for the Topographic Service. Rejected points, which were still very useful for topographical mapping, had to be converted to the readjusted R.D.-system.

In 1970-71 an investigation was carried out by the Topographic Service among others, with the object of improving the coordination between the land survey duties of four governmental services. This resulted in 1974 in the establishment of the CCLK, a consultation committee dealing with surveying and cartographic activities. The CCLK is made up of representatives of the Cadastral Service, the Landinrichtingsdienst (Land Use and Regional Planning Service), the Survey Department of the Rijkswaterstaat, and the Topographic Service.

5 The future

It looks as if the future base of the Topographic Service will be in the town of Emmen, situated in the lovely countryside of the northeastern part of The Netherlands. The relocation is part of a governmental plan to spread a number of public services throughout the country. In the new surroundings, in a new and purpose-designed building, the further development of the automatic engraving of maps has to be realised.

The contacts with the Netherlands Geodetic Commission will be maintained with the understanding that, as in the past, the theoretical-scientific approach of the Commission and the practice-orientated attitude of the Topographic Service are not likely to lead to close contacts between the two groups.

A very concrete matter which will arise in the future in The Netherlands, concerns the introduction of a new, international geodetic reference system for topographical maps amongst others. This can be compared with the introduction of the UTM-system in 1950.

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11. THE HYDROGRAPHIC SERVICE OF THE ROYAL NETHERLANDS NAVY

by J. C. KREFFER*)

1 Historical background

In 1911 it was felt that not only scientists from the fields covered by the Netherlands Geodetic Commission, but also representatives of technical services, which make practical use of any possible result from its activities, should sit on the Commission. At the same time these representatives could provide the Commission with a useful feedback. This change in the composition of the Commission was effected by Royal Decree No. 37 of 1st June 1911.

One of the representatives was the Hydrographer of the Royal Netherlands Navy. The first Hydrographer to become a member of the Commission was Captain C. J. DE JONG. He was succeeded in 1914 by Captain J. M. PHAFF who had an active part in the establishment of the International Hydrographic Bureau (IHB). After retiring in 1920 Captain PHAFF became a member of the Directing Committee of the IHB.

His successor Captain J. L. H. LUYMES, who remained in office for 14 years, played a very active part in the activities of the Netherlands Geodetic Commission, as he did in many other fields. Captain LUYMES might be called the father of the International Nautical Chart, to which we shall pay attention in the course of this chapter. His successor, Rear Admiral J. C. F. HOOYKAAS, served from 1935–40 and was succeeded by Captain R. VAN TIJEN, who was interned in prison camp in 1942. He died on 4th July of the same year at Neurenberg.

In 1943 Commander TH. K. BARON VAN ASBECK, who served as an escort commander in the West Indies, was called to London and appointed acting Hydrographer of the Royal Netherlands Navy. In this capacity he re-established, nearly from scratch, the Hydrographic Office at The Hague in 1945. On 29th March 1946 Captain VAN ASBECK had his first meeting with the Netherlands Geodetic Commission. During his term of office the Decca electronic positioning system came into use in the North Sea, and such a system was also acquired for survey work in New Guinea.

In 1961 Rear Admiral VAN ASBECK retired from the Navy and was succeeded by Captain Ir. W. LANGERAAR, who had completed his geodetic studies in 1953. Captain LANGERAAR was promoted Rear Admiral in 1966. He introduced oceanography in the Hydrographic Service and soon became involved in the Intergovernmental Oceanographic Commission (IOC) of UNESCO, of which he became vice-chairman in 1965 and chairman in 1967. In 1971 Rear Admiral H. H. VAN WEELDE took over from Rear Admiral LANGERAAR. He revived the subcommission Marine Geodesy of the Netherlands Geodetic Commission, which had been dormant since 1969. Furthermore he guided the programmes of the con-

*) Hydrographer of the Royal Netherlands Navy.

struction of new survey ships and of automation, the preparations of which had started in 1969. Ships and hydrographic automatic systems are now fully operational. Rear Admiral J. C. KREFFER succeeded Rear Admiral H. H. VAN WEELDE on 1st June 1977.

The role of the Hydrographic Service of the Netherlands Navy will be further described by singling out some subjects which are still unfinished and will require our attention for the future.

2 Marine geodesy

The growing interest in the exploration and exploitation of the sea, the sea bottom, its mineral resources and its related geodetic problems, resulted in setting up of a subcommission Marine Geodesy by the Netherlands Geodetic Commission in December 1967. Under the chairmanship of Rear Admiral LANGERAAR the subcommission's first interest was focussed on the problems of calculating and charting the patterns radiated by electronic position fixing systems. When discussing concession limits for exploration and exploitation in 1969 the subcommission indicated the desirability of only one positioning system in the North Sea. Eight years would go by before the subject of accurate position fixing of drilling platforms was taken up again.

Some people seemed to have their doubts about the chances of survival of the subcommission, the principle task of which one still thought to be advising on accurate position fixing at sea. All members were government officials but soon it was felt inevitable that the discussions should be joined by somebody from the industry. At the end of 1969 a representative of Shell joined the subcommission. A development like this also took place on international level.

During the XIIth Congress of the International Federation of Surveyors (FIG) held in London from 2nd–12th September 1968 the Hydrographer of the United Kingdom Rear Admiral G. S. RITCHIE suggested as an experiment to include a Commission on Hydrography. The discussions during the congress turned out to be interesting and lively, which led to a change in the numbering of the commissions as a result of which Hydrographic Surveying was inserted as Commission 4. Three years later, during the XIIIth Congress in September 1971, the active Commission 4 established a working party "to agree, internationally, desirable standards of competence within the profession of surveying at sea". In April 1972, during the Xth International Hydrographic Conference at Monaco, the International Hydrographic Organization (IHO) discussed a proposal by Canada on this subject, which resulted in combining the efforts of both organizations in a FIG/IHO Working Group. In 1977 the proposed standards of competence were accepted by FIG and IHO and an Advisory Board on the training of sea surveyors was established. It should result in a correct basis for education and the protection of the profession, the work of which became of growing importance over recent years, because more and more private firms became engaged in sea surveying.

The subcommission on Marine Geodesy increased its activities in the course of the seventies. In 1977 it was decided that position fixing of drilling platforms on the Netherlands part of the North Sea continental shelf demanded its attention. A suggestion was made to the Netherlands Geodetic Commission to support the set-up of an interdepartmental body, which would be responsible for correct triangulation in the North Sea.

Because of his responsibility for control on the accuracy in position fixing of drilling platforms according to the Continental Shelf Mining Act, the Hydrographer was considered to be in the best position to coordinate the activities. Not only will this new body serve a more accurate position fixing, but soon its results will be necessary for planning purposes in the North Sea.

3 The General Bathymetric Chart of the Oceans (GEBCO)

The General Bathymetric Chart of the Oceans was originally decided upon at the Seventh International Geographical Congress in Berlin in 1899, and it became a reality when Prince ALBERT I of Monaco assembled a small group of scientists into a special "Cabinet Scientifique" to work on the first edition in 1903. A project of 24 large sheets to cover the world on a scale of 1:10 million was developed and issued. A second edition was brought out by the Cabinet between 1912 and 1930.

With the invention of continuous echo sounding, however, the flood of data became so great that the International Hydrographic Bureau (IHB) in Monaco was asked by the International Hydrographic Conferences in 1929 and 1932 to take over the programme. In 1932 the IHB commenced work on the third edition which was completed in 1955. Eighteen sheets have been published of the 24 sheets which constitute GEBCO. Of the eight polar cap sheets just two were compiled. Preceding the VIIth International Hydrographic Conference (1957) a proposal was made by the IHB stating that in view of the fact that the General Bathymetric Chart of the Oceans is primarily intended for the use of oceanographers and other scientists, a decision be reached regarding whether or not the IHB shall continue the work on compiling the 4th edition of the sheets.

During its 208th meeting on 7th December 1956 the Netherlands Geodetic Commission paid much attention to the IHB proposal. There was no difference of opinion among the members about the continuation of GEBCO, which everyone thought most important and of which a new edition should appear every 10–15 years. Rear Admiral VAN ASBECK was asked to plead in favour of the continuation of the Bathymetric Chart. During the VIIth International Hydrographic Conference VAN ASBECK happened to become chairman of the Sub-committee on the Bathymetric Chart. Members unanimously stated "that a general bathymetric chart of the oceans is primarily for use in oceanography and other branches of sciences but that the work involved in producing the chart is in urgent need of continuation". They thought it desirable to spread the work between the IHB, a central organization concerned with the topography and morphology of the ocean floor, under the International Council of Scientific Unions (ICSU) and certain hydrographic offices on a regional basis.

Between 1957 and 1962 difficulties were experienced among the IHB, the Hydrographic Offices and certain International Organizations in completing cooperative arrangements and again GEBCO became a problem item on the Agenda of the VIIIth Conference in 1962. The increase of expenditure was discussed and whether or not the financial contribution of Member States should be raised. It was resolved that 1:1 million plotting sheets be compiled by the Hydrographic Services of States Members and that the IHB draw up the final 1:10 million scale charts. Again it was stated that GEBCO was not the primary interest of Hydrographic Offices; therefore oceanic and other scientific institutions, whose main interest was the speeding up of the production of sheets, should play a greater part. The response came in 1964 when France and the USSR offered assistance. The French offer was accepted and in 1965 the conditions were set on which the Institut Géographique National in Paris would resume the responsibility of the new GEBCO edition, with the co-operation and assistance of the French Naval Hydrographic Office.

In 1974, once again, the workload became so heavy that the IHB (which had become in the meantime the executive office to the International Hydrographic Organization (IHO)) agreed to cooperate on this project with the Intergovernmental Oceanographic Commission of UNESCO and to set up a joint IOC-IHO Guiding Committee of GEBCO. This Committee is composed of ten members, five nominated by the IHO and five by the IOC. The IHO experts are selected from volunteering Hydrographic Offices, whereas the IOC experts are nominated after consultation with the Scientific Committee on Oceanic Research (SCOR), the International Association for the Physical Sciences of the Oceans (IAPSO) (of the International Union of Geodesy and Geophysics (IUGG)) and the Commission for Marine Geology (CMG). The IOC experts are marine geologists and geophysicists, specialized in morphological mapping of the ocean floor.

The IHO and the IOC work in close collaboration and a rough division of activity has been agreed: IHO is responsible, in conjunction with 19 volunteering Hydrographic Offices in its member states, for maintenance of 655 master sounding sheets on a scale of 1:1 million, and for cartographic advice on and supervision over the final product, which initially will consist of 18 charts covering the world on a scale of 1:10 million. On the other hand the IOC in conjunction with SCOR, IAPSO and CMG has accepted responsibility for all scientific input into the project, including contouring of the bathymetric data and compilation of the final water-work for each sheet. The basic projection, graticule and land-work is taken from the Carte Générale du Monde by permission of the Institut Géographique National, France, and uses similar sheet limits.

The Government of Canada has agreed to scribe and print the first four sheets of the series which are at present partly published or in course of preparation, and is prepared to accept the task of scribing and printing the remaining 14 sheets of the 5th edition. Since January 1963 the Netherlands Hydrographic Service has taken the responsibility for the compilation of 6 master sounding sheets in the Carribean and 7 sheets in the Pacific. At the moment progress is only made on the Caribbean sheets. Finally on board the oceanographic vessel N.Nl.M.S. Tydeman a routine is being developed, together with the Vening Meinesz Laboratory of the Utrecht University, for the automatic data handling of deep sea bathymetry.

4 The International Nautical Chart

"Thanks to the International Hydrographic Conference, held in London in 1919, and to the International Hydrographic Bureau, which is an outcome of the Conference, uniformity is gradually increasing in the charts published by the various Hydrographic Offices. The main reason for holding the Conference was the proposal to establish uniformity, the principal proposer of which was the late gifted head of the French Hydrographic Service Monsieur J. Renaud. He advocated it strongly in his article "La Carte Marine Internationale", written in 1914 but published in the Annales Hydrographiques of 1918."

These lines were written by Captain J. L. H. LUYMES in the Hydrographic Review of May 1924. The object of the International Hydrographic Bureau was to standardize the charts of all nations as much as possible. Nevertheless the production of charts was primarily a national commitment, whereas some larger countries for the benefit of their Navy cover the whole world. When realising for example that the chart of the North Sea was published by 7 nations, LUYMES wondered if one could not leave the publication to the principal coastal state. The seaman should conquer his aversion to using charts other than those published by his own nation. He should be provided with an international catalogue, giving a complete list of the original charts of the world. If acceptable, of course the greatest possible uniformity should exist in charting. Development in the technique of reproduction after World War II made a quite different solution possible: facsimile prints from copies of the reproduction material supplied by the maker.

The idea of international charts was now advanced formally to the International Hydrographic Organization at its IXth Conference (1967) in a motion tabled by France and The Netherlands. A resolution of that Conference established the Commission on the International Chart on small scales. Five years later, the Xth Conference (1972) resolved that a study be conducted into applying the international concept to medium and large scale charts as well. The North Sea International Chart Commission (NSICC) was accordingly formed to carry out the study on behalf of the IHO. The aim of the NSICC's study was the production of a set of charts suitable for the needs of international shipping. In preparing the requisite chart specification, the NSICC became aware of the wide variations in the way its member offices showed many types of detail on their charts. The preparation of this specification proved to be the largest single task of the NSICC. Most of the work was done by correspondence, after having been prepared by the chairman Mr. D. W. NEWSON, Director of Hydrographic Charting and Sciences of the Hydrographic Department at Taunton, U.K. The International Hydrographic Bureau felt that the NSICC specifications could provide a firm basis on which the IHO could develop a set of specifications for world-wide application.

After the Report of NSICC had been adopted unanimously during the XIth International Hydrographic Conference (1977) a Chart Specifications Committee, formed by 17 volunteering nations again under the chairmanship of Mr. NEWSON, was established. We shall be anxious to read their report to the XIIth International Hydrographic Conference in 1982. Meanwhile the international medium and large scale charts for the North Sea area are being prepared by the countries responsible. The producing Hydrographic Office will send copies of the reproduction material on request to others wanting to print the chart. Those other Hydrographic Offices are allowed to adjust the originals to their own need whereby preferably only the language should be changed.

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12. THE NETHERLANDS GEODETIC COMMISSION AND THE ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE

by J. VELDKAMP*)

1. Introduction

The Royal Netherlands Meteorological Institute (K.N.M.I.) was set up in 1854 by a Royal Decree, in which this Institute was described as follows:

> "The Meteorological Institute has the task of carrying out meteorological observations at various places in the Kingdom, in the Colonies, on the ships of the Navy and the Merchant Service, and of collecting and publishing the results of such observations".

Although in this Royal Decree only meteorological observations were mentioned, measurements of the geomagnetic field and of its variations have been carried out from the beginning. Not only was the geomagnetic field of interest to the meteorologists and the geophysicists of the K.N.M.I., the study of earthquakes was considered also to belong to the work-programme of the Meteorological Institute. Soon after the move of the K.N.M.I. from Utrecht to De Bilt (in 1897) seismographs were installed in the Institute to record the seismic waves caused by heavy earthquakes in distant countries, as well as the weak vibrations which now and then occurred deep underground in The Netherlands. This extension of the work of the K.N.M.I. was laid down in further Royal Decrees. Nowadays the task of the Institute is described as follows:

> "The Institute has the task of carrying out research into physical phenomena in the atmosphere, on the surface of the earth, in the solid earth and in the sea. It has to make available the outcome of these researches and of the allied sciences to navigation, aviation, agriculture and other interests".

In the Regulations of the K.N.M.I. which are nowadays in force, this task is explained in more detail. Observations of meteorological, oceanographical, geomagnetical, seismological and other geophysical phenomena must be performed. Fundamental as well as applied scientific research of geophysical phenomena must be carried out. Information about the above-mentioned geophysical phenomena must be given on request.

It is obvious that the very broad field in which the K.N.M.I. has to develop its activities, partly overlaps that of the Netherlands Geodetic Commission. Projects of common interest to the K.N.M.I. and the Commission are the physical properties of the solid earth, the crustal movements connected with seismic activity, and oceanographical studies. Three fields of cooperation between the K.N.M.I. and the Commission will be discussed, viz. gravity research, measurement of crustal movements and oceanographical studies.

*) At the request of the present Director-General of K.N.M.I., Dr. H. C. BIJVOET.

2. Gravity measurements

The contacts between the K.N.M.I. and the Netherlands Geodetic Commission date from the time when a young civil engineer, F. A. VENING MEINESZ, was charged by the Commission with the great task of measuring the acceleration of gravity at as many places as possible, all over the world.

The main object of this project was to obtain data about the shape of the earth, and especially about its equatorial cross-section. Preliminary geodetic measurements had aroused suspicion that the equatorial cross-section of the earth has a somewhat elliptical form, which was difficult to understand from a physical point of view. The question whether the equatorial cross-section of the earth is in a first approximation a circle or an ellipse, in other words whether the shape of the earth can be approximated by a two-axial or by a tri-axial ellipsoid, can be solved by making measurements of gravity.

The shape of the earth can be approximated by a two-axial ellipsoid, whose short axis coincides with the rotational axis of the earth. A more physical approximation is the geoid, which is formed by the mean sea level in the oceans. The problem of the shape of the earth is the determination of the position of the geoid with respect to the standard ellipsoid. The distance between geoid and ellipsoid can be calculated from gravity values by means of a theorem of STOKES.

VENING MEINESZ' interest in gravity measurements dates from 1912, when he tried to carry out a gravity survey in The Netherlands. The unstable soil in the western part of the country caused difficulties, which ultimately led to the development of a new method for determining gravity at sea.

After having finished his studies for civil engineer, VENING MEINESZ accepted a post with the Commission on Arc-measurement and Levelling (Rijkscommissie voor Graadmeting en Waterpassing), the name of which was later changed to Netherlands Geodetic Commission. This Commission was in possession of two pendulum instruments, and VENING MEINESZ tried to make measurements in the Geodetic Institute at Delft. He noticed that not only passing cars caused disturbances, but that ships steaming in a canal near the institute made even stronger vibrations. It was clear that vibrations could pass through the soil over great distances. Storms were of course a nuisance for the pendulum measurements. However, a remarkable fact was that the vibrations of the ground continued for some days after the storm was over. In other cases they appeared before the storm began. This phenomenon (the microseismic activity accompanying the storm) directed VENING MEINESZ to the Meteorological Institute at De Bilt, where seismographs had been installed for recording earthquakes. One of the seismographs (a WIECHERT reversed pendulum) had a natural frequency which made it especially suitable for recording the microseismic vibrations. This made frequent visits by VENING MEINESZ understandable. Moreover, the subsoil of the K.N.M.I. appeared to be much firmer than that of the Geodetic Institute at Delft. Therefore, VENING MEINESZ chose the K.N.M.I. as a reference-point for his gravity measurements, instead of the Geodetic Institute at Delft.

It proved to be possible to remove the disturbing influence of the ground vibrations on a swinging pendulum by swinging two pendulums at the same time in the same swinging plane, but in opposite directions; in this way the effect of the horizontal accelerations of the ground could (to a first approximation) be eliminated.

As the Commission considered gravity research as one of its tasks, VENING MEINESZ, whose theoretical and practical insight in this matter had resulted in a doctoral thesis entitled: "Bijdragen tot de theorie der slingerwaarnemingen (Contributions to the theory of pendulum observations)" was entrusted with this task.

The success of the method using two pendulums whose differential movement was recorded, led to the question if it also could be applied on board ships. Some trials proved that measurements of gravity by means of pendulum observations on board ships could only be successful if the sea was completely calm. Already a relatively slight movement of the sea completely spoiled the records of the pendulum movements. The idea of making observations on board submarines was first mentioned to VENING MEINESZ by Prof. Dr. F. K. TH. VAN ITERSON, director of the Dutch State Mines, who on a trip in a submarine had noticed that the rolling and pitching of the ship ceased when it steamed at a depth of some tens of metres below sea level.

For using a pendulum apparatus in the cramped space of a submarine, a photographic recording device was made in the workshop of the K.N.M.I. at De Bilt, and the apparatus was tested during a voyage from Holland to Java. It appeared that determining the periods of the pendulums was only possible if the tilt of the longitudinal axis of the ship during submersion remained smaller than half a degree. This made it necessary to keep the whole crew at their places during the half hour of the observation. As this made diving a great stress for every member of the crew, VENING MEINESZ developed a new pendulum apparatus which was mounted in a gimbal suspension. The apparatus was built in the workshop of the K.N.M.I. by its chief mechanic Mr. L. M. VAN REST, after the plans of Dr. VENING MEINESZ, and with the advice of Dr. C. SCHOUTE, deputy-director of the K.N.M.I. (Fig. 1). The new apparatus was tested in a 20000 miles long voyage from Holland to Java by Hr. Ms. K XIII in the year 1928, and the instrument behaved fully as expected.

After arrival of the K XIII in the East Indies, the Netherlands Geodetic Commission asked permission for a gravity survey by means of a submarine in the waters of the East Indian Archipelago. Again VENING MEINESZ joined the crew of the K XIII and carried out hundreds of gravity observations in the Archipelago.

During some observations near the island of Sumba, no echo-soundings could be obtained by the K XIII. Knowledge of the sea-depth is essential for the topographic reduction of the measurements. Lack of echo-soundings would have meant a serious drawback if no help had come from the K.N.M.I. The director of the Oceanographic Section of the K.N.M.I., Mr. P. M. VAN RIEL, happened to be the leader of an oceanographic expedition on board the "Willebrord Snellius" which was operating in the East Indian Archipelago, at the time when VENING MEINESZ carried out his gravity survey. Mr. VAN RIEL kindly consented to make a special trip to supply the missing data. This was a new and unexpected contact between the Netherlands Geodetic Commission and the Meteorological Institute, which turned out to be a fruitful one. The results of the sea-depth measurements of the "Willibrord Snellius" were published in a bathymetric map of the Archipelago. It was based on 33000 echo-soundings, and it proved to be essential for the detailed topographic reduction of VENING MEINESZ' measurements.

One of the main results of the gravity survey was the discovery of a belt of negative anomalies, more than 6000 km long. This belt runs south of Sumatra, Java and the Sunda

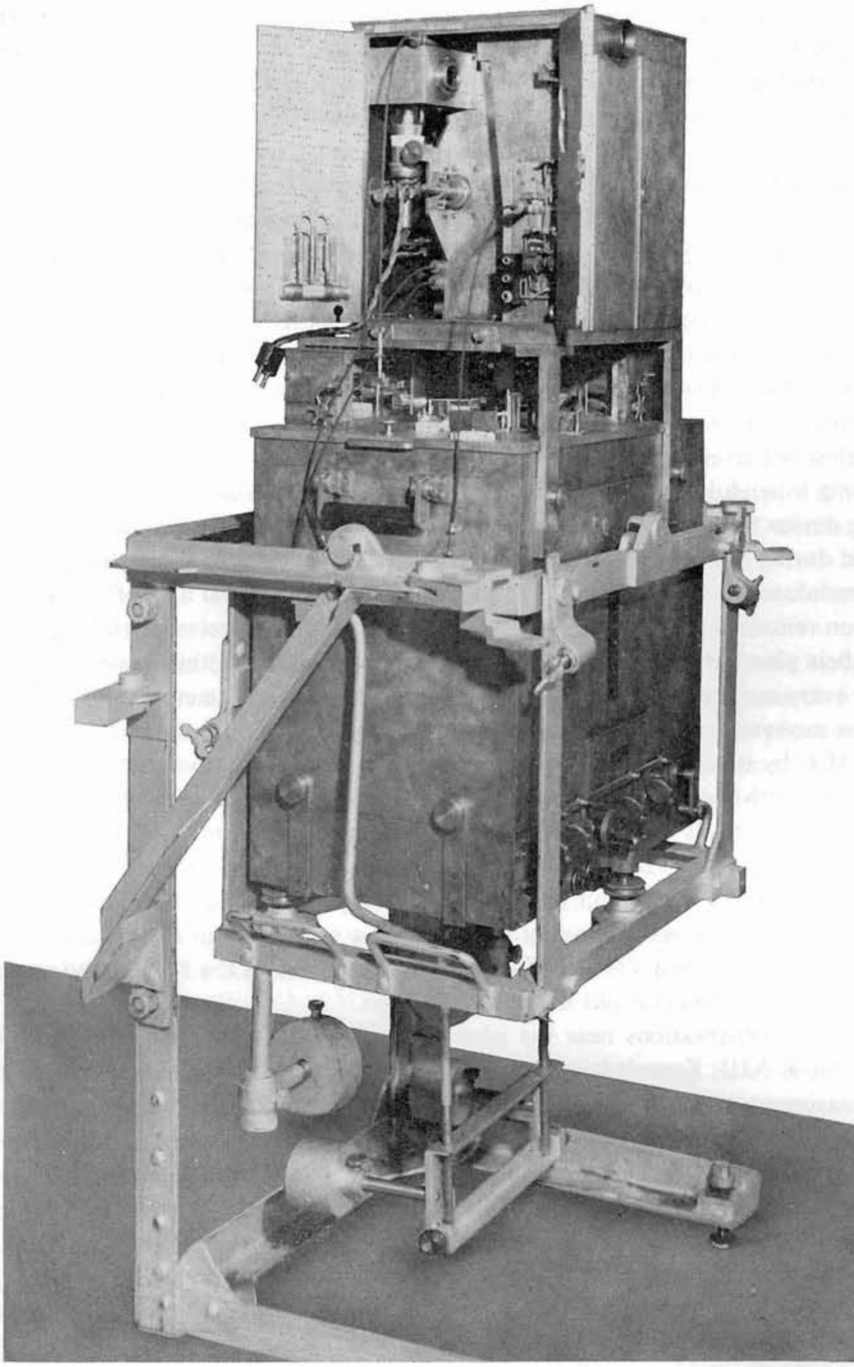

Fig. 1. Pendulum apparatus designed by VENING MEINESZ for gravity measurements on board submarines.

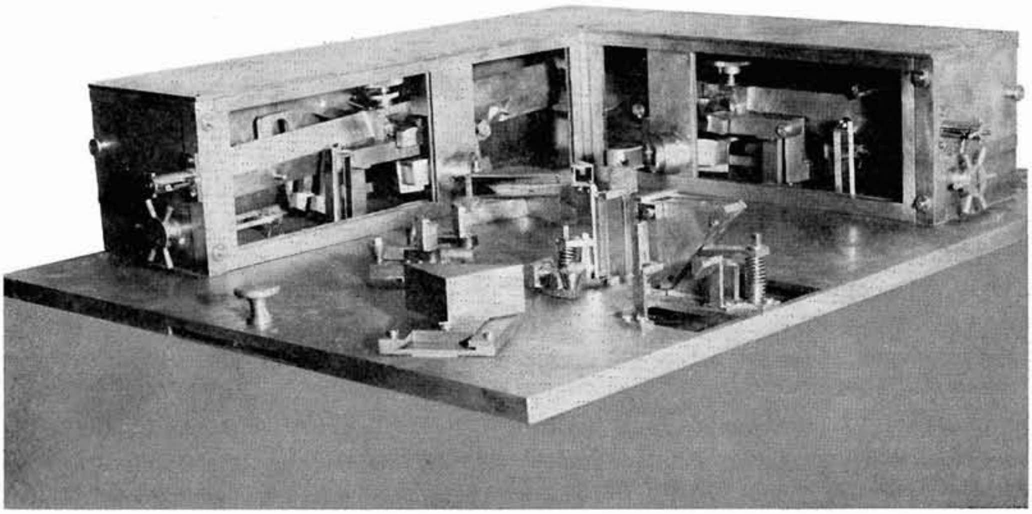

Fig. 2. Unit of the VENING MEINESZ apparatus containing the two long period pendulums for recording the rolling and pitching of the submarine. It is mounted in between the pendulum unit (bottom) and recording unit (top), see Fig. 1.

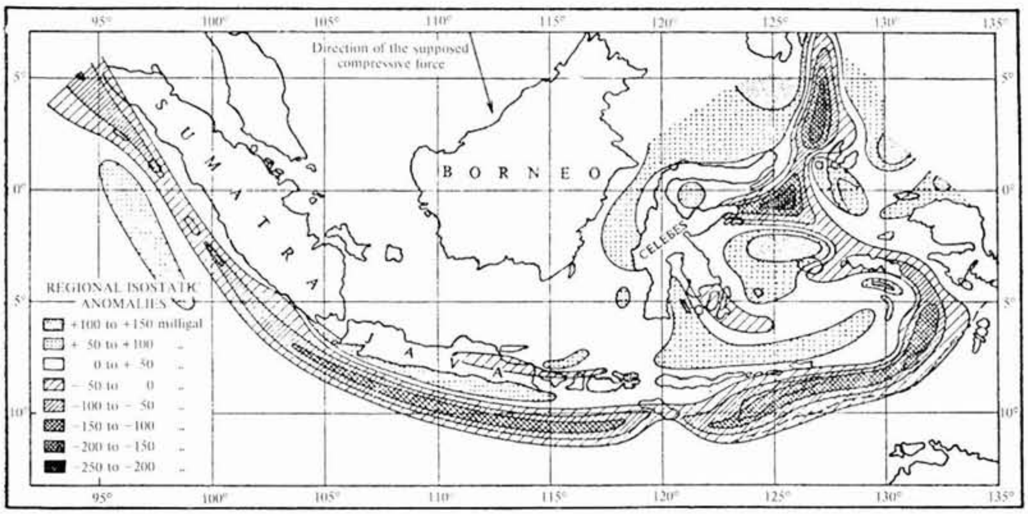

Fig. 3. Belt of low gravity values in the Indonesian Archipelago, discovered by VENING MEINESZ.

Islands, and ends off the Philippines (Fig. 3). VENING MEINESZ explained the belt of low gravity values by his downbuckling theory. He thought that under the influence of horizontal pressure forces, the crust of the earth formed a narrow fold which was deeply pressed into the earth's mantle. Later on belts of low gravity were also found along other island arcs, e.g. in the Carribean Sea (the theory of plate tectonics gives an explanation of the negative belts which differs somewhat from VENING MEINESZ' conception).

The K.N.M.I. became the home-base of VENING MEINESZ' gravity measurements. After each expedition base-observations were made in the cellar of the institute, and it often appeared necessary to make repairs and improvements to the pendulum instrument. This was also done at the K.N.M.I.

In 1937, a geodetic student in Cambridge, Mr. B. C. BROWNE, wrote a letter to VENING MEINESZ, in which he pointed out that in the case of strong wave movements the influence on gravity measurements of certain second order disturbance terms – neglected by VENING MEINESZ – might attain values of 10 mgal and even more. In order to correct for these second order terms it was necessary to find a method for recording and measuring accurately the horizontal accelerations of the pendulum apparatus. This problem was solved by adding two pendulums with very long periods to the apparatus which recorded the movements of the ship (Figs. 1 and 2). This alteration was made by Mr. D. VAN LUNTEREN, then chief mechanic of the workshop of the K.N.M.I. It enabled calculation of the Browne-corrections.

In 1945 Prof. VENING MEINESZ was appointed Director-General of the K.N.M.I. No wonder that the gravity surveys after the war were carried out by geophysicists of the K.N.M.I. as well as by geodesists of the Netherlands Geodetic Commission, but the responsibility for all gravity work remained with the Commission.

Because of the war gravity measurements were interrupted for ten years, but they were resumed in 1948. After the war the submarine voyages were directed towards the West Indies. The pendulum apparatus was taken care of by alternately Mr. H. J. A. VESSEUR, Dr. R. DORRESTEIN and Ir. L. OTTO, scientists at the K.N.M.I. Cruises were made to Curaçao in the years 1948 and 1951, and in the Caribbean Sea and in the Pacific near the coasts to Columbia, Ecuador, Costa Rica and Panama in 1957. For recording the time, the instrument was improved by adding a crystal-clock, designed by VESSEUR. As in these years a crystal-clock was not yet commercially available, the clock was built at the K.M.M.I. In 1957 this home-built crystal-clock was replaced by a commercially obtainable frequency-standard.

In 1957 gravity measurements were carried out by VELDKAMP (K.N.M.I.) and VAN BOECKEL in Surinam, under the auspices of the Netherlands Geodetic Commission. These measurements were of interest for the interpretation of the gravity values obtained in 1949 on board Hr. Ms. O 24 in the Atlantic Ocean off Surinam and French Guyana. Moreover, the measurements fitted into the programme of the International Geophysical Year, which recommended measurements of gravity where they might be done in combination with other geophysical measurements. The interpretation of the gravity values obtained in Surinam shows that along the coast there is a gradual change from the continental into the oceanic crust under local isostatic equilibrium. Farther inland the gravity field shows important anomalies. The interpretation of these anomalies was published by VAN BOECKEL in his doctoral thesis: "Gravitational and geomagnetic investigations in Surinam and their structural implications".

After 1958 the VENING MEINESZ pendulum apparatus, which had been by far the best sea-gravimeter for 35 years, was no longer used. This was due to the development of a gravimeter that in combination with a stabilized platform could be used on board surface ships. As the Netherlands Meteorological Institute did not consider gravity research as its task, and as the pendulum apparatus needed no further repair or development, the gravimetrical cooperation between the K.N.M.I. and the Commission came to an end.

3 Crustal movements

The importance of studying recent movements of the earth's crust in The Netherlands for geodetic purposes prompted the Commission to establish a subcommission Crustal Movements. From the beginning (in 1962) the section Seismology of the K.N.M.I. has been represented in this subcommission and has contributed to its work.

Earthquakes are caused by sudden movements along fault planes in the subsoil. However, it often happens that earthquakes occur at such depth in the earth's crust that the fault plane does not extend to the surface. Even in such cases it can be expected that zones of displacements and changes of level appear at the surface of the earth. A study of the local seismicity can therefore provide data from which conclusions about the places of possible horizontal and vertical ground movements can be drawn.

Seismologists of the K.N.M.I. made a compilation of seismological data for the construction of a seismo-tectonic map of Europe. These data have also been used for a report on the seismicity in The Netherlands and on the estimated frequency and intensity of possible future earthquakes. Surface movements resulting from earthquakes can mainly be expected in the province of Limburg and in the eastern part of North Brabant, where a fault zone running southeast-northwest is present in the underground. Most earthquakes which occurred in the past in The Netherlands were connected with this fault zone. The K.N.M.I.-report on the seismicity of our country, supplemented by data from geology and ground mechanics, gave the Commission indications for setting up new measuring lines for a levelling network in The Netherlands. The cooperation of the K.N.M.I. with the Commission in the study of crustal movement will be continued.

A special common point of interest for the K.N.M.I. and for the Commission is the study of the slow crustal movements caused by the attracting forces of the moon and the sun. These tidal forces, well known from ebb and flow in the oceans, give rise to small periodical deformations of the earth, so that the earth's surface at a certain place moves up and down over some centimetres or decimetres. Favoured by opportunities given by space research, the Delft University of Technology started a programme of satellite geodesy, and founded in 1973 a station at Kootwijk, where measurements of directions and distances to passing satellites can be performed with a high accuracy. It is hoped to reach an accuracy of some decimetres in the future. In such circumstances the measurements must be corrected for the tidal movements of the earth's crust. The K.N.M.I. feels responsible for the study of these slow movements of the earth's surface. A gravimeter was adapted for recording very small height differences. In the seismograph building at De Bilt records of earth tides are being obtained. It is intended to install such a gravimeter at Kootwijk for correcting the satellite measurements, if necessary.

4 Marine geodesy

A third field in which a cooperation developed between the Commission and the K.N.M.I.

is marine geodesy. One of the aims of marine geodesy is to determine positions at sea. Positioning systems are therefore studied and compared, with a view to their accuracy and applicability. International projects in which systems for accurate positioning play a role, are not only of interest to the Commission but they often contain elements which are important to the K.N.M.I.

Examples of common interest for the Commission and the K.N.M.I. are the construction of accurate depth charts of the sea bottom and the determination of the mean sea level in the North Sea. This determination may eventually be applied to improve the model for the evaluation of a mean current pattern of the North Sea; the current pattern can be used for calculating water levels along the coast. On the other hand the knowledge of the bottom topography will be useful for calculating refraction patterns of sea waves. These calculations can be applied to the operational model for forecasting sea waves, which is used in the K.N.M.I.

With a view to the above-mentioned common interests the Commission established a subcommission Marine Geodesy in 1967. A representative of the K.N.M.I. was appointed a member of this subcommission. The following items have been considered until now:

a. accurate locations in the southern part of the North Sea;
b. hydrostatic levelling for comparing sea levels at drilling platforms;
c. height measurements of the sea topography by means of satellites (SEASAT).

Other points of interest are:

d. gravity measurements at sea;
e. contacts with oceanographic institutions in other countries.

The work of the subcommission for marine geodesy will remain of interest to both the Netherlands Geodetic Commission and the K.N.M.I.

5 Conclusions

The cooperation between the Netherlands Geodetic Commission and the K.N.M.I. has been fruitful to both and it is desirable that this cooperation be continued.

13. THE NETHERLANDS GEODETIC COMMISSION AND THE DEPARTMENT OF PUBLIC WORKS (RIJKSWATERSTAAT)

by A. WAALEWIJN* and H. RIETVELD*

1 Representation of Rijkswaterstaat in the Commission

Precise levelling has long been the responsibility of Waterstaat. For example, part of Krayenhoff's levelling (1797–1812), namely the lines along the IJ and the coast of the Zuyderzee, was carried out by the "Inspectors and Employees" of Waterstaat [1, page V]. The General Service Inspector of Waterstaat was closely associated with the First Precise Levelling (1875–1885) [2, page III]. The great importance still attached by Rijkswaterstaat**) to the maintenance of a reliable network of bench marks is reflected in the Department's current terms of reference which mention "the collecting of data to increase our knowledge of hydraulic conditions . . ." [3, page N17]; in many instances the height of the measuring points is a very important factor in these data.

It is therefore not surprising that one of the five members appointed when the "Rijkscommissie voor Graadmeting en Waterpassing" (Commission on Arc-measurement and Levelling), now called Rijkscommissie voor Geodesie (Netherlands Geodetic Commission) was formally set up by Royal Decree No. 3 of 20th February 1879 should be a Waterstaat engineer. After all, it was part of the Commission's task to continue and complete the precise levelling. The appointment of the Senior Engineer of the district of Zeeland, G. VAN DIESEN, was probably due to his great personal qualities, the fact of his being a member of the Royal Academy of Sciences, [4, page 376] and his experience of surveying (he had carried out survey work for the river map and levelling along the principal rivers) [4, page 367 and 377].

VAN DIESEN was a member of the Netherlands Geodetic Commission for thirty one years (1879–1910), and acted as secretary between 1897 and 1900. Although he can be considered a representative of Waterstaat, he was in fact a personal member of the Commission. His work within Waterstaat had no direct connection with the geodetic work, although at the end of his career, as Chief Inspector (1891–1894), he was responsible for the whole of the Department. In 1910 VAN DIESEN submitted his resignation in view of his age; he was then 84 years old. Since A. W. E. KWISTHOUT, at that time "ingenieur-verificateur" (inspector of the Cadastral Service) and a member of the Commission since 1889, resigned in 1911 for the same reason [5, page A64], it was decided by Royal Decree of 1st July 1911 that in future four respresentatives of government departments dealing with surveying and mapping would officially sit on the Commission. The senior engineer, director of the General

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*) Survey Department Rijkswaterstaat.

**) A Provincial Public Works Department (Provinciale Waterstaat) came into being for each province between 1864 and 1882, and since then the Public Works Department of the central government has been called the Department of Public Works (Rijkswaterstaat).

Service, (Algemene Dienst) was appointed ex-officio as a member of the Commission for Waterstaat.

The General Service had been set up in 1819 for the purpose of collecting and publishing data necessary for the knowledge of hydraulic conditions in The Netherlands.

In the early decades of the 20th century this entailed the following:

1. maintaining the network of bench marks and publishing the relevant data;
2. collecting and processing the readings from a large number of gauges on the North Sea coast and along the rivers;
3. surveying and mapping for compiling a map on the scale of 1 : 10 000 of the winter bed (including the main dikes) of the principal rivers (the river map);
4. compiling and publishing a map on the scale of 1 : 50 000, giving information on the infrastructure pertaining to water management (Waterstaat-map);
5. the central management of instruments used by Waterstaat.

It was mainly the duties listed in points 1 to 3 which were the basis of the contribution of Waterstaat to the activities of the Netherlands Geodetic Commission. The work of maintaining the network of bench marks is described more fully in section 2.

In the period between 1920 and 1930 the need was increasingly felt in Rijkswaterstaat for a special division which, apart from the geodetic work already performed by the General Service, would execute precise topographical mapping on the scale of 1 : 1000 for the major civil engineering works of Rijkswaterstaat [6]. One of the prime reasons for this was the increasing specialisation in the technical sciences and, as a consequence of this, geodetical expertise was no longer automatically a skill possessed by the civil engineers or technical staff of Rijkswaterstaat.

In a number of major projects in that period, the surveying work was entrusted to a firm of consulting engineers, the Geodetic Bureau set up by Prof. Dr. Ir. W. SCHERMERHORN. The precise levelling was also originally contracted out to this Geodetic Bureau (from 1926 until 1931). This development led to the forming in 1931 of a specialist geodetic service within Rijkswaterstaat through an amalgamation of the Geodetic Bureau with a part of the General Service. The following duties were assigned to this new service, the Survey Department (Meetkundige Dienst):

1. maintaining the network of bench marks and the publication of relevant data (point 1 of the General Service duties);
2. surveying and mapping for compiling a map on the scale of 1 : 10 000 of the winter bed (including the main dikes) of the principal rivers (the river map) (point 3 of the General Service duties);
3. the central management of instruments used by Rijkswaterstaat (point 5 of the General Service duties);
4. measuring and mapping for compiling maps on the scale of 1 : 1000 (occasionally 1 : 2000) for the planning and maintenance of civil engineering projects;
5. extending geodetic assistance to Rijkswaterstaat.

The Survey Department was a section of the General Service until 1959, increasing in this way the latter's responsibility for geodetic work within Rijkswaterstaat. Consequently the senior engineer in charge of the General Service represented Rijkswaterstaat in the Netherlands Geodetic Commission as an ex-officio member and this situation was maintained when in 1937 the name was changed from "Rijkscommissie voor Graadmeting en Waterpassing" to "Rijkscommissie voor Geodesie".

This situation changed when the Survey Department became an independent Directorate within Rijkswaterstaat in 1959 and responsibility for geodetic work in Rijkswaterstaat (with the exception of the processing of the results from the gauges and the Waterstaat-map) was passed to the Head of the Survey Department. Accordingly, the present representation of Rijkswaterstaat in the Netherlands Geodetic Commission was established by Royal Decree of 8th June 1961, in which the Head of the Survey Department of Rijkswaterstaat was appointed an ex-officio member of the Commission.

2 Precise levelling in The Netherlands

The first comprehensive levelling in The Netherlands was performed by KRAYENHOFF [1], partly in cooperation with Waterstaat, from 1797 to 1812; these measurements, however, cannot be considered precise levelling by present standards. A major step into the modern era came with the first precise levelling which was carried out from 1875 to 1885. This was a direct result of a request by the Prussian Government in 1874 to be allowed to link up its levelling with the Amsterdam Ordnance Datum (AP = Amsterdamsch Peil). The decision was then quickly taken, to carry out a Dutch precise levelling, partly because otherwise . . . "the Government could not, without giving offence, prevent Prussian officers or officials from carrying out levelling in this country . . ." [7].

The measurements were initiated by Prof. Dr. L. COHEN STUART and carried out under his guidance by young civil engineers and students at the Polytechnical School in Delft. The Netherlands Geodetic Commission, set up after the death of COHEN STUART (in 1878), carried on the measurements and calculations under the direct guidance of two of its members, Prof. Dr. H. G. VAN DE SANDE BAKHUYZEN and G. VAN DIESEN. As in 1812, the Amsterdam Ordnance Datum (AP) was taken as a reference level, indicated by marble bench marks which had been positioned in locks in Amsterdam in 1682.

A number of interesting facts about the first precise levelling were published in Nederlands Geodetisch Tijdschrift in 1975 [8]. The results of the levelling were published in 1888 [2]. With this, the Netherlands Geodetic Commission considered its task in this field completed; on 29th December 1888 the Minister of the Interior handed over responsibility for maintaining and where necessary replacing the bench marks to the General Service of Waterstaat. The task was in turn passed on to the Survey Department of Rijkswaterstaat in 1931, and has remained its responsibility to this day.

Immediately on completion of the first precise levelling, five more lines linking up with the Commission's network were levelled by the General Service in 1886 and 1887. The results were published separately in 1890 [9]. From 1888 Waterstaat regularly carried out secondary levellings as part of the work of maintaining and where necessary extending the network of marks. Data on all known bench marks were regularly published in the registers composed for each province, called "Hoogte van Verkenmerken" (Height of Bench Marks) [10].

By about 1920 it was becoming increasingly evident that the rather widely spaced lines of the first precise levelling were inadequate for practical purposes. Moreover, its reliability was seriously impaired owing to marks disappearing and the vertical movement of buildings in which the marks were situated. Consequently, the Netherlands Geodetic Commission recommended a repeat of the "National Levelling" to the Minister of Waterstaat in 1923. This resulted in the second precise levelling, carried out in the years 1926–1939. The assignment was contracted out by the General Service to the Geodetic Bureau (run by Prof. Dr. Ir. W. SCHERMERHORN) in 1926. The Survey Department, which was set up in 1931, saw the measurements through to completion in 1939; general management of the project rested with Prof. SCHERMERHORN in his capacity of advisor of the Survey Department and member of the Netherlands Geodetic Commission.

The network of the second precise levelling covered the same area as in 1875–1885 but has more lines with less spacing between them. The Amsterdam Ordnance Datum (since 1890 called N.A.P., Normaal Amsterdamsch Peil) was once more taken as a reference level, which was made possible by connecting the network to the two remaining marble bench marks in Amsterdam. The computations of the second precise levelling were based on the mean height of these two marks; the heights of all the other old marks in The Netherlands were calculated anew. The results were published in the "Normaal Amsterdamsch Peil"-registers for each province [11]. Details of the measurement and computation of the second precise levelling will appear in the near future in a publication by the Netherlands Geodetic Commission. During the second precise levelling, several dozen underground marks, some 30 km apart, were placed throughout The Netherlands, all resting in diluvial or older layers. In this way the Amsterdam Ordnance Datum was preserved for the future.

The third precise levelling was measured from 1950–1959. The network adopted in this levelling more or less coincides with that of the second levelling. The main aim was to check the stability of the underground marks. Moreover the number of underground marks was increased, particularly in areas where it had not been possible to use underground marks of the original design owing to the depth of the diluvium. In these areas special piles were driven into the ground until a layer of dilivium sand was reached. In 1955 a similar underground mark was placed in Amsterdam, replacing the last original marble bench mark. During the third precise levelling a start was also made on placing underground marks in the immediate surroundings of each major gauge (known as zero piles).

The results of the third levelling indicate no significant change in the respective heights of the underground marks. Consequently, the measurements were locally linked to the levels of the underground marks calculated in the second precise levelling. The published heights [18] are therefore "heights for practical use" and are not suitable for the purposes of scientific research.

Since 1959, the Survey Department has had at its disposal an operational system for conducting hydrostatic levelling over great distances by means of a 6 km long lead pipe filled with water [12]. The system was developed for use in the coastal area of the North Sea and the Waddenzee. If the lead pipe is laid down on the bottom of a canal or river, parallel to its axis, readings can be taken at 6 km intervals along the waterway, giving a very accurate levelling of the end points. This system can to some extent replace the traditional optical levelling, and enables some of the possible systematic errors in optical levelling to be avoided [13].

Since The Netherlands has an interconnected network of waterways throughout the country, it was possible to design a framework of widely spaced lines for hydrostatic levelling. This was used in the fourth precise levelling which was conducted hydrostatically between 1964 and 1977 [14]. As many underground marks as possible were linked up with this network, for which purpose short sections of optical levelling were required. The results of the fourth levelling do not warrant any revision of the height of the underground marks. However, in the interests of the study of recent crustal movements an analysis of the results of the second, third and fourth levellings will shortly take place.

Since the beginning of precise levelling in The Netherlands, cooperation with the geodetic services in neighbouring countries has played an important part; the first precise levelling was in fact a direct result of such cooperation. Links with the Belgian and German networks have been established at various points along the borders in all four precise levellings.

Three lines from the third precise levelling (1950–1959), all merging at the nodal point of Amsterdam, were incorporated in the joint adjustment of the European levelling systems, UELN. (United European Levelling Network, REUN). The N.A.P. was taken as a reference level for the UELN.; the results of the adjustment were published by SIMONSEN [15].

A large part of the network used in the third precise levelling formed the Dutch contribution to the NWELL (North West European Lowlands Levelling), a joint adjustment of the levellings along the North Sea, stretching from Ostend on the Belgian coast to Kaap Skagen in Denmark and Lübeck on the Baltic. The heights of the nodal points in this adjustment were published by NITTINGER [16], while the heights of intermediate bench marks were published separately for The Netherlands by the Netherlands Geodetic Commission [17]. The data from the NWELL can provide a basis for the study of recent crustal movements in the North West European Lowlands in the future.

Since many European levellings have been remeasured since 1950, a second adjustment of the UELN is in preparation. The Dutch contribution to this work will consist of a number of circuits from the fourth (hydrostatic) precise levelling.

3 The Survey Department of Rijkswaterstaat nowadays

The work of the Survey Department is not essentially different nowadays from it was when it was set up in 1931. All the duties listed in section 1 are still carried out, although the amount of work has increased and there has been a considerable shift of emphasis. The reason for the shift is that Rijkswaterstaat will be facing entirely different problems in 1979 from those of 1931. A few aspects may serve as an example:

- safeguarding the land against the water has led to projects being carried out under the Delta Project which stretch technical ability to the limit;
- the rapid expansion of the network of motorways, bridges and tunnels owing to industrialisation and population growth has entailed a great deal of work and effort;
- an ever-watchful eye is needed to maintain water supplies and the quality of the water;
- Rijkswaterstaat is increasingly involved in scientific and practical research of the quality of the surface waters and how they can be protected against pollution.

On the one hand the Survey Department is required to have a maximum production of maps etc., on the other to assist other departments of Rijkswaterstaat in solving new problems confronting them. The Survey Department's present terms of reference, in addition to the points mentioned in section 1, page 222, contain the following points (which can largely be seen as an elaboration of point 5):

- conducting survey work to assist in the construction and management of civil engineering projects;
- aerial photography for mapping and study purposes;
- compiling vegetation and geomorphological maps;
- performing measurements and calculations for purposes other than mapping;
- research, consultation and information geared to the application of geodesy within Rijkswaterstaat in general, but in particular in relation to survey problems at sea and on rivers (marine geodesy) and in the field of modern observation techniques (remote sensing) and the requisite instruments;
- managing and maintaining radio-positioning systems in use within Rijkswaterstaat.

Lastly, for general purposes, there is the production of the Altitude-map of The Netherlands, in cooperation with the Topographic Service of the Ministery of Defence.

Below is a brief outline of current developments in modern methods.

Photogrammetry

- Photogrammetry has been used in the production of maps right from the early years of the Survey Department. The constant demand for new maps led to a search for labour-saving methods and the answer seems to have been found in digital photogrammetry.
- Photogrammetry is also used for special applications, for example establishing the sea surface or other dynamic phenomena by means of stereo-photography.

Hydrostatic Levelling

The Survey Department has developed hydrostatic levelling into a practical method. The great accuracy achieved by it led to hydrostatic levelling being adopted in the fourth primary levelling of The Netherlands.

Automation

The Survey Department has used computers and plotters since they first became available. A lot of routine work readily lent itself to computer processing as the relatively simple problems were well formulated. After the smooth and successful start with simple work, the computer has now become an indispendable aid in new working methods. Automation originally referred to large computers only, but nowadays relatively simple electronic desk-top calculators with the necessary peripheral equipment, are used to perform and (to some extent) process measurements on the spot. In general it can be said that within Rijkswaterstaat automation is applied more intensively in the geodesy sector than in the other technical fields.

Marine Geodesy

- Being entrused with the maintenance of rivers and coasts and as designer of large-scale civil engineering projects, Rijkswaterstaat has a growing need of positioning equipment. The Survey Department evaluates the geometric and physical qualities of the various

systems, keeps abreast of developments in the instrumental sector and tests the possibilities of new equipment in practice.
- Where positioning is used in conjunction with depth measurement, there is the problem of combining the correct depth and location data whilst checking their accuracy during the operation if possible. The Survey Department has assisted in the development of a system for automated recording.
- In the current construction method for tunnels, tunnel elements are built in a construction dock, floated and towed over water to the site of the tunnel where they are sunk. The transport and sinking at the precise location are supervised by modern positioning systems, the actual position of the tunnel element being depicted graphically on a map in real time.
- The large-scale hydraulic engineering projects carried out by Rijkswaterstaat necessitate a search for methods of observing dams, stone revetments etc. under water. With the help of the Survey Department, investigations have been carried out successfully and a practical method has been developed for carrying out such inspections under water with the aid of side-scan sonar.

Remote Sensing
Modern aerial surveying techniques using a wide range of the electromagnetic spectrum offer good prospects for use in various aspects of the work of Rijkswaterstaat. Equipment is now available which uses for example, the microwaves and infra-red bands.

In the period from 1971–77, the Netherlands Interdepartmental Working Community for the Application of Remote Sensing techniques (NIWARS) investigated the suitability of the new techniques for a number of civil engineering problems such as detecting oil pollution at sea, cooling water discharges, observation of shipping, etc. The Rijkswaterstaat (including the Survey Department) took part in these investigations and now uses several of these techniques. After the conclusion of the NIWARS-project, the Survey Department was given a major role in introducing the new techniques and in the coordination of the relevant research.

Motorway Profile Surveying
Accurate checks on the levels of motorways are regularly required. Almost insurmountable difficulties are entailed because of the high volume of traffic. A method is therefore being studied which involves a tracking device which automatically records the position of a light mounted on a moving survey vehicle; the position is recorded in three dimensions and from this the longitudinal profile of the road is deduced.

The place that the Survey Department holds within Rijkswaterstaat and the geodetic world can be readily shown by listing a few facts.
- Since the first years of its existence, the Survey Department has used photogrammetry in map making, encouragement in this direction having been given by Prof. Dr. Ir. W. Schermerhorn. The Survey Department has currently the largest number of photogrammetric instruments in The Netherlands and was also among the first within the international surveying world to computerise photogrammetric mapping.
- The Survey Department is the only one in the world capable of conducting hydrostatic levelling on a large scale.

- The Survey Department plays an important part in the introduction of Remote Sensing techniques in The Netherlands.

Its importance within Rijkswaterstaat is most clearly indicated by the fact that it became an independent Directorate in 1959. This meant that the specialization of geodesy received equal status along with the other special technical fields within Rijkswaterstaat, such as traffic engineering and information processing. Consequently, the Survey Department is committed to following developments in geodesy and keeping an eye open for their potential uses within Rijkswaterstaat.

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