The Triangulation of Ceylon

By J. E. JACKSON, B.A. CANTAB.

(Ceylon Survey Department).

1. HISTORICAL.

Although the object of this Paper is to describe the Triangulation of Ceylon in its present condition, it seems desirable first to glance at the history of this branch of the activities of the Survey Department.

In 1857 the Negombo Base was measured by Corporal Winzer with an iron chain which was calibrated in the field by means of a brass Standard Yard. In the following three years trigonometrical observations were taken, chiefly by one J. O'Donnell, with a 13 inch Everest theodolite at about 25 prominent points in the Western and Southern Provinces. This vernier theodolite was of course considered a "podian," in those days, when 36 inch micrometer theodolites were in use for primary triangulation work. In 1860 a Base Line was measured at Batticaloa, and an 8 inch vernier theodolite was used for observations at a number of points in the Eastern Province. In the Eighteen-seventies the 13 inch instrument was again in action and observations were taken at about 35 points in the Central and Eastern parts of Ceylon, and a few years later this work was extended Northwards in the form of a chain of some 25 points which eventually terminated on Delft Island where it joined up with the Great Trigonometrical Survey of India.

What an interesting, but arduous work, triangulation must have been in those days, when transport was slow, instruments were far from perfect, and the distant signals were 30 or 40 miles away. From the point of view of the trigonometrical observer Ceylon is like the Curate's Egg: the central hills are ideal and points like Adam's Peak, Pidurutalagala, Namunakuli, and Knuckles must inevitably become Principal Trig. Points: most parts of the Low-Country are studded with
those peculiar hills which rise so steeply from the plains and make such excellent view points. But there are regions, especially in the extreme North, where there are no hills, and in those parts hills had to be made, that is to say wooden 'stages' or masonry 'towers' had to be built. The stages were made of jungle timber and some of them were over 100 ft. high: moreover they were double, the inner stage for the theodolite and the outer stage for the observer.

Little is known of the methods by which this early triangulation was first computed, but in 1890 a Mr. A. E. Wackrill was called in to report on the situation with the result that he was instructed to re-compute the whole of the existing triangulation. Mr. Wackrill used his own methods of adjustment some of which he had described before the Institution of Civil Engineers. The adjustment was controlled by the two Base Lines and some Astronomical observations which had been taken by Winzer at Colombo Clock Tower and at Pidurutalagala. Co-ordinates were computed by the simple rectangular formulae.

After 1890 the Principal Triangulation was extended till it covered most of the Island except the extreme South-East, and a great deal of what might be called Secondary Triangulation was done to break down the larger triangles of the principal framework. Of the many schemes of triangulation done between 1890 and 1910 the chain along the North-East Coast may be mentioned, on account of the curious 'Gautier' theodolite that was used; this seems to have been the first micrometer theodolite used in Ceylon. It may also be mentioned that in 1904-1907 a large area in Central Province and Uva was triangulated with a small vernier theodolite, the observations being taken by the method of 'repetitions.' A micrometer theodolite of the conventional pattern first appeared on the scene in 1908, and was used for three seasons in observing the 'Matale-Knuckles' triangulation by which several hundreds of points were fixed in the Central and North-Central Provinces.

Now, until about 1910 the main purpose of the Triangulation was to provide control for the Topographical Survey by Plane-Table on the
scale of \( \frac{1}{4} \) mile to 1 inch; from that point of view the triangulation was practically complete, and it was actually completed by an extensive scheme in Eastern Province and Southern Province, observed in 1919-1923, mainly by the repetition method. But the Block Surveys imposed a new condition on the triangulation: each Block Survey Area required a small scheme of Minor Triangulation with points only a few miles apart, and a comparatively high order of accuracy was demanded. These small schemes were adjusted to fit on to the existing Principal and Secondary points, but the fitting process was found in many cases to be somewhat tricky and in fact several schemes had to be adjusted independently of the old triangulation. This state of affairs naturally led to much loss of time, duplication of work, and confusion of records. It could hardly be expected that co-ordinates computed by the simplest of methods for a topographical survey would be sufficiently precise for the control of cadastral plans on a ten times larger scale. It was therefore decided in 1930 to make a second re-computation of the whole triangulation. This decision was not an easy one to make, for although the triangulation could obviously be improved considerably by employing more rigorous methods of computation, it was not quite clear whether the old observations were sufficiently accurate to give the 10-fold improvement required.

For this re-computation the old observations were used throughout, except that the Base Lines were re-measured, the Batticaloa Base Extension figure of 6 points was re-observed, and a new Astronomical Datum was obtained.

The re-computation is now practically complete and the results have been found to be adequate to the control of Block Surveys and similar work: all new triangulation is adjusted to fit on to this 'New Conformal' system of points and the adjustment has so far presented no serious difficulties.

2. THE PRINCIPAL TRIANGULATION

The first step, after the re-computation had been decided upon, was to select an initial scheme of observations, covering as large an area as possible, which could be adjusted so as to form a controlling
framework for subsidiary triangulation. The adjustment of a triangulation starts with the observed values of the angles, and the heterogenous nature of the observations in Ceylon has already been indicated: about 35 different observers using several instruments of entirely different types had been engaged at various times since 1858 in producing the hundreds of observation sheets kept in the Trigonometrical Office. Eventually the scheme shewn in Diagram A was selected: there are 110 points and 500 observed angles in it. The average length of the observations is 16 miles and the longest observation is 50 miles (Ritigala-Knuckles). The scheme was divided into 17 parts which were adjusted by the method of Least Squares so that they fitted together exactly and formed a geometrically consistent network. The main part of the work was of course the solution of the Normal Equations: in adjusting Figure X there were 26 equations to be solved simultaneously, and the average number of equations was 15.

Diagram B shews the 159 triangles which form the adjusted network. The mean triangular error was 3.08 seconds and the maximum was 15.09 seconds (triangle No. 70): the average correction to the angles was 1.92 seconds and the maximum 9.08 seconds. It cannot be claimed therefore, that the triangulation is of Geodetic accuracy: on the other hand it is fairly clear that the results now obtained are as good as any that could be obtained from the available observations, and the conclusion that the re-computation has succeeded in eliminating a large part of the observational errors is justified by several pieces of evidence, in particular by the good agreement between the two Bases.

3. THE BASE LINES.

The two lines drawn extra thickly on Diagram A represent the Bases: they are component lines of the Principal Triangulation and they are each about 54½ miles long. They were re-measured in 1930; two 100 ft. Invar Tapes were used with special apparatus, by which it is possible to obtain the length of a line several miles long correct within an inch or less. As a matter of fact, the
Batticaloa Base was measured twice and the two values differed by an eighth of an inch; the Negombo Base was measured only once. These re-measurements disclosed another cause of error in the old results for it was found that the old value of the Batticaloa Base was $4\frac{1}{4}$ ft. too long. The most gratifying result of the re-computation was however obtained when the new value of the Negombo Base was introduced into triangle No. 1 and the lengths of the other lines were computed. The length thus found for the Batticaloa Base was only $\frac{1}{4}$ ft. different from its measured value. A difference of four times this amount might have been expected.

On account of the close agreement between the Bases it would have been an unnecessary refinement to alter the triangulation so as to fit them both exactly, and a mean scale was therefore taken. The adopted values of the lines are the means of the two values that would be obtained from the two Bases, and the adopted lengths of the Bases are therefore one-eighth of a foot different from the measured values.

4. ASTRONOMICAL DATUM.

Having determined the shape and size of the geometrical figure forming the Principal Triangulation, we then had to fix it in position on the Earth. The Latitude and Longitude were derived from Colombo Observatory for the Transit Instrument there could be connected, by means of the City Survey traverses, to Colombo Clock Tower Principal Point. In 1930 the True Bearing of each Base Line was measured by series of Star Observations. Starting from the adopted Coordinates of Colombo Clock Tower and the observed bearing of the Negombo Base, the bearing of the Batticaloa Base was computed and the result differed from the observed bearing by only 3.3 seconds. A mean bearing was adopted, and in this final position the Geographical Co-ordinates of all the Principal Points were calculated by Clarke's Formulae: for this purpose the dimensions of the Earth were taken to be the same as those adopted by the Survey of India, that is the Everest Figure.
5. **RECTANGULAR CO-ORDINATES**

The ultimate object of the Triangulation was of course to provide linear co-ordinates for the control of traverses and other detail surveys. It was therefore necessary to decide upon a pair of formulae for calculating linear co-ordinates from Latitudes and Longitudes; in other words a Projection had to adopted. The Transverse Mercator Projection, with a reduction factor, was used, and suitable Tables based on this projection were prepared. With its central meridian passing through Pidurutalagala this projection has a maximum scale error of 1 in 10,000. The Co-ordinates of all the points and the Grid Bearings of all the lines were computed by two independent methods. Pidurutalagala is the point \((0, 0)\), co-ordinates North and East are plus, co-ordinates South and West are minus.

If any further justification for the re-computation had been required it was provided by the differences between old and new values of the co-ordinates. Some points were shifted more than two chains. The new values for the distances between points were in all cases less than the old values, and the general effect of the re-computation was a fairly uniform contraction towards Pidurutalagala. Integrated over the whole Island this contraction amounts to a reduction of about 5 sq. miles in area.

6. **SUBSIDIARY TRIANGULATION**

The Principal Triangulation comprises 110 points spread over an area of 20,000 sq. miles, at an average distance of 16 miles apart, but for Block Survey and similar work points are required 2 or 3 miles apart.

A great many subsidiary observations were taken during the course of the observation of the Principal Triangulation, and there were in 1930 about 30 small schemes of Minor triangulation which had been observed during the preceding 20 years. In fact all the observations which had not already been used had to be examined carefully before any subsidiary triangulation could be computed, and several months were spent solely in making new abstracts. The programme of Secondary re-computation was guided chiefly
by the desire to provide the necessary framework for the fixation of the various, more or less isolated, schemes of recent Minor triangulation. After that, the extensive "1919-1923 Topo. Triangulation" was tackled: in some places this triangulation forms a considerable extension of the Principal framework.

Most of the subsidiary points were computed, one at a time, by semi-graphic methods. Such methods are particularly suited to conditions in Ceylon where, in fixing a point, it is necessary to take account of all the available observations and to balance the adjustment so that the shortest shots can be given the greatest weight and any faulty observations can be at once detected. Two types of semi-graphic computation are employed, one which takes account of the curvature of the Earth and is used for Secondary and Minor points, and the other which is done on plane co-ordinates and is used for the more subsidiary points. Geographical Co-ordinates are computed for Secondary points only.

Practically all the computations for the triangulation are done on specially designed forms which are arranged so as to give automatic cross-checks on all the important results: the method of checking by merely verifying previously written figures is avoided as far as possible. No case of failure of the checking system has so far come to light.

7. RECORDS

One of the arguments for the re-computation was the chaotic state of the trigonometrical records and documents. It is hoped that the new records cannot be criticised on that account. All the essential results such as Co-ordinates and Bearings are tabulated in 'Bearing Books,' and the numerous computations are classified and filed in numerical order. Every constituent triangle of the Principal, Secondary and Minor triangulation is numbered and its sides and angles are recorded in a special series of Abstracts. All the records are fully cross-referenced and an alphabetical Card Index gives complete references for every Trig. Point. Finally a set of 1 mile to an inch diagrams, corresponding with the Topographical Maps, shews all Conformal Points and all lines whose lengths and bearings are on record.
The most important record, that is, the actual mark on the face of the Earth, has not yet been mentioned. Most of the older points are, or were, holes 'jumped' on rock or large buried stones. At one period circular platforms of concrete or masonry were constructed at the more important points. For Topographical Mapping purposes every Trig. had to be made conspicuous, so the observer's last rite on leaving a point was to put up a pole and build a large pile of stones round it: these piles have frequently been very useful in locating old points. Nowadays the policy is to mark the more important points with brass bolts set with cement in holes in live rock or large buried stones, and to mark less important points by the holes without the bolts.

A very necessary part of the trigonometrical records is the series of files of Descriptions of Points. In former days descriptions were generally written on the observation sheets, but we now have printed forms on which full information regarding the nature of the centre-mark, dimensions of the pile and signal, nature of the surrounding land, visibility, best method of approach, etc., are entered.

As regards the existence and permanence of the centre-marks, the list of points known to be lost contains only a score or so of names. This however refers only to points whose loss has been discovered incidentally during the last few years, as there has never been any systematic inspection of Trig. Points. The very inaccessibility of some of the more important points is excellent protection, and the policy of making centre-marks simple and inconspicuous has undoubtedly helped in their preservation. A question which has given rise to much thought and discussion at various times is that of Reservations for Trig. Points. It seems that the root of the trouble is the impossibility of framing a definition which will be applicable in all practical cases. To ensure visibility it is necessary to retain control of all land round the point within, say, 60 ft. elevation; but such a reservation would be, in many cases, ridiculously large. And the problem is further complicated by the cold fact that many of our important Trigs. are on land over which the Crown has no control, short of acquisition. On the other hand it is
debatably whether it is really necessary to preserve any but the most prominent points in an area which has been completely surveyed. The policy at present is to demarcate reservations where possible, for the more important points.

8. CONCLUSION

Ceylon has a system of triangulation covering the whole Island. There are over 1,600 points but they are by no means evenly distributed. In some parts, notably those which have been Block Surveyed, Trigs. are 2 or 3 miles apart, but in remote districts they may be 20 miles apart. The Latitude, Longitude and True Bearings at all Principal and Secondary points have been computed. Rectangular Co-ordinates and Grid Bearings based on the Transverse Mercator Projection, which is of course a 'conformal' or 'orthomorphic' Projection, have been computed for all points. Bearings are generally given to the nearest second, measured from North through East; Co-ordinates are in chains (of 100 links) to the nearest 0.001 chain with Pidurutalagala Trig. as origin.

As regards accuracy, it is obvious that the triangulation cannot be classed as "Geodetic," but it is accurate enough to control surveys done on normal cadastral scales. That is all that is required in Ceylon, for our isolated position relieves us of any problems of fitting our surveys with those of adjoining countries.

Small schemes of Minor triangulation are added from time to time, in the course of Departmental activities. In 1935, which was a comparatively busy year for the triangulation staff, 86 new points were fixed. The instruments now used are 5 inch or 6 inch Micrometer Theodolites. From time to time angles which were originally observed with the old vernier theodolites are re-observed and, although the differences are often quite appreciable they are never serious: we therefore feel confidently that the whole of the triangulation is of sufficient accuracy to control the work of the Survey Department. Most of our work is based on traverses which have to misclose by less than 3 links per square root mile, and there has never been any difficulty in fitting our traverses on to the Conformal Triangulation.
CEYLON

PRINCIPAL TRIANGULATION
FIXATION DIAGRAM

Scale of 25 Miles to an Inch

Showing the observations used,
and the division into Figures.