UNIFICATION OF GEODETIC GRIDS OF THE WORLD APPLICATION TO GENERAL PROBLEMS OF NAVIGATION

(Lecture delivered during the VIth International Hydrographic Conference, Monaco, April-May 1952, by Professor P. TARDI, U.G.G.I.)

The following sentence appears in Admiral Nares' report on the IXth General Assembly of the International Union of Geodesy and Geophysics (Brussels, August 1951), published in the November 1951 issue of the *International Hydrographic Review :*

« During the course of the meetings... lengthy discussions took place on the subject of the co-ordination of the geodetic grids of the World. Captain Viglieri presented a paper... in which he pointed out that... the Vth International Hydrographic Conference had adopted a resolution specifying the needs of Hydrographic Offices regarding such co-ordination. As far as he (Captain Viglieri) was aware, he said, no information as regards the work done in this field... had been received by the I.H.B. »

Admiral Nares also added that « he hoped M. Tardi, Secretary General of the International Association of Geodesy, would present a report on this subject at the VIth International Hydrographic Conference ».

This is the report that I have come to deliver in person, in order that Delegates interested in this question may be supplied with additional information they may be desirous of obtaining.

The Resolution, adopted at the Vth International Hydrographic Conference, it may be pointed out, was the following :

« *Co-ordination of geographical grids of the World :*

« The Conference recommends that the Directing Committee of the International Hydrographic Bureau get in touch with the International Union of Geodesy and Geophysics, to specify the needs of the Hydrographic Offices, and to offer such co-operation as may be possible in finding the best possible means of making and reducing observations for obtaining *the absolute geographic coordinates* of points on the globe, with the highest possible standard of accuracy. »

This short paper will be divided into three sections and each will successively be translated into English.

I shall first mention the work carried out *in Europe* under the auspices of the International Association of Geodesy, and point out the rather special nature of this work, in which Science is occasionally brought into opposition with questions of military secrecy.

I shall then describe work of a more scientific nature *on a world-wide scale* at present being carried out, whose purpose is the determination of a *general ellip-*

soid defined not only as regards size, but also as *to position* with respect to the vertical of any place. It is in connection with this general ellipsoid that the *absolute geographic coordinates* requested by Hydrographers in their 1947 Resolution are defined.

Finally, although I am neither a Hydrographer nor a Navigator (unless it be as a passenger) I shall venture to give my own opinion as to the manner in which these problems should be considered in connection with the difficult art of navigation.

I. — *Present work of Geodetic Standardization in Europe.*

The work is represented on the chart that I have put up in this room. There are five different sections, which in the last analysis consist of one uniform area : Central Europe - Southeastern Europe - Southwestern Europe and North Africa - Northern Europe - Great Britain.

Let us rapidly examine a few characteristic aspects of this work, involving a huge amount of calculation which was only possible to complete within a reasonable time-limit with the aid of electronic computers and the punched-card system (1).

1°) The section comprising Great Britain has not yet been joined to the Continent, which greatly detracts from the interest of this work for navigation, with special reference to the English Channel and the North Sea. The geodetic linking up of France and Great Britain was accurately repeated last year. In spite of this accuracy, the position of Great Britain with respect to the Continent is like that of a top balanced on its tip. The linking up of Northern Scotland and Norway has been considered by using methods of the radar type, as well as between the extremity of Cornwall and Brittany. Will these connections take place one day, and if so, when ? I have no information on this point.

2°) The Central European Section had been calculated for strictly military purposes. These calculations were carried out by German geodesists working under orders from the American Army. The Army Map Service is in sole possession of the results, and I should mention that certain countries interested in these calculations were not consulted when their own national grids were incorporated in the overall calculations.

3°) The same situation applies with regard to the Southeastern European Section, as in the case of the grids of Bulgaria and Rumania ;

4°) The International Association of Geodesy had no part in these huge computations except in the case of the Southwestern and Northern European Sections, and collaborated in operations that in spite of everything retained a certain military character under conditions that I feel should be specified as follows :

— If the Association had not helped, calculations would have been made in any case, but under conditions no longer involving an operation of a scientific character.

— It would never have been by itself in a *material* position to resume operations, since it is far from having the enormous resources of the Army Map Service and Coast and Geodetic Survey. And the unification of European geodetic grids is one of the *essential* aims of the I.A.G., which at the time of its founding in 1867 was called the « Europäische Gradmessung ».

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(1) 1332 normal simultaneous equations to be solved for the Central Section — and 2348 for the Southeastern Section.

— Several Western European nations were notably unenthusiastic at the idea of being included in an overall calculation, with particular reference to Great Britain (which finally remained outside) and Italy.

— A convention was finally signed in 1948 by the 8 Countries interested in the calculations for the Southwestern European Section. They would supply all their most recent observations. *But the results of the final calculations would only be communicated to each interested country and only for its own grid.*

— Up to the present time no agreement has been reached to remove this restriction.

— The Army Map Service and the Coast and Geodetic Survey are the only organizations acquainted with the overall results, but they have promised not to publish them without the formal acquiescence of the interested parties.

— As far as the International Association of Geodesy is concerned, it only has the values of the *relative deviations from the vertical for all of Europe*, that is comparisons of the geodetic coordinates of the new system with the *astronomical* values of these coordinates, whenever they have been determined directly. These results are practically the only ones that interest the Association, as it will therefore be enabled to plot a local chart of the geoid for Europe with respect to the surface of reference on which the calculations were made (there are 858 values for latitude and 644 for longitude).

— But these results are of little interest to navigation. What Hydrographers need is a comparison of the old geodetic coordinates of each country and the new values in the European system.

We do not have these comparisons and it has been agreed not to publish them until further notice.

As one delegate put it at the time of the delicate negotiations undertaken by us in 1947 : « We are not especially eager that the essential positions in our capital have their coordinates included in an overall system together with other countries, from which a long-range radio-guided missile might depart some day. »

Here is a problem that you Hydrographers must be well acquainted with, when you think that the best charts you plot of the coasts of your country might be used some day by the Navy of an enemy country. You, at least, can resort to blacking out your lighthouses and anchoring mines. The same possibilities do not exist on land.

And this is why we have not yet answered your 1947 Resolution.

At the time of our 1951 General Assembly, the following motion was made by a certain delegates, and it was even adopted by our Triangulation Section. However, our Executive Committee decided at the request of two countries interested in calculations for Europe not to approve the proposal, which was as follows :

« The International Association of Geodesy :

« — Considering that an homogeneous geodetic network already covers the main part of Europe,

« — Considering further the subsequent advantages in the fields of Geodesy, Cartography and Navigation :

« Expresses the wish that the results of such adjustments be used by the different Nations as a basis for any work intended to meet international needs. »

This situation is naturally not irremediable. Let us only say that *the question is not yet ripe.*

I have strong hopes that I shall be able to reach a positive result when our next General Assembly takes place in Rome in two years' time. Direct negotiations, carried on quietly and not in the busy atmosphere of a General Assembly, will take place until then with the interested countries. One of the most important arguments I intend to use is the interest you have shown in the problem, and I shall later deliver to the President the text of a Resolution intended to replace the one adopted by you in 1947, which is better adapted to present circumstances.

II. — *Determination of absolute geodetic co-ordinates*

M. Verstelle, of the Hydrographic Office of the Royal Netherlands Navy, describes in a memorandum (para. 5) the different methods used by geodesists in obtaining coordination between geodetic grids. As this memorandum has been communicated to you, I take the liberty of referring you to it in connection with various scientific or technical questions.

I should only like to stress the interest of the gravimetric method, based on the use of Stokes' formula in arriving at an actual *World Geodetic System.*

This is one of the *fundamental* aims of the International Association of Geodesy. But the number of gravimetric stations known on the earth and especially on the ocean surface is still too small for making valid general calculations.

A powerful organization is being formed in the United States under the scientific leadership of Professor Heiskanen of Ohio State University, Columbus, Ohio. It may reasonably be expected that interesting results will be attained in approximately ten years, which in my opinion is a very short period.

These *World Geodetic Co-ordinates* would indeed be of interest to navigation, and your 1947 Resolution was fully justified, although at the moment unrealizable.

Other methods have been tried in an attempt to obtain a knowledge of the differences that may exist between the geoid and ellipsoid (that is, between a real level surface and the mathematical surface used in making calculations : observations made of total eclipses of the sun or occultation of stars by the moon by placing oneself on 2 points of the exact line of eclipse or occultation. No positive result has as yet been obtained, particularly owing to difficulties of observation and the unknown influence of lunar relief. At any rate, each observation only supplies a conditional equation between several unknown quantities.

The fact is that only the gravimetric method is a general method.

In a few years it will provide essential results. But as yet the question has not reached a sufficiently ripe stage.

I should like at this point to mention that metrical discrepancies between positions belonging to separate systems may frequently reach from 200 to 300 metres. The discrepancies involved here apply to co-ordinates reckoned on surfaces that are different with regard to *size* but especially *position.* Such discrepancies may excep-

tionally be as large as 1 km. M. Verstelle estimates in his memorandum that the degree of accuracy in navigation to be sought for is on the order of 1 second, or 30 metres. It would therefore only be necessary for you to known the *principal part* of these discrepancies, which after all simplifies the problem.

III. — *Use of Unified Co-ordinates in Navigation*

When the *World Geodetic Co-ordinates* system is defined, this will of course be the appropriate one to refer to, but only if one is navigating very accurately and using such methods as Shoran, Decca and others where *distance calculations* (or distance difference calculations) carried out on a well-defined mathematical surface come into play. Results are of little interest if the good old astronomical navigation system is used. *Astronomical* co-ordinates have already been unified. They belong to a well defined surface : the geoid. Unfortunately it has undulations and computations neither of angles nor of distances can be made on it.

For the moment, and as far as Europe is concerned, these problems interest only navigation in inland seas when such navigation is by radio-electric aids :

Mediterranean Sea,

Baltic Sea.

When Great Britain is connected to the continent under conditions which I have previously detailed, there may then be added :

The Channel,

The North Sea,

and naturally that zone of the Atlantic lying relatively close to the coasts.

How can the use in navigation of unified co-ordinates belonging to the European system — and later to the World Geodetic System — be regarded in a reasonable way ? There will naturally be no question of modifying the innumerable charts already published. However, given the required accuracy which as previously estimated should be only 30 m., every case might be limited to a few marginal notes on the charts, indicating the corrections to be applied to the system of co-ordinates on the chart if it is desired to make them comparable to the co-ordinates used in the neighbouring countries. Moreover, short tables, which might be published by the I.H.B., could give to navigators wishing to make use of it, information concerning unified geographical co-ordinates for a certain number of important points : radio-beacons, Decca chains or those of other systems, etc...

Here, however, we must not entertain too many illusions : to accurate co-ordinates must correspond accurate computations ; the computations must therefore be ellipsoidic and not spherical. These computations seems to me to be very lengthy indeed, and very delicate for navigators whose position is changing even while they calculate it.

I think that, *in reality,* the matter will be reduced *especially* to the following : that Decca (or other) navigational charts, with previous drawing of hyperboles, must be established on the unified system. This system must also be used for certain semi-fixed operations in inland seas.

To resume, I consider that the works of the International Association of Geodesy, namely :

the present European system, which will be completed in the near future when the British grid shall have been connected with it ;

the World Geodetic System ;

are not called upon (far from it) to upset navigational methods even in inland seas surrounded by several different countries.

It is, however, no less certain that hydrographers must be made aware of the new problems which thus present themselves : the necessary information *must* be communicated to them. I have demonstrated to you that, insofar as the unified European net is concerned, this does not depend solely on us ; but I believe that the restrictions which exist at present concerning divulgation of the results will shortly be lifted.

I ask your indulgence for having so long retained your attention on these somewhat theoretical problems. And, in conclusion, I propose to you the text of a resolution which you can naturally modify to your satisfaction — but which might take the following form which I now hand over to the President.

DRAFT RESOLUTION

The VIth International Hydrographic Conference has examined with interest the work carried out under the auspices of the International Association of Geodesy in view of the unification of all the European Geodetic nets.

Having taken into account the difficulties which for the time being prevent general publication of the results obtained, and which the Conference hopes will disappear in the near future,

The Conference emphasizes the importance which certain of these results present for navigational problems and makes the following recommendation :

a) That this unification be extended to North-Western European nets ;

b) That, in any case, all interested countries make known to the International Hydrographic Bureau the discrepancies presently existing, with regard to a certain number of coastal positions, between the geodetic co-ordinates used for the construction of charts at present published and geodetic co-ordinates belonling to the adjusted European geodetic system. It would suffice to give these discrepancies to 0''5.

LECTURE BY PROFESSOR TARDI

Wednesday, 7 May 1952

DISCUSSION

The CHAIRMAN asked for an explanation on the following point :

The lecturer had said that it might be hoped that the British geodetic grid would be attached to the continental grid in a not too distant future. Did this mean, in three weeks, or in fifty years ? It would be useful to have a scale of size, because, at the moment, a certain number of countries were contemplating layouts and corrections and they would not wish to run the risk of having to begin again some time later.

Professor TARDI replied that, in fact, he knew nothing, and could only express personal views. The purely geodetic liaison had been achieved last year, but two things were lacking : in the first place, two lateral liaisons were lacking which would allow of the putting into place of the geodetic grid, and also there was as yet no possibility of making calculations.

Mr ATHERTON (British Commonwealth) said that, if he understood Professor Tardi, aright, the request for absolute geodetic coordinates was some 15 years in advance of the possibility of obtaining these by considering fully gravimetric data with the use of Stokes' formula. If this were so, would it be right for Hydrographic Departments to alter their charts now as the result of the present adjustment being made by the U.S. Army Map Service ? As had been stated, there was no possibility of making modifications to existing charts, but the question arose as to whether new charts also, should yet be planned on the new data.

Professor TARDI thought that this calculation on quite general lines of the world geodetic system would require about fifteen years, but the future could not be predicted, and the time-lag might perhaps be too long. The calculations would not be valid until the gravimetrical determinations on and under the sea had been multiplied. At the moment, such determinations had been made in certain parts of not very densely inhabited continents, *e.g.*, in the area of the Amazon in Brazil, and in the centre of Africa. In order that Stokes' formula might be usefully employed, it was necessary to know some values of gravity anomalies. It was necessary that, for each square, some value of gravity anomaly should be given, in order to make an integral calculation.

In mentioning fifteen years, therefore, he had perhaps been optimistic. Heiskanen, last year, had said three years. Perhaps fifteen years would not be enough. There were great difficulties, and, in the system referred to, which consisted in mentioning air nautical charts, in relation to a standardized European system, the co-ordinates of the port of Algiers, of the port of Toulon, etc., corrections would have to be made in the co-ordinates. So far as he was concerned, he did not see any disadvantage in introducing changes, because even if later on another system had to be introduced, it was a small matter to make it known to navigators.

The problem was altogether different for the land, when the co-ordinates had to be changed. This had just been done for France, in special liaison with Italy and Switzerland. There were 130,000 points to be transformed by means of the electronic computer. This had been an immense work.

Mr. ATHERTON (British Commonwealth) pointed out that an endeavour had been made to apply Stokes' formula to find the deflection of the vertical of one or two places in England. An interesting result was that the geodetic longitude of Greenwich Observatory was not exactly 0° 00' but differed by 1" or 2 " (the astronomical

longitude was of course exactly 0°0'). The results of some calculations made by the Department of Geodesy and Geophysics at Cambridge, were given in the Proceedings of the Royal Society.

Professor TARDI emphasized the fact that Stokes' formula would not be valid until it could be applied to the whole of the world. For the time being, in the calculations which it had been possible to make, only local anomalies could be introduced, and there were undoubtedly discordances because distant points could not be used. There were not sufficient known data.

Capt. VIGLIERI (Italy) observed, in connection with the resolution at the end of the lecture, that the figure of 0".5 was not sufficient.

Professor TARDI stated that the conference text actually mentioned 0".5, but observed that in reading the text he had replaced his figure by an indefinite number. One might put 0".1.

Capt. VIGLIERI (Italy) was of the same opinion and thought that for fixing the ship's position to the accurary available from present radio-electric appliances, under conditions of good resection, the positions of stations should be approximate by two or three metres.

Kommandör JENSEN (Denmark) said he was in agreement with the new approximation of 0".1. In these circumstances, it would seem that the draft resolution submitted was well-nigh ideal.

He would like to know if it would be possible at once to have the new co-ordination of certain points in Europe, and if a list had already been published.

Professor TARDI replied that this list did not exist, since an agreement had been come to between the various nations that the results should not be published. But on the basis of a draft resolution such as the one before the Conference, it was hoped to obtain a new agreement for at least partial publication. As regards discrepancies, there were a certain number of them between the previous and the new co-ordinates. If France had to publish 130,000 new co-ordinates, a whole library would be needed.

Kommandör JENSEN (Denmark) stated that two years ago he had undertaken negotiations with the National Institute of Geodesy of Denmark as regards adjustments to be made in charts of the Baltic Sea. The answer had been given to him that these data would never be published, and that they were of purely scientific interest. Perhaps the resolution proposed might allow of this information being obtained. In any case, it would seem that a national institute of geodesy should not refuse to communicate differences to its own geographic service.

Professor TARDI remembered having said that a draft resolution had been submitted at Brussels with the object of making public these co-ordinates. Some nations had put forward a counter-proposal, appealing to the fact that this was not what had been agreed. In particular, Denmark had taken this view, through the medium of Professor N., who was anxious that the co-ordinates should not be made public.

Speaking personally, he was not convinced of the efficacity of keeping military secrets. Such a procedure only irritated those who needed the information, but was no obstacle to foreign intelligence services, who paid their agents a little more dearly for the information, and that was all. Thus, the lists of co-ordinates in France would be published in 5,000 copies and would be used by the troops. They were « secret » documents, and could not be officially communicated, but if some toher nation, for unspecified reasons, wished to possess them, it would pay the large sum necessary. « Secrets » of such a nature were completely ineffective.

Capt. VIGLIERI (Italy) thought that, for the moment, hydrographic experts did not wish to have all the co-ordinates in order to change their charts. But perhaps there were some nations which possessed radio-electric systems in common, and these nations might desire to have merely the co-ordinates of the stations concerned. Such states could then reach agreement between themselves for the purpose of obtaining these co-ordinates.

Professor TARDI said that he was in complete agreement with this. It was for this reason that he had proposed his resolution.

Mr. ATHERTON (British Commonwealth), on the subject of the secrecy of the information referred to the fact that in 1947 certain countries did not want it to be published because it would reveal the positions if their capitals. It was only necessary, however, for one or two points to be known on the new data in each country, because owing to the high degree of accuracy both in scale and orientation of existing government triangulation systems, the whole adjustment of the European network would then become known. Any attempt to keep the information secret was bound to fail.

Professor TARDI thought that this was one more argument in favour of the publication of these lists of co-ordinates.

Mr. ATHERTON (British Commonwealth) agreed with this view.

Kommandör JENSEN (Denmark) was happy to have met at the Conference a geodetic expert who was capable of talking the same language as the hydrographic experts, whereas in Denmark this was not at all the case. He thanked the lecturer for being willing to help him, and also his colleagues.

Professor TARDI replied that he would do his best.

The CHAIRMAN said that he would like to know what the Americans were doing with regard to the utilization of the new geodetic grid, and if they had taken any decision on the question, because they were publishing charts of the whole world.

Mr. MEDINA (U.S.A.) stated that attention was being mainly paid to adjustments of the European geodetic grid. As regards charts already made, it was difficult to modify them, but notes could be added in accordance with the suggestion of Professor Tardi.

Professor TARDI pointed out that, last year, at the Association of Geodesy, he had collaborated closely with the U.S.A. services for the purposes of a preliminary campaign for a liaison between the American continent and the European continent, by means of observations of stars, etc., but occultation gives no general results. It merely gives an equation containing four or five unknown quantities according to the manner in which the problem is considered. Therefore, if about ten occultations were observed, the result would be as many equations which could be made linear and which might result in experimental distances and experimental comparisons, between the American continent, the Azores and the African or European continents. However the project had not given satisfactory results.

The essential difficulty which had arisen was in connection with observations of occultations. There were rudimentary methods in existence, by means of the photo-electric cellule, and certain astronomers thought that this method was defective. Nevertheless, a fresh start is to be made with a better organization.

The CHAIRMAN wished to raise a question on the subjet of the new geodetic grid. Had Germany and Belgium already thought about the question ?

Dr. BÖHNECKE (Germany) said that up to now Germany had not taken any definite attitude on the question, but was maintaining close relations with Dr. Gigas and hoped to arrive at a decision which would be communicated to the I.H.B. and to other international organizations.

The CHAIRMAN said that he would like to be kept informed of this decision.

Mr. HEIDERSCHEIDT (Belgium) pointed out that he had been in communication with the Geographic Military Institute of Brussels, which would inform him of any decision taken.

The CHAIRMAN asked the delegate of Belgium to communicate his information to the delegate of the Netherlands.

He then thanked Professor Tardi for his lecture and associated himself with Kommandör Jensen in noting with pleasure that the language spoken by the geodetic and the hydrographic experts was so very similar. Any difficulties which there might be should not discourage the efforts of the geodetic experts.