Survey of India Department.

PROFESSIONAL PAPER—No. 3.

METHOD OF MEASURING

GEODETIC BASES

BY MEANS OF

COLBY'S COMPENSATED BARS.

COMPILED BY

LIEUTENANT H. Mc C. COWIE, R.E.,

PREPARED UNDER THE DIRECTION OF

COLONEL St. G. C. GORE, R.E.,

SURVEYOR GENERAL OF INDIA.

Dehra Dun:

PRINTED AT THE OFFICE OF THE TRIGONOMETRICAL BRANCH, SURVEY OF INDIA.

1900.

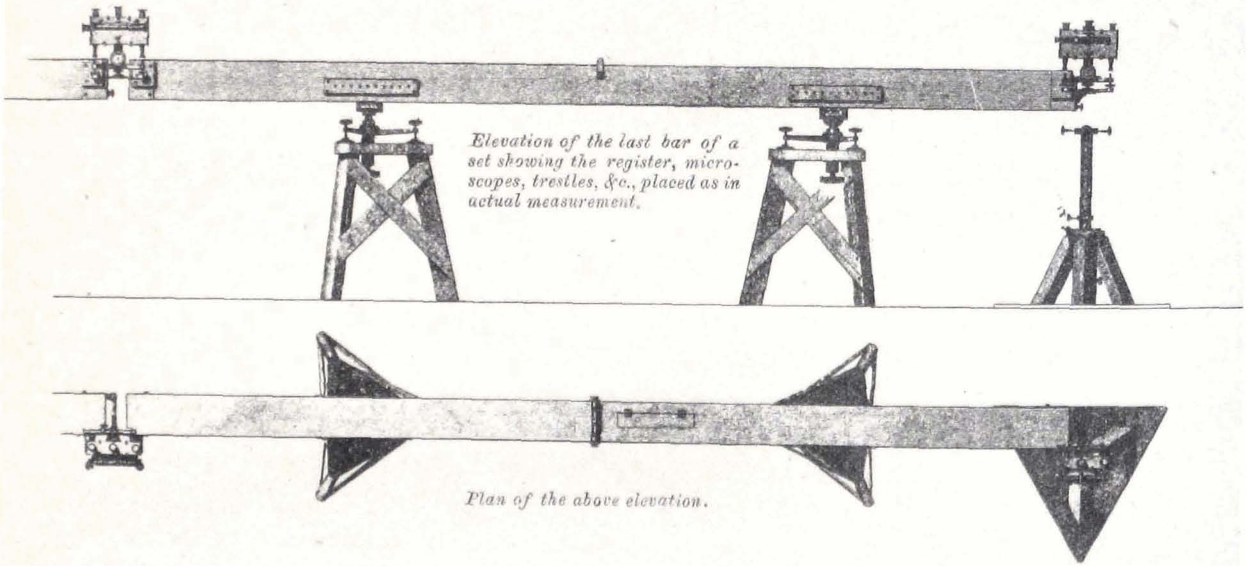

Elevation of the last bar of a set showing the register, microscopes, trestles, &c., placed as in actual measurement.
Plan of the above elevation.

Fig. 1.

METHOD OF MEASURING

GEODETIC BASES

BY MEANS OF COLBY'S COMPENSATED BARS.

Of the processes connected with a trigonometrical survey of a country, the first consists in the measurement of the distance between two points: this distance forms a base, to which the whole extent of country surveyed is to be referred and gives a means of verifying the results of the angular measures.

The measurement of a base though generally undertaken first, need not necessarily precede the angular observations; it can be equally well done after completion of the other portions of the work. The measurement is generally expressed in terms of the standard of length of the country in which the operations are carried on, though the actual measurement, in the first instance, may have been given in terms of some other standard.

The standards used in India are the iron standard bar **A** of 10 feet, and the brass standard bar *A* of 6 inches, both originally the property of the Hon. East India Company.

The method which has been employed at all Base-Line Operations of the Survey of India since 1830, is that originally instituted by Major-General Colby, in which the measurement is performed with an apparatus of compensated bars and microscopes invented by him in 1827. This apparatus is constructed on the principle of eliminating the errors arising from changes of temperature by compensation or self-correction. It consists of a set of six compensated bars and seven microscopes (see fig. 1) and is adapted to measure 63 feet at one time, the length given by each bar being 10 feet, that by each intermediate microscope 6 inches and that by each terminal microscope 3 inches. From the ends of each bar, steel tongues project transversely and have dots marked on them, whose distance apart is the true measuring length of the bar. This distance by the peculiar construction of the bar remains constant for all changes of temperature.

The apparatus is used as follows:—The set of six bars is accurately laid, so that the compensation dots are all in the line to be measured. The bars are not placed in contact nor is the dot at the rear end of the set made to coincide with the point marking the end of the base-line. They are so placed that the dot at the end of one bar is 6 inches from the dot at the end of the next and the dot at the rear end of the set, 3 inches from the terminal point of the base.

The bars having been carefully aligned and levelled, the distances from the dot on one bar to the dot on the next and from the end dot to the terminal point of the base, are accurately measured by means of microscopes. At the forward end, a dot on a slab of iron or stone registers the end of the set. The distance, 3 inches, from the dot at the forward end of the bars to this register dot, is measured by a microscope.

The register having been accurately placed, a record of the measurement is entered in the field book, the set of bars is moved and the measurement continued from the register dot in exactly the same manner as it was commenced from the mark at the end of the base. This process is continued till the measurement closes on the mark at the other end of the base-line.

From the record of the number of sets of bars and the length of the residual small distance, supposing the base not to be an exact number of sets of bars in length, the length of the base can be determined. This residual distance can be measured by means of a scale and a beam compass.

Description of Bars.

The hypothesis on which the construction of the bars is based is as follows:—Let the two lines A B and A′ B′ (see fig. 2) be firmly united at the points A and A′ so as not to admit of longitudinal movement on that side, and let a third line D $p\,p'$ cut these two lines in p and p'. Then if these points p and p' are supposed to move outwards from A and A′ respectively into new positions $p_1\,p'_1$, $p_2\,p'_2$ so that,

$$\frac{p\,p_1}{p'\,p'_1} = \frac{p\,p_2}{p'\,p'_2} = \frac{\mathrm{D}\,p}{\mathrm{D}\,p'},$$

it is manifest that the point D will be a nodal or neutral point, in which all the lines drawn through $p'_1\,p_1$, $p'_2\,p_2$, etc. must meet.

If now A B and A′ B′ are respectively sections in the plane of the paper of bars of iron and brass and if Dp and Dp' are in the ratio of the expansions of these metals (2 : 3 nearly), then as the points p and p' will recede from or approach to A A′ also in that proportion, from the effect of variation of temperature, we have before us the case above mentioned.

But it will be remarked that the same hypothesis requires, when reduced to practice, that if Dpp' be the section of the tongue of metal joining the bars, its expansion must be such that,

$$\frac{\mathrm{D}p_1}{\mathrm{D}p'_1} = \frac{\mathrm{D}p_2}{\mathrm{D}p'_2} = \frac{\mathrm{D}p}{\mathrm{D}p'}.$$

A similar state of things must exist on the other side of AA′, so that if D and D_1 are two dots similarly situated with respect to AA′, but on opposite sides of that line, the distance between them will be invariable and not liable to be affected by changes of temperature.

The practical fulfilment of the above hypothesis is as follows:—Two bars, one of brass and one of hammered iron, each 10·1 feet in length, 0·55 inch in breadth and 1·5 inches in

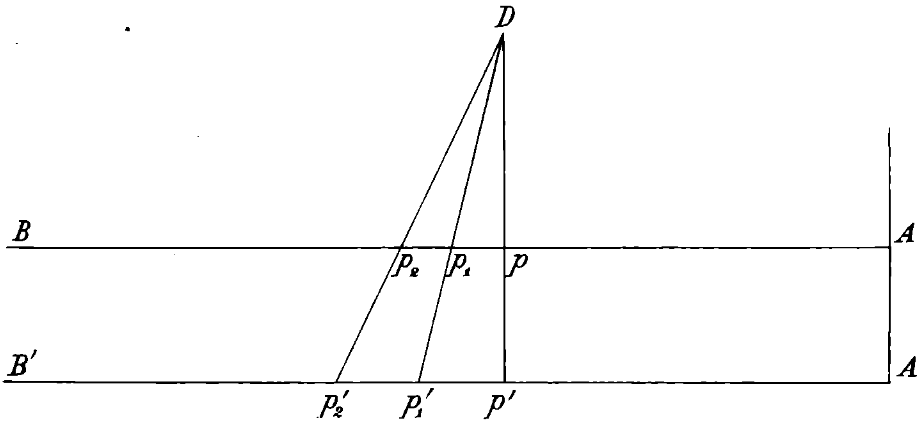


Fig. 2.

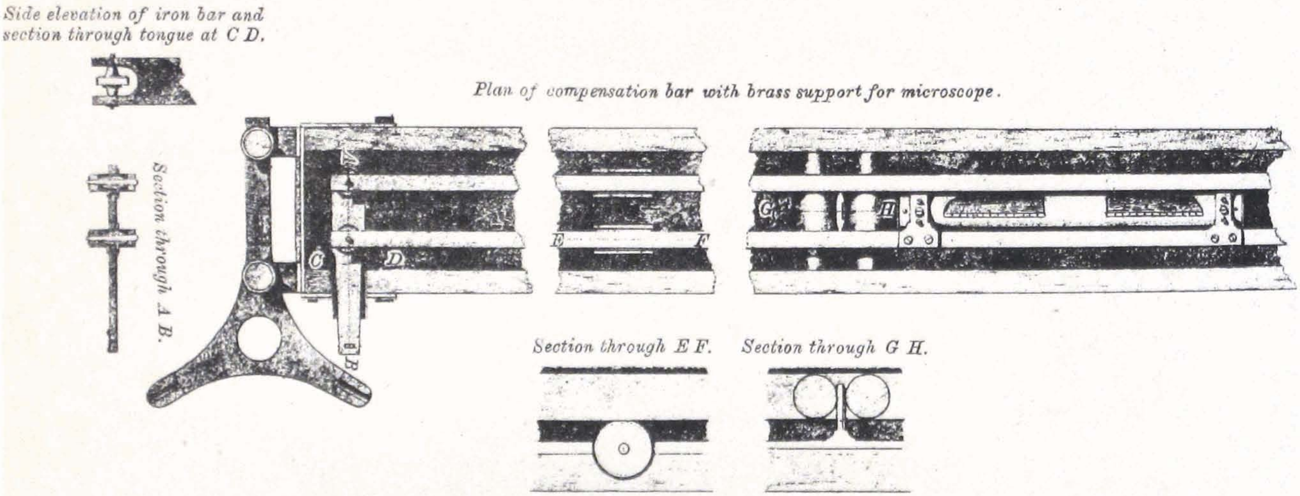

Side elevation of iron bar and
section through tongue at C D.
Plan of compensation bar with brass support for microscope.
Section through A B.
C
D
E
F
G
H
B
Section through E F.
Section through G H.

Fig. 3.

depth nearly, are firmly clamped 1·3 inches apart, at their centres by two transverse steel cylinders so that any expansion arising from change of temperature must have effect towards the extremities (see fig. 3).

At each extremity the bars are connected by a flat iron tongue, one end of which projects horizontally, transversely to the length of the bars. This tongue, 6·3 inches long, 0·25 inches thick and of a breadth tapering from 1·1 inches to 0·6 inches is attached by pivots in such a manner as to permit the bars to expand freely, while the tongue oscillates on the pivots. The attachment of the brass bar is made near the broad end of the tongue, while the narrow end projects to a distance of 3·4 inches beyond the iron bar. The true neutral or compensation point is marked by a small dot on a silver pin near the extremity of each tongue and the distance between these compensation dots is the true measuring length of the bar.

The compound bar thus formed is enclosed in a deal case and each component rests, at one fourth and three fourths of its length, on brass rollers having raised flanges to prevent lateral motion, each revolving on an axis fixed into the deal case. Longitudinal motion of the bar is prevented by a brass stay fixed firmly to the bottom of the box at its centre and projecting upwards between the two steel cylinders by which the bars are rigidly connected at their centres.

At the centre of the bars a spirit level is attached parallel to the direction of the bars and is read through a glass window in the lid of the box.

The tongues at each end project about 2 inches beyond the side of the box next the iron bar, and are protected by brass caps or nozzles provided with sliding pieces which may be turned round, thereby disclosing a circular aperture through which the compensation dots may be viewed.

The box enclosing the bars is also provided with mountings for a pair of cross-levels. It would have been a great improvement if, instead of these levels fitted to the outer case, two small cross-levels had been fixed to the bars themselves at a quarter of the whole length from each extremity and admitting of inspection in the same manner as the longitudinal level.

The bars admit of no adjustment and all that can be done is to ascertain the readings of the two ends of the bubble when the plane passing through the dots is horizontal.

To accomplish this, let the bar be raised to a convenient height, so that the dots may be on a level with the eye of an observer, when looking through the telescope of an instrument which has a motion in azimuth. Level this instrument by means of its own level. To render of no effect any small vertical error in the line of collimation of the telescope and to avoid the necessity of altering the focal length, the point selected for the instrument to stand over should be such as to form an isosceles triangle with those vertically beneath the two compensation dots. With the instrument in this position and duly levelled, let it be directed in its horizontal position first to one dot and then to the other, a minute cone of brass being placed over each dot at the time of observation by way of affording a clearly defined object. The dots by means of vertical screws under each end of the bar, can be raised or lowered till they are in a horizontal position. The level can now be read and its error determined.

Comparison of Bars with a Standard of Length.

The compensation bars are never trusted to retain an invariable length, but are frequently compared with one of the 10-foot Standard Bars, in the process of the measurement of each base line. And this is the more necessary in order to guard against the errors which may have been made in fixing the compensation points, as well as those which may arise from one component acquiring a different temperature from the other, in the course of the diurnal changes of temperature under which the operations are carried on. It is evident that these errors will be eliminated, if the comparisons with the standard are made under precisely the same conditions as those which obtain during the measurement.

The comparisons between the compensation bars and the standard bar are conducted as follows :—On the top of two carefully isolated masonry pillars, about 10 feet apart from centre to centre, two micrometer microscopes are securely placed (see fig. 4). These microscopes are, in the first instance, placed at a distance apart approximately equal to the length of the standard bar.

Between these pillars is a low masonry platform also isolated. On this rests a strong wooden frame, carrying two iron guides placed at right angles to the line joining the centres of the pillars. On these guides, a strong wooden traveller moves on four small rollers. At each end of the traveller next the pillars, are placed two brass carriers termed "camels" (see fig. 4').

On these camels, the cradles of which can be raised or lowered as well as traversed longitudinally and transversely, the standard bar and the bar under comparison are placed, the camels of the latter being raised on blocks of wood $2\frac{3}{4}$ inches high.

The mountings of the microscopes project from the faces of the pillars sufficiently far to allow of the traveller being moved so as to bring the bar, outermost in position, under the microscopes, without the innermost bar being in any way touched or disturbed by the pillar. The innermost bar is usually the standard, the compensation bar being placed outermost on the traveller with the tongues towards the standard. The tangent screw of the compensated bar's camel should be beside that of the standard's camel.

This arrangement admits of the compensation bars being brought under the microscopes in succession and compared against the standard, without having to move this latter or to disturb it in any way after it has once been levelled and brought into focus under the microscopes. The distance apart of the microscopes should be such that the dots on the standard bar come well into the centres of their fields.

Both microscopes are furnished with micrometers and it is convenient to arrange that the zeros of these micrometers are either both inside or both outside the dots on the bar. The computations are thereby simplified in that the micrometer readings are both of the same sign relative to the distance apart of the microscopes.

The micrometer should be so placed with regard to the microscope, that, in bringing the movable wire from the zero up to the dot in the field, the micrometer head shews increasing readings. This condition will be obtained if,

(i) When the dots are in reality both outside the zeros, the micrometer heads of the two microscopes are turned towards one another.

(ii) When the dots are both inside the zeros, the micrometer heads are turned away from one another.

When the movable wire is set at zero, it should be in the vertical axis of the instrument, that is, the line of collimation when the wire is set at zero should be coincident with this axis. To effect this, level the microscope, in every position of the attached level, by means of the capstan-headed screws which take the place of foot-screws and take readings, of the centre of the dot in two positions of the microscope differing by 180° in azimuth. Set the wire at the mean of these readings. Traverse the bar till the dot is again bisected, and then, keeping the wire on the

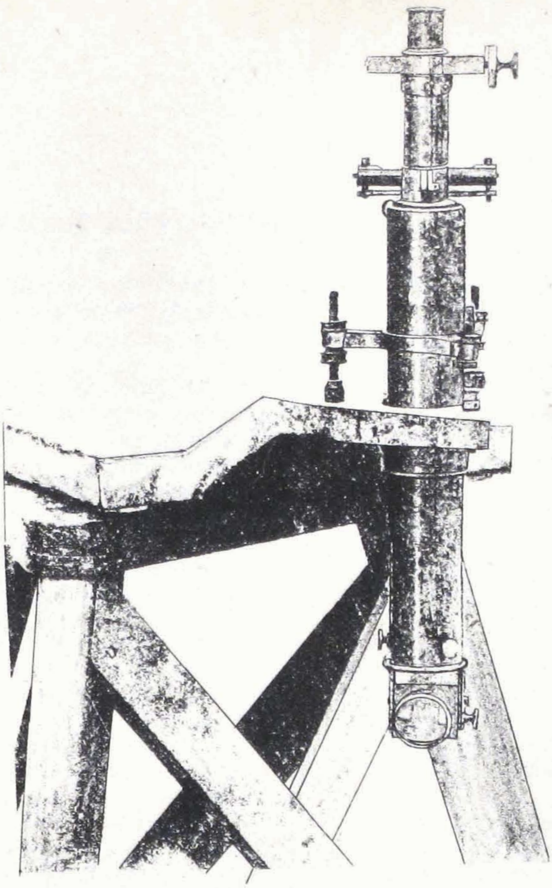


Fig. 4.

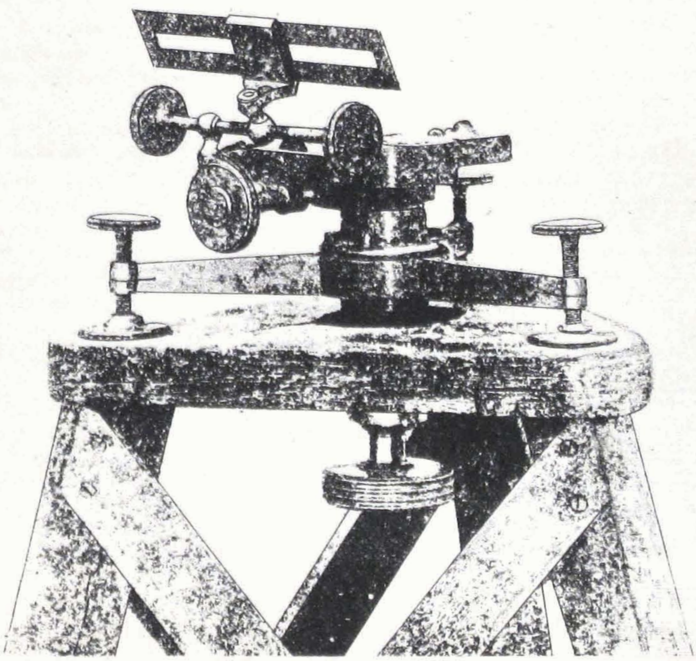


Fig. 4′.

dot, very gently set the micrometer head to read zero and if necessary move the comb by slightly tightening or loosening the screw, at the end of the micrometer box, which holds the comb in place.

The microscopes having been set up firmly in position and adjusted, the micrometer runs should be determined by comparison against two of the $\frac{1}{20}$ inch spaces between the graduations of the standard steel foot **I.F.**, the temperatures at the times of observation being recorded. The readings are corrected to a temperature of 62° F. and from the mean of the results and the known lengths at 62° of the spaces utilized, (given on page 51, Appendices Volume I of the Account of the Operations of the G. T. Survey of India) the value of one division of each micrometer can be determined. After having been placed and adjusted as above and the eye-piece adapted to suit the observer, the microscopes should not be again disturbed, unless the instrument is found to have got out of adjustment. The less handling consistent with correct adjustment the better.

The standard bar should now be placed on its camels, which are of gun metal, and brought under the microscopes. Here it is levelled and the dot at one extremity brought into the focus of the microscope above it, by raising or lowering the bar by means of the camel screws. When the dot is satisfactorily in focus and the bar is at the same time level, the other microscope is then focussed on the dot below it by raising or lowering it, by means of the capstan-headed nuts (see fig. 4).

The approximate heights and distances when the various parts are in their proper relative positions are,—from ground to surface of steel foot 35 inches; from ground to top of box of standard 36½ inches; distance of object-glass collar of H microscope to surface of steel foot 4 inches.

When the microscopes have been brought into position as above, and re-examined for collimation, the first bar to be compared is brought up and placed on the pair of camels outermost on the traveller, the compensation dots being turned towards the standard bar. It is then brought under the microscope by traversing the traveller, and the dots brought into focus by raising or lowering the bar by the camel screws. It will be seen from the previous setting of the microscopes, that the bar will then be level.

The standard bar is adapted to take six thermometers whose bent bulbs fit into small wells sunk in the metal. It is usual, however to make use of two only, one at each end, when carrying out ordinary comparisons with the compensated bars. These thermometers should be placed in position as soon as the standard has been put on the camel, before focussing the microscopes and levelling the bar. One of the compensated bars, B, is also furnished with wells for thermometers, two at each end, one of each pair indicating the temperature of the brass component and the other that of the iron. To allow the thermometers to take up the true temperatures of the metals as nearly as possible, the bulbs in the wells are surrounded by mercury in the case of the iron bar, and by oil in that of the brass bar. The compensated bar, B, should be provided with its thermometers, a sufficiently long time before taking actual comparisons to allow the thermometers to take up the temperatures of the components, completely. The bar should then be placed in a convenient position easy of access, as the thermometers have to be read frequently.

It was decided that the temperature of only one of the compensated bars need be taken, as the results of experiments shewed it to be highly probable, that the materials of which the respective components of the bars were constructed, were very similar; this is borne out by the fact that the hourly variations between the lengths of the compensated bars and the standard, during the course of the daily comparisons, have invariably been found to be much the same for each of the bars. From this similarity of the curves of the hourly excess of each of the bars over the standard it is obvious that any one of them may be taken as a fair representative of the others and bar B was selected for this purpose.

The microscopes, bars and thermometers having all been placed and adjusted, the comparisons are then made as follows:—

The first bar for comparison is placed on the camel. The traveller is run in till the dots come into the fields of the microscopes. By means of the elevating screws of the camels, the bar is raised or lowered till the dots are in good focus. The traveller is again drawn out till the dots of the standard come into view. The bar is then traversed by the traversing screws of the camels over the small amount necessary to bring the defining marks on the silver dots between the two fixed longitudinal wires of the microscopes, these marks being at the same time on the proper side of the micrometer zero point so as to simplify the computations as mentioned on page 6.

The thermometers are then read in the following order:—(i) those in the standard bar, (ii) those in the bar B, (iii) the thermometers freely suspended in air close to the ends of the bars. The time is noted and the micrometer readings of the marks on the dots of the standard bar are taken and recorded. The traveller is then moved over and readings are taken on the compensation dots of the bar under comparison. This bar is then removed and the other bars placed in position and read in succession. The standard is again read and last of all the thermometer readings and the time noted. This completes one set of comparisons and should not take more than 20 minutes. If a longer time is likely to elapse between the beginning and completion of the set the thermometers should be read in the middle.

As many sets of comparisons as possible should be taken. They must be taken both before and after the measurement of the base and if the latter occupies any considerable amount of time, they should also be taken in the middle.

The number of sets taken at Cape Comorin Base-line was as follows:—

before	1st	measurement	33
after	1st	„	39
before	2nd	„	39
after	2nd	„	40
before	3rd	„	40
after	3rd	„	40
before	4th	„	40
after	4th	„	40

Description of Microscopes.

When two or more bars are used contiguously, there will be as has been said, a space of about 6 inches between the forward dot of one bar and the rear dot of the next bar. This distance requires to be measured as accurately as that between the dots of each bar, and the principle of compensation, which has been above described, has here been put into practice.

If two microscopes be united together by two bars a brass one near the eye-end, and an iron one near the object-end, in such a manner that the distances from the external focal points to the two points of fixture may be in the ratio of the expansions of these metals, then the two focal points become neutral points and the length of the imaginary line between them will not be effected by changes of temperature.

The bars uniting the two microscopes are perforated in the middle, and through these perforations and firmly fixed there, passes the tube of an intermediate telescope, the line of collimation of which is unaffected by changes of temperature.

The microscopes, united by the two bars, can revolve on the vertical axis of the central telescope, the male axis being the tube of this telescope and the female axis, a tube attached to a horizontal plate and standing vertically over a tribrach perforated in the middle. The tribrach has three levelling screws and is furnished with adjusting screws giving both longitudinal and lateral movement to the system of microscopes. To the latter and revolving with it, is attached a level parallel to the line joining the foci of the microscopes. On the side opposite to the level, there is fitted a small telescope capable of being turned over in altitude. This also should be parallel to the line joining the foci.

When in use, the levelling screws of the tribrach fit into the V's of a three armed bracket. One arm of the latter is longer than the others, and by this it is attached by screws to a brass plate on the end of the box enclosing the compensated bar. The attaching screws work through slots in the arm so as to allow of a small lateral movement of the bracket if required.

Each microscope is furnished with a brass scale fitted to a base-board. On the scale there are two small silver dots whose distance apart is approximately 6 inches at 62° F. the true value being given at page (32) of Volume I of the Account of the Operations of the G. T. Survey. Close to each dot is fixed a small brass pyramid for aligning the dots as will be explained later. A thermometer can be attached to the brass scale, to determine the temperature of the metal, for computing the distance between the dots at the time of observation At one end of the scale there is a micrometer screw, carrying a small plate. This latter has a circular aperture furnished with cross wires protected by a thin lamina of mica. These cross wires can be made to intersect the dot when the micrometer screw is nearly at the centre of its run. Down the inner sides of the brass pyramids there is a black line, which when the pyramids are attached to the scale, should be carefully made to coincide with the line joining the dots.

Adjustment of the Microscopes.

The several adjustments of the microscopes are :—

(1.) Adjusting the microscopes over the dots of the brass scale.

(2.) Adjusting the level.

(3.) Adjusting the telescope to move in a vertical plane.

(4.) Adjusting the telescope to move in a plane parallel to the line joining the dots of the scale.

The first and second are done as follows :—Level and cross level the brass-scale on its board by means of the two elevating screws at one end of the latter. Place the system of microscopes in position over the brass bar. Bring one microscope over a dot and examine the other dot through the other microscope. If the latter dot is not approximately in the centre of the field, correct the error half by revolving the microscopes about the central axis and half by traversing the whole system laterally.

For this, the dots need not be in good focus as this adjustment is only a very rough one. This method may fail to adjust the microscopes in the case when M C M′ are not in the same straight line, M and M′ being the horizontal projections of the lines of collimation of the microscopes, C that of the central axis of rotation and *a* and *b*, the dots on the scale.

In the position shown in fig. 5 both dots *a* and *b*, are bisected by M and M′, but when the system is revolved till M is over *b* as shown in fig. 5′, M′ is found to be in error.

Correct this by moving the wires of both M and M′ over one quarter of the error in the same direction with regard to the line *a b* which will bring M C M′ into one straight line. Then proceed as before, adjusting by the lateral traversing screw and rotating the system, to bring the microscopes approximately into the line of the dots.

.Now focus each microscope on its respective dot by means of the elevating screws of the tribrach using that screw nearest to the microscope in question at the same time manipulating the third screw so that when the microscopes are brought to focus, they may be approximately vertical. When both dots are in satisfactory focus, bring the bubble of the level to the centre of its run by means of the elevating screws of the base board. Revolve the system of microscopes 180° in azimuth. If the bubble is not now in the centre of its run, adjust the level in the ordinary way, taking care to use the foot-screws of the base board only, and not those of the tribrach.

Now bisect one dot by the longitudinal wire of one microscope, and correct any error in the bisection of the other dot by the wire of the other microscope half by rotating about the central axis and half by traversing as above explained. Continue the process till both dots are satisfactorily bisected by the longitudinal wires of corresponding microscopes.

Next bisect one dot by the transverse wire of the microscope above it and revolve the system about its central axis till the microscope is over the other dot. If the latter is not bisected by the transverse wire, correct the error, half by the collimating screws of the diaphragm and half by traversing the whole system longitudinally. Continue this process till the transverse wire of the microscope bisects both dots when the system is revolved. This is the adjustment for one microscope. To adjust the other, bisect one dot by the wires of the adjusted microscope. If the other dot is not bisected by the transverse wire of the other microscope, correct the error entirely by the collimating screws.

The third adjustment is done as follows:—At a suitable distance from the instrument, say 40 feet, suspend a plummet. Set the side telescope on the lower end of the string of the plumbob, revolve it in altitude and note whether the cross wires remain on the string while doing so. If they do not, correct the error half by the antagonizing screws *p,p* (see fig. 6) and half by revolving the instrument about its central axis. While carrying out this adjustment it is convenient to arrange, that one microscope may be over a dot, the wires correctly bisecting the latter, while the side telescope is on the lower end of the string. By doing so it will be easily ascertained, after revolving the telescope, whether the error is due entirely to the latter or partly to the whole instrument having accidentally revolved slightly in azimuth.

The fourth adjustment is done as follows:—In a suitably long room, set up a theodolite, its line of collimation being approximately perpendicular to two opposite walls. Its position should be such as to allow of the microscope being later on placed more or less half way between the walls. The telescope of the theodolite being adjusted for collimation, fix a mark on one wall reverse the telescope and fix another mark on the opposite wall. By means of the theodolite place the base board of the microscope, with its brass scale, in such a manner that the aligning pyramids of the latter are in the line joining the marks. Level the scale, by means of the two foot-screws of the base board, using the small detached spirit level, belonging to the instrument. Re-examine the alignment of the pyramids and correct if necessary. When this is satisfactory

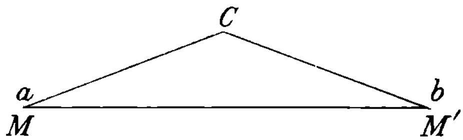


Fig. 5.

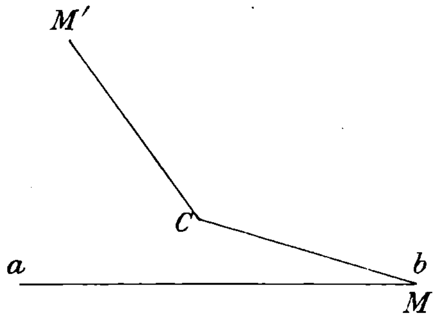


Fig. 5′.

Survey of India.

Please alter the numbering of

Professional Paper—No. 2 of 1902.

"Account of a determination

of the

Coefficients of Expansion

of the wires

of the

Jäderin Base-line Apparatus".

so as to read as follows:—

PROFESSIONAL PAPERS–1902.

SERIAL NO. 6.

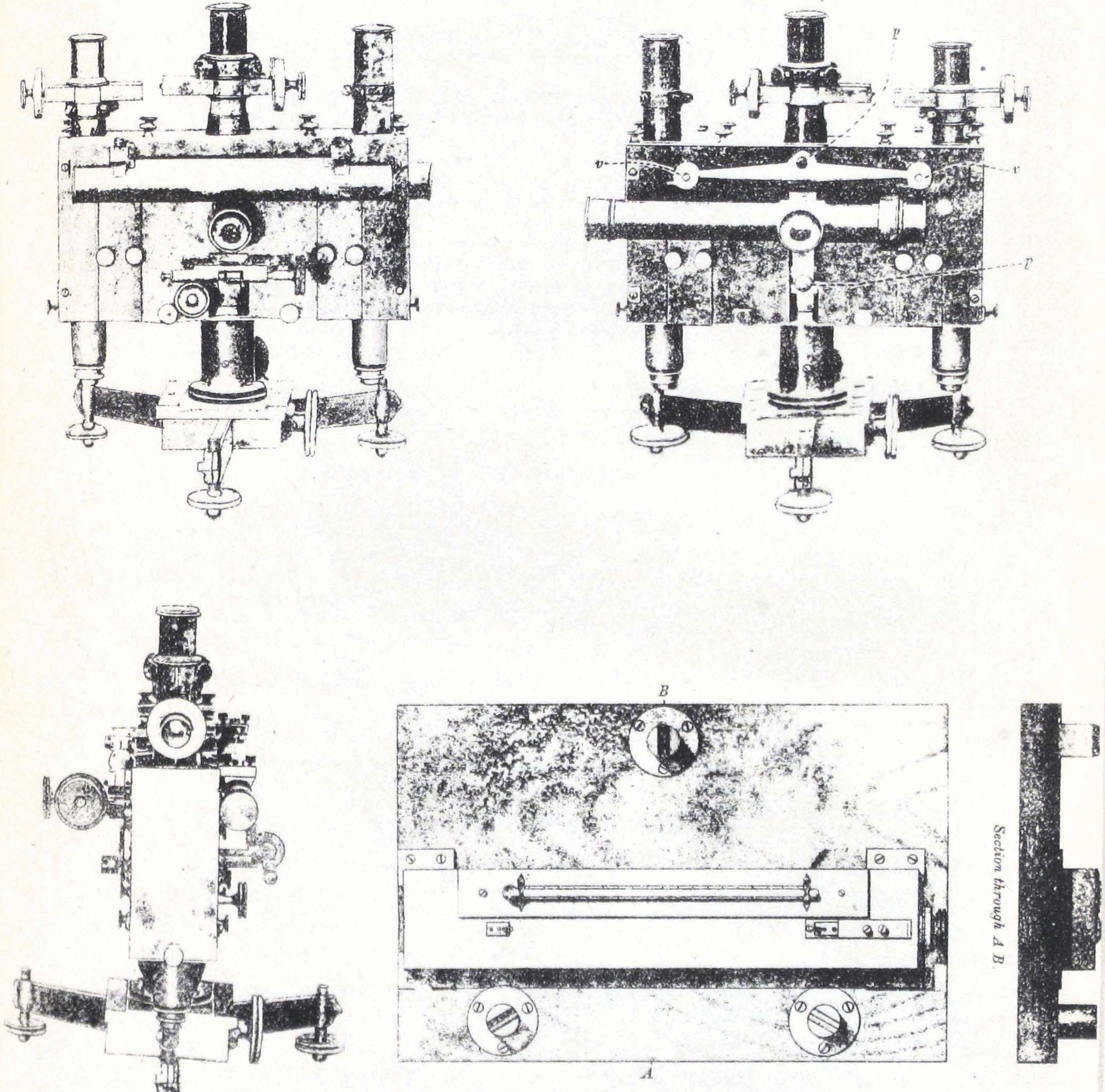


Fig. 6.

and the scale is level, place the microscopes over the latter, focus them on the dots and level the instrument correctly using the foot-screws of the base-board only.

Measure the distance from the line joining the centres of the microscopes to the axis of the side telescope with a pair of dividers. Set off this distance from the marks on the walls, both new marks being towards the same direction. Now rotate the microscopes bringing the side telescope also towards the same direction. Intersect one dot by the cross wires of a microscope and look through the side telescope towards one of the last made marks. If the latter is not bisected by the cross wires, correct the error by means of the screws *v*, *v* (see fig. 6). Now reverse the telescope and see if the mark on the opposite wall is correctly bisected by the wires. If there is any error, correct this time half by the screws *v*, *v* and half by the tightening screws of the collar of the telescope or by the collimation screws according to the pattern of the microscope. Reverse the telescope on the first mark, correct any error in the same way and reverse on the second mark. Continue the process until the adjustment is perfect. Now re-examine the telescope for verticality and re-adjust if necessary. In this adjustment care should be taken to see that one dot is correctly intersected by the wires of the microscope above it during the whole process.

The two adjustments for verticality and for parallelism may be done simultaneously if the marks set out on the walls are given by strings stretched vertically by weights.

Comparisons of Microscopes with their Scales.

The next thing is to compare the distance between the foci of the two microscopes of the instrument with the distance between the two dots on the corresponding brass scale. These comparisons should be made before and after the base measurement and if occasion offers, during the operations as well. The excess or defect longitudinally of each instrument over its scale is noted as well as the temperature at the time of observation; these, with the constant quantities requisite to refer each scale to the standard bar **A**, form a list of corrections for the instruments at the time of making the comparisons.

The procedure in these comparisons should be as follows:—

1. Set the eye-pieces of the microscopes to distinct vision.

2. Level the brass scale, attach the thermometer belonging to it and place the microscope in position over it.

3. Level the microscope and illuminate the dots of the scale.

4. Bring the instrument over the dots by means of the traversing screws moving the system and look at the dot not covered by talc and see if there is any parallax. Fixing the attention on wires, if the dot move with the eye there is distant parallax and the microscope is too high and if the dot move contrary to the eye, there is near parallax and the microscope is too low.

5. Correct for parallax by nearest foot-screw and relevel the instrument by the other foot-screws. Re-examine for parallax and correct till perfect and the level remains true.

6. Intersect dot not covered by talc. Look into the other microscope and see how the dot lies with respect to the wire. The microscope inverts objects and therefore if the dot is apparently inside, the microscope is in defect and if apparently

outside, the microscope is in excess. While looking into the microscope over the micrometer dot, screw the micrometer backwards and forwards and ascertain how the smoothest motion is obtained. When making comparisons adopt this motion.

7. Supposing, by adopting this motion, the cross on the talc arrives first at the microscope wire and then on the dot. Bisect the uncovered dot under the other microscope. Run up the talc cross till it intersects the microscope wire. Read the micrometer and register the reading. Move the microscope bodily to one side by the traversing screw, till a clear view of the dot is obtained. Run up the talc cross till over the centre of the dot and register the reading. Read the thermometer.

8. Suppose on the other hand the talc cross comes over the dot first. Move the microscope till the dot is distinctly seen. Intersect the dot by the talc cross and take the micrometer reading. Intersect the uncovered dot by the wires of the other microscope. Now intersect the wires of the first microscope and take the reading. Read the thermometer.

At least three sets of readings should be taken to form any comparison between the microscopes and their scales.

The Boning Instrument.

In the actual measurement of the base-line an instrument called a Boning Instrument, adjusted in rear of and as near the rear bar as the focal distance will allow, serves to align the whole apparatus. To facilitate this alignment several small sight-vanes or directors are provided with the instrument. These are placed upright in the aperture left for the central telescope of the compound microscope, each of which is in turn brought into its lateral position according to signals given by the man at the boning instrument.

The boning instrument consists of a telescope having a limited motion in altitude, but capable of being revolved in azimuth.

It is mounted on **V's** carried by a frame which can be traversed in guides which are attached to the upper horizontal plate in a direction perpendicular to the axis of the telescope.

The instrument which is provided with a detachable hanging level is levelled by means of the usual three foot-screws.

The adjustments required are (1) for collimation and (2) for the level of the transit axis.

(1) The adjustment is made in the ordinary way but the line of collimation will not remain constant, when the wires are moved by the rack and pinion for change of focus. There is always a certain amount of wobbling motion and a considerable difference will be found if the drawing out and pushing in motion are used indifferently. One motion should be adhered to, and as the alignment proceeds from rear to front, the screwing in motion is the one most generally to be used.

(2) Attach the hanging level to the pivots, and level the instrument by means of the foot-screws Level the transit axis carefully. Read the bubble, reverse the level end for end and read again. Half the difference of the readings is the error to be corrected by the capstan-

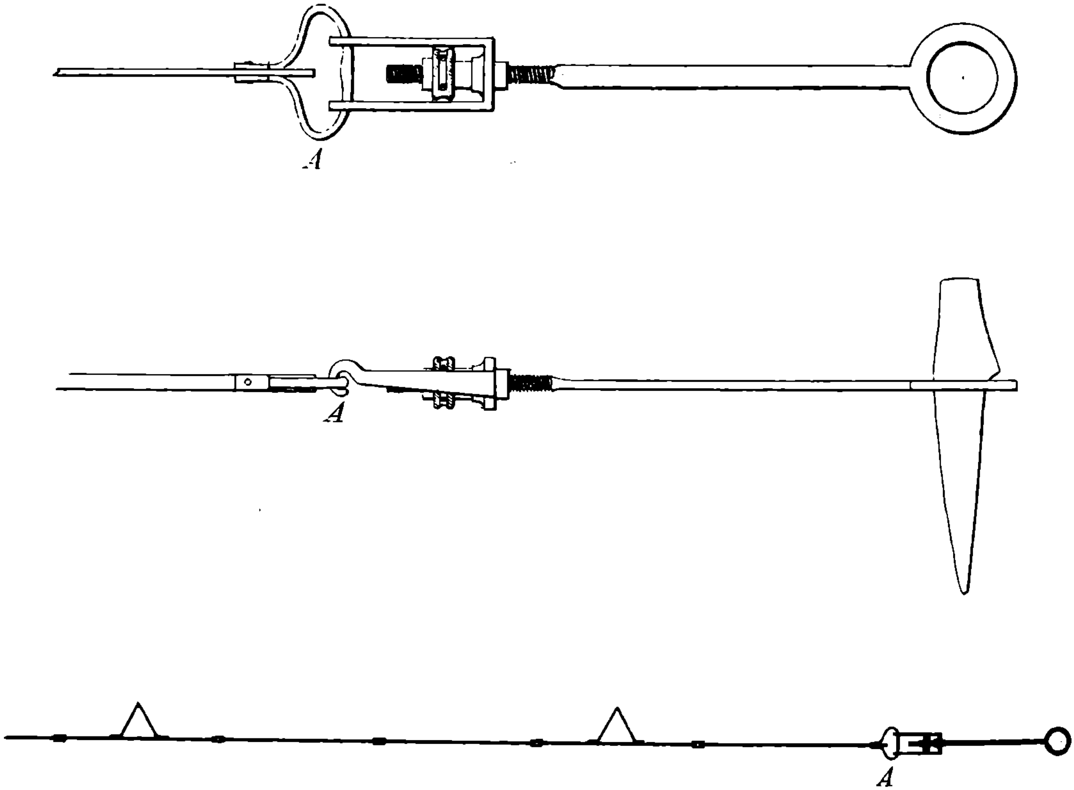


Fig. 7.

headed screw acting on one of the **V**'s. This adjustment should be attended to at every set of bars, but in order to save the screw of the **V** from constant use, the correction when small may be applied by one of the foot-screws, which for this purpose must be placed at right angles to the line. In this adjustment allowance should be made for difference in thickness of the pivots (which formerly caused an error of one division of the level).

To determine the inequality of the pivots in terms of the divisions of the level, read the latter in one position, take it off and reverse the position of the pivots in the **V**'s and replace the level without reversal. Half the difference of the readings is the measure of the inequality of the pivots and that pivot is larger which gives higher readings.

The Chain and Trestles.

For the purpose of placing the trestles, which are to carry the bars, correctly in position, a chain of special type is provided.

This chain (see fig. 7) is constructed from flat bar iron, and from one side triangular frames project whose distances apart are as follows :—

From the end A to the centre of 1st triangle	2 feet	9	inches
From centre of triangle 1 to centre of triangle 2 . . .	5 ,,	0	,,
From centre of triangle 2 to centre of triangle 3 . . .	5 ,,	6	,,

and so on, the distances apart being alternately 5 feet 0 inches and 5 feet 6 inches. The other end of the chain is 2 feet 9 inches from the last triangle.

The distance of the apex of each triangle from the chain proper is 4½ inches approximately. The chain is stretched between two pegs, accurately driven in the line to be measured, the triangles being turned towards that side of the base-line on which the observers will ultimately stand, that is, the side away from the tongues of the bars. Trestles are then placed over the apexes of the triangles by means of a plumb line from the centre of the former.

The bars are placed on the trestles, the centre line of the bar being more or less over the centre of the trestle. Now as the distance of the compensation dot from the centre line of the bar box is approximately 4½ inches, it is evident that when the bar is placed as above it will require only a small amount of lateral traversing, either one way or the other, to bring the dots accurately into the line.

When the chain is laid, the point A is brought by eye over the dot or mark at which the measurement is to commence. The first trestle should be 2 feet 9 inches from this mark when placed correctly over the apex of the first triangle, and the second trestle should be 5 feet 0 inches from the first. This disposition will bring the trestles under the points of support of the bar components, at one quarter and three quarters of their length from one end for, from point of support to end of bar = $\frac{10}{4}$ feet = 2 feet 6 inches and half the end microscope over mark = 3 inches, so that from mark to first support = 2 feet 9 inches.

As the bars are 10 feet and the microscope 6 inches long and the trestles are alternately 5 feet 0 inches and 5 feet 6 inches apart, it is evident that each trestle will be under the point of support of the components of a bar.

The trestles are three legged and strongly cross-braced, having an opening in the centre of the top to admit the elevating screw of the camel.

Procedure during Measurement.

The terminal marks of the base-line having been prepared and the preliminary operations of clearing and preparing the site (see Appendix II) having been completed, sight-vanes or heliotropes are erected, the former every 200 yards and the latter every half mile in the line of the base for the purpose of aligning the boning instrument. These vanes should be fixed at times most favourable for accurate observation—at sunrise or half an hour before sunset. The tents are then erected at the end from which it is proposed to commence operations.

A mark is next selected in prolongation of the base-line and 21 feet from the terminal mark. Over this the boning instrument is centred and levelled and the telescope directed on the nearest sight-vane.

The chain is then extended and laid approximately in position and pegs are driven in correct alignment and in positions, where they can take the ends of the chain. The aligning of the pegs is done by the boning instrument with the help of a plumb line. The chain is then placed on the pegs and the shackles at the extremities screwed up till the chain is tight and the rear end is seen to be over the terminal mark. In placing the chain, the triangular projecting pieces must be turned towards the side of the base-line opposite to that to which the tongues of the bars will point, that is, towards the side on which the observers will stand. By so doing, the body of the chain will be in the line and the apexes of the triangles will give points over which the trestles are to be placed.

The trestles are then brought up and centred over the apexes of the triangles. There are two trestles for each bar, and the pairs should be so placed that one leg of each trestle is in the line joining the apexes of the triangles, these legs being turned towards one another (see fig. 8). This arrangement allows of the traversing screws of the camels, which are to be placed on the trestles, being all on the observers' side of the bars. The trestles are next levelled, each with regard to the one immediately in rear of it, as well as in itself. The trestles should be perfectly secure and firm. To this end and to facilitate levelling, one arrangement is that (see fig. 9) where A is a triangular board of a size that will easily take the feet of the trestles and about ¾ inch thick carried by pegs, driven in position as nearly as possible under where the feet of the trestles will come.

As soon as the trestles for one set of bars have been placed in position, the chain should be carefully withdrawn and stretched in position for the next set, the alignment being given by the boning instrument as before. The trestles for the second set should then be placed and made ready, and the chain again withdrawn and stretched for the third set and a third lot of trestles brought up. There should thus be three sets of trestles in use, one set on which a measurement is actually in process, a second set quite ready to take the camels and a third set in process of being placed and levelled.

By this arrangement, the trestle men will not be in the way of the observers and bar-khalásics, and the chain will not interfere with the placing of the register at the end of the set in measurement.

The trestles being all ready, the camels are placed on them so that their traversing screws are all on the observers' side of the line. The trestles and camels being placed as above, it will be found that the camels having the longitudinal traversing motion will all be at the rear end of

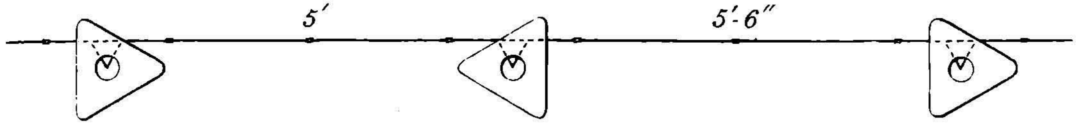


Fig. 8.

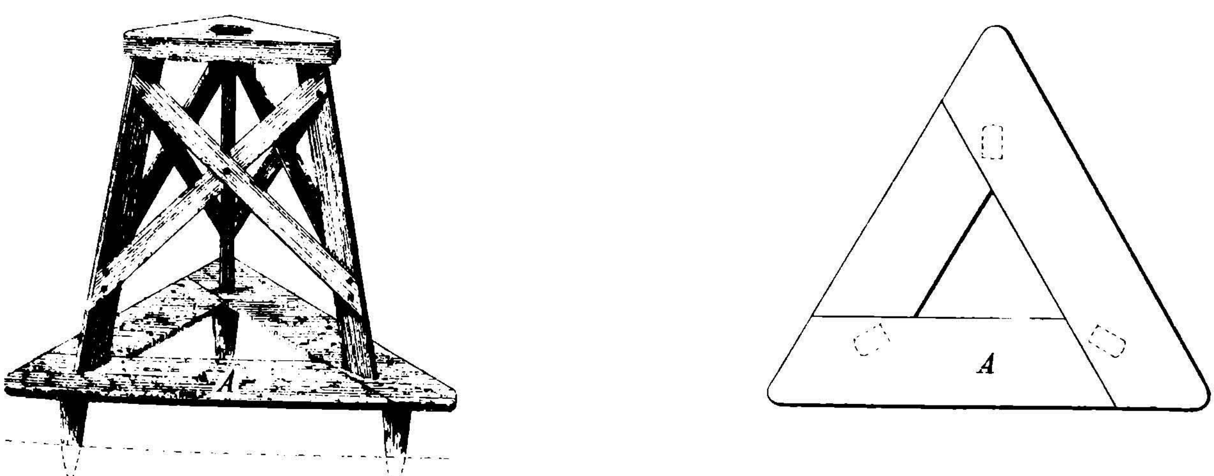


Fig. 9.

each bar. The camels are cross-levelled and levelled and the compensation bars brought up and placed on them. They are all brought up together but are placed in succession from the rear, and in placing them the compensated dots should all be on the side away from the observers.

The wooden protecting pieces having been removed from the ends of the bars, the brackets to carry the microscopes are screwed in place, one to the advanced end of each bar and also one to the rear end of the rear bar. Small reflectors for lighting the dots are next fixed into the brass sockets attached to the bar box close above the tongues.

The microscopes can now be placed on the brackets, each to that bar, to which it has been the custom to attach it. If each instrument is allotted to a particular bar and is used in connection with that bar only throughout the measurement, much time will be saved as, the instrument being in correct adjustment, once the foot-screws have been adjusted to the focus of the microscopes and the level of the instrument, they will require very little manipulation, if any, when replacing the microscopes on a fresh set of bars. When placing V and W microscopes, the two at the extremities of the set, their central look-down telescopes should be fitted with an object glass of a focal length suited to the height of the bar over the register dot.

The rear bar is then levelled longitudinally and one of the microscopes of the instrument at the rear end focussed on the compensation dot of the bar, the instrument being at the same time levelled and cross levelled.

The eye-piece of the look-down telescope having been made to suit the observer, and the telescope focussed on the dot of the terminal mark, the bar is traversed as required till the dot is correctly intersected by the wires. The look-down telescope is provided with a micrometer eye-piece, and in the intersection of the terminal or register dots the movable wire must be brought correctly into the line of collimation of the telescope. To do this, the dot is intersected and the micrometer reading taken; the instrument is now revolved through 180° and the dot again intersected, care being taken that the instrument is still level, and the micrometer again read. If the wire is set to the mean reading, it will be in the line of collimation of the telescope as long as the focus is not altered, in which case a fresh determination must be made.

The dot having been thus correctly intersected, a director is placed on the eye-piece of the look-down telescope. The boning instrument, by being revolved in azimuth, is directed on the sight-vane giving the line of measurement, and its horizontal plate clamped. The telescope is then directed towards the director on the rear microscope and if the cross wires do not correctly intersect it they are made to do so by traversing the telescope of the boning instrument perpendicular to its axis. The telescope is again directed on the sight-vane and rotated by the slow motion screw till the wires are correctly on the line. It is again pointed to the director and if there is still any error it is corrected by traversing as before. This process is continued till the cross wires correctly intersect both sight-vane and director. The boning instrument will then be in exact alignment. It is understood that the level of the instrument has been true throughout the adjustment.

As soon as this has been done, the bars are roughly aligned by means of the sights attached to the boxes and then each observer in charge of a microscope, in turn adjusts his instrument approximately beginning from the rear end of the bars. The rear microscope is already in position; the next microscope, that at the advanced end of the rear bar, should be turned till one of the microscopes is over the dot of the rear bar and the instrument manipulated till the dot is in focus and the instrument is level in both directions. The second bar is then traversed till the dot comes under the other side microscope and raised or lowered till this dot comes into focus, the level of the bar being at the same time kept true. This raising or lowering is done by the elevating screws of the camels. The next microscope is then treated in the same way till it is in focus over the dot of the bar to which it is attached, and at the same time, is level. The bar next in advance is then brought up to focus and levelled. In this way each compound microscope is in turn focussed on the dots and levelled and each bar brought into level from rear to front.

The whole apparatus has now to be brought into line. The boning instrument is examined and if still in correct alignment, the director is placed successively on the central look-down telescope of each instrument, which must be brought into correct alignment by traversing the bar carrying the microscope, by means of the camel screws. By this traversing of the advanced end of each bar, the dot at the rear end will be moved away from under the microscope above it. The observer in charge of this latter must correct this from time to time by traversing his end of the bar one turn of his traversing screw for every three turns given at the advanced end. Each instrument is thus aligned in turn. Each microscope is now in focus over the dots and level; the bars are likewise level and the whole is in approximate alignment.

The first alignment being thus completed, the man at the boning instrument should re-examine all the adjustments of his instrument and prepare for a second accurate alignment. The microscopes are examined in turn. The rear microscope is corrected if necessary till the wire of the microscope correctly bisects the rear dot of the rear bar, the level of the instrument being true. The observer next looks through the side telescope of the instrument and if its cross wires do not intersect the white line marked on the frame called "horns", attached to the boning instrument, he makes them do so, by revolving the instrument about its central axis. This will throw the microscope off the compensated dot and it is brought back again by traversing the instrument by means of its own screw. The white line on the horn is again examined through the side telescope, and any error in intersection by the cross wires is again corrected by revolving the compound microscope. The microscope is again brought over the dot by traversing. This process is repeated until the dot is bisected by the microscope wires and at the same time, the white line on the horn is intersected by the wires of the side telescope. The bar is then traversed as required till the terminal mark is correctly bisected by the wire of the look-down telescope.

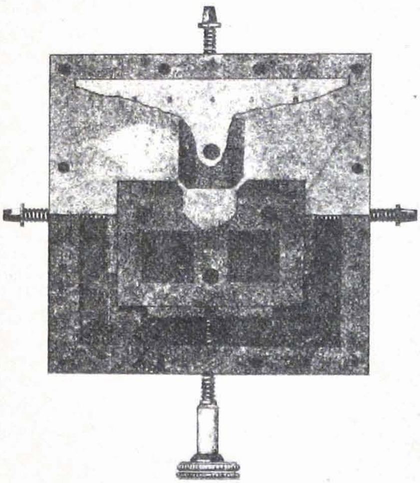
The next microscope is then taken in hand. The compensated dot at the advanced end of the rear bar is bisected by the microscope and the side telescope directed towards the horn. If the intersection is not correct then by repeated approximations, as in the case of the first instrument, the compensated dot is bisected by the microscope, while the side telescope is on the white line of the horn.

If the line of collimation of that telescope is parallel, as it should be, to the plane passing through the focal points of the microscopes, it is evident that with the central look-down telescope in alignment, with the advanced dot of the rear bar under one microscope, and the side telescope aligned on the white line on the horn, the rear dot of the advanced bar, to occupy its correct position, has only to be brought under the other microscope. The next bar in succession, is therefore traversed by the camel screw till the dot at its rear end is bisected by the advanced microscope of the instrument. The succeeding microscopes are each in turn treated in the same way, and when all have been so adjusted, the director is again placed over each and they are all correctly aligned by the boning instrument. The latter is then directed on the sight-vane to determine whether the instrument has altered at all during the interim between first and second alignments.

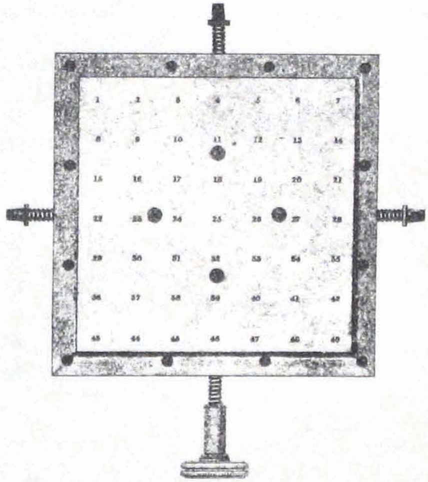
The register is then placed in position under the advanced microscope and the movable plate (see fig. 10) adjusted so as to bring a selected dot on the register head, under the wires of the central look-down telescope.

This having been done, each microscope is examined to see that the dots are correctly bisected by the wires of the microscopes, that the instrument is correctly levelled and that the side

Plan of the register head, parts of the upper surface and of the plate below it being removed.



Plan of the register head upper surface.



Elevation of the register head with part of the iron pin to which it is attached.

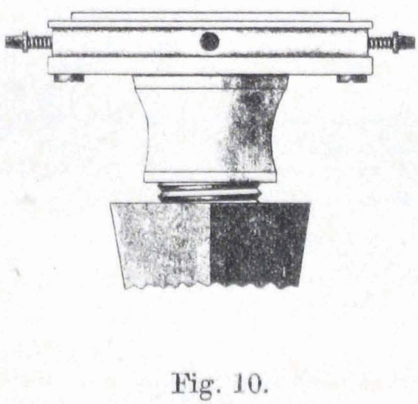


Fig. 10.

telescope is on the white line. If any large corrections are necessary, the alignment should be given once more by the boning instrument. If it is found that all are correct, each observer keeps his attention on his own instrument and each in succession from the rear end of the set says "right". When the word reaches the observer in advance he adjusts the register dot carefully so that it is intersected by the wires of the look-down telescope. He then says "right". The word is once more passed down from rear to front, and if it comes quickly, the set is recorded and the temperatures and the time taken. The temperatures to be recorded are the temperatures of each end of the two components of bar B and the temperature of air.

This having been done, the heights of the rear and advanced compensation dots above the register dots are measured and recorded. This was formerly done by means of an instrument called a "height differimeter" described in the manuscript register of the Chach Base-Line. As its advantages did not compensate for the labour of using it, a steel tape is now used for the purpose.

Preparations are now made for moving the apparatus to measure the next set. The axis of N microscope is perforated to allow of a plumb line being passed through. This microscope is placed at the end of bar D the fourth from the rear, and after the 2nd alignment, it is the duty of the person in charge of it, to fix a mark on the ground vertically below its axis. This mark may conveniently be a disc of lead with a small hole in its centre. Its object is to enable the boning instrument to be set up quickly in the line, approximately, and its use expedites the work considerably. The mark having been fixed, and the bars moved for a fresh set, the boning instrument is brought up and erected over this spot. This arrangement will bring the boning instrument 21 feet from the rear end of the fresh set, the near working limit of the telescope. This distance, 21 feet is made up of two bars, one microscope and two half microscopes.

Moving Bars and Microscopes for a new set.

One set having been measured and recorded, the microscopes are lifted from the brackets, each by the observer concerned.

The bars are then lifted, each by two khalásies told off for the purpose. The bars should be raised in succession from the advanced end, for if all bars were raised at once accidents of one bar knocking against the end of another would be liable to occur.

The bars being raised all the camels are removed each by its own man. These are then taken to the trestles prepared for the new set. The khalásies carrying the camels should not be allowed to alter their order of place, but should always be in the same relative places in the line of camel-men. This guards against the interchange of camels, and consequent loss of time.

The camels are placed on the new set of trestles and at once levelled and cross-levelled by means of their foot-screws. If the trestles are fairly carefully levelled when being put in position, the camels having been levelled on one set, ought to require very little adjustment on the succeeding sets.

When the camels are ready, all the bars are moved forward at the same time and carefully placed on their respective camels. They should be placed in succession from the rear of the set. The bars being placed, the microscopes are put on their brackets and the work of adjusting and aligning proceeds as before, the measurement being taken from the dot on the register placed at the last set and the advanced end of the set marked by a new register.

APPENDIX I.

Want of Compensation of Bars.

Colonel Everest, in his work on the Indian Arc has stated that no dependence can be placed on the permanent length of the compensation bars.

It is this uncertainty which renders it necessary, at every base-line, after every march or any change of circumstances, to compare them with the standard. An attentive consideration of a day's comparisons will shew that their length is not constant for a single hour of the day. From sunrise their length first increases a little and then diminishes for a time, although the temperature is increasing. After which they again expand, the temperature still increasing. These variations may be explained almost entirely by the effects of dissimilar radiating powers in the brass and iron components. There is a great difference between the heating and cooling capabilities of brass and iron and this difference prevents the components from having the same temperature for any length of time. The want of identity in temperature of the metals will apparently produce under some circumstances the effects of over-compensation while in other circumstances the bar will appear under-compensated.

The cause of the observed change in length appears to be the difference of temperatures of the two metals, independent altogether of absolute temperature; the alteration in length varying according to the rate at which the temperature of the air is undergoing change. At sunrise, under tents the bars go on cooling for a short time and their apparent length increases. As they begin to acquire heat their length decreases until both bars are uniformly heated—when the length increases until the hottest period of the day, from which time it again begins to decrease as the temperature decreases.

Degree of Accuracy.

The value of G micrometer used for bar comparisons is as follows:—one Division = ·0000415 inches.

Now if repeated intersections be made with the micrometer, the limit of uncertainty with the magnifying power available, will be found to be at least one division. Hence $\frac{1}{25000}$ inch may be assumed to be the limit of appreciable accuracy.

Applying this to the 6-inch scales and microscopes, we find that it may be dislevelled 12′ without appreciably affecting its length.

For,

$$\log 6{\cdot}00000 = 0{\cdot}7781513,$$

$$\log 6{\cdot}00004 = 0{\cdot}7781542,$$

therefore $\log \cos$ (angle of inclination) $= \bar{1}{\cdot}9999971,$

and angle of inclination $= 0^\circ\ 12'\ 36''.$

The microscope may be also out of alignment to the same angular extent, with the same linear results.

The alignment of microscopes is regulated by their side telescopes which are directed on the horns of the boning instrument, which is set up 21 feet behind the rear register and is moved forward after aligning two sets. Hence the distance from the horns to the microscopes varies from 21 feet to 147 feet at which distances 12′ subtend 0·44 and 3·08 inches respectively. These limits are well outside any errors that are likely to arise from the intersections with the side telescopes.

The level attached to a microscope has usually 50 divisions to an inch and these 50 divisions are equal to 80 to 100 seconds of arc. As the instrument can easily be levelled to 2 divisions or say 4″, the error from uncertainty in dislevelment can have no appreciable effect.

Again considering the 10-foot bars,

$$\log 120{\cdot}00000 = 2{\cdot}0791812,$$

$$\log 120{\cdot}00004 = 2{\cdot}0791813,$$

therefore $\log \cos$ (angle of inclination) $= \bar{1}{\cdot}9999999,$

and angle of inclination $= 0^\circ\ 2'.$

Hence if a 10-foot bar was dislevelled 2′ the error would not appreciably affect the horizontal linear value, and as 2′ is equal to 36 divisions nearly in most of the bar levels, an error of 2 or 3 divisions is of little consequence.

With regard, however, to the effect produced by an error of verticality in the look-down telescope, accuracy of levelling is much more important because the linear error varies as the distance of the dot from the microscope. The magnifying power of the telescope also diminishes as the distance increases. The object-glasses of the look-down telescope range from 4 inches to 22 feet 2 inches in focal length. Since 1 division = 2″ nearly, and 1″ subtends ·000058164 inches at a distance of 12 inches, therefore the errors due to bad levelling are as follows :—

with the 4-inch	object-glass	1 division of	level error	. . . . =	·000039 inches.
12	,,	,,	,,	. . . . =	·000116 ,,
24	,,	,,	,,	. . . . =	·000233 ,,

Consequently with a 4-inch object-glass a level error of 2 divisions is appreciable, and with longer focal distance the linear error increases, while the difficulty of levelling also increases and the magnifying power diminishes. Practically $4\frac{1}{2}$-inch or 5-inch object-glasses are most convenient and the end microscopes should have the best levels attached to them.

The standard bar is perforated over each roller for the reception of the bent bulb thermometers. It was found when experiments for factors of expansion were made, that it was necessary to fill up these cavities with mercury to ensure quick conduction between the bar and the thermometer bulb. The double microscopes are adjusted by reference to brass scales, the temperature of which is given by thermometers in contact with those scales. In consequence, however, of the material being brass, mercury cannot be employed.

To ascertain the probable amount of error from this defect, a supplemental piece of brass of the same scantling as the scales was provided, perforated for the reception of a bent bulb thermometer, the cavity being filled with mercury. The trials made indicated a difference between the readings of the thermometers, under the relative circumstances, of occasionally 2°. Since these trials, this supplemental apparatus was used in conjunction with the scales which were all placed, as far as possible, under similar circumstances.

APPENDIX II.

Instructions for selecting Base-lines and preparing the ground for measurement.

The following conditions must be attended to in choosing a base-line:—

The ground should be flat and free from watercourses, marshes, ravines or other interruptions. As these conditions cannot always be completely satisfied, the flattest and least broken ground the country admits of should be selected.

Provided the slopes be gentle, there is some advantage in placing the ends of a base on ground a little more elevated than the rest of the line, because the view along it will be facilitated, and the ray, being clear of the ground, will give better angles. The station marks will also be more secure from inundation.

For the same reasons the intermediate stations, by which the line is to be subdivided into sections for the purpose of verifying the measurement, may also advantageously be placed on ground slightly elevated, provided the view from end to end be not interrupted thereby.

Thus the best configuration for a base in four sections would be like that in Fig. 11, which would give easy surface for measurement and at the same time facilitate vision of signals.

Level ground has become a more important desideratum since the introduction of the compensation apparatus, for in the old chain measurements hypothenuses could be measured with facility, but the compensation bars must be laid level, and a change of elevation can only be effected by successive steps, see Fig. 12.

At each change of level, one or other of the end microscopes will obviously stand at an increased elevation above the Register Mark, whereby magnifying power will be lost at that end. Moreover, as in the practical manipulation of the microscopes, some residual level error always remains, the angular deviation, therefrom arising, will subtend a larger linear quantity in proportion to the distance*. Thus an angular error which might have no sensible effect at a focal distance of 4 inches, may produce a considerable discrepancy at 36 inches, the effect being augmented no less than 9 times, while the optical magnifying power will also diminish in the same ratio. For these reasons great changes of level should be avoided.

If, however, the slope be gradual, a considerable difference of level can be surmounted in several steps without much loss of instrumental power. One set measures 63 feet or $\frac{1}{84}$th

---

* *Vide* Appendix I. "Degree of Accuracy".

part of a mile nearly. A difference of 3 inches in the level of the ground, on a distance of 63 feet, would therefore amount to 21 feet per mile, and a gradient of this slope would not sensibly deteriorate the measurement.

As a guide in judging of the practicability of ground, the following statement is given, showing the greatest difference of level in the entire line, as well as in a single set, which occurred at the Bidar Base-line situated in a hilly country and measured with the compensation apparatus. These irregularities of level may be considered as limits which it is desirable to avoid, and which cannot be transgressed without incurring practical difficulties as well as deteriorating the accuracy of the work.

	feet
Extreme difference of level between highest and lowest point of the Bidar Base-line	126·3
Maximum difference in a single set of 6 bars	3·2

The approach to the East End of the Dehra Dún Base was so excessively steep that the apparatus required to be divided into half sets of three bars each, which is disadvantageous.

The bad effect of irregular surface may, however, be slightly diminished by using high trestles in measuring over low ground and low trestles over high ground, and ridges may also be trenched or cut through, if they are not very extensive. Embanking or raising low ground should not be relied on, because made ground is never perfectly steady and takes a long time to consolidate. When a sudden difference of level occurs, it may be advantageously dispersed over several sets by trestles of appropriate height, but in measuring over flat ground, there should be a sufficient number of trestles of standard height to keep the measurement uniform and prevent unnecessary deviation.

The chief obstructions met with in laying out bases are ravines, streams, rocks and marshes, all of which should be avoided. If unavoidable, they must be overcome by suitable contrivances.

Dry ravines may be measured across by successive changes of level with complete or partial sets of bars, but the usual practice is to fill them up by an embankment, 20 feet broad at top, with natural lateral slopes. An earthen work of this kind should be constructed as long as possible before the commencement of the measurement, in order that the earth may become consolidated, and its settlement should further be accelerated by ramming. Finally it will be found advantageous to employ elephants to tread it down.

Turf, being an elastic substance, should not be employed in the construction of an embankment for a base, except for revetting side slopes, for which purpose it is useful. If the ravine contains a turf bottom, it should be pared off before throwing on the earth.

When a ravine is liable to become a channel for rain water, the embankment must be protected from the effects of accumulated water either by turning the channel of drainage in another direction or by leaving a sufficient passage for the current. Similar precautions will be necessary if there be a permanent stream in the ravine.

When the quantity of drainage is trivial, it may be allowed to percolate through the embankment by using large boulders in the foundation, otherwise a water-way may be left open and bridged over with stones or logs of wood. No wooden bridge, however, can be considered sufficiently inelastic for measuring over, unless its span is very narrow and the logs deeply covered with well-consolidated earth. It may sometimes be practicable to overcome the difficulty by leaving a water-way in the embankment to be filled up, a few days before the measurement, with earth rammed hard.

Running streams may be crossed either by regular masonry bridges with embanked approaches, or a supplemental channel may be cut in such wise that, when the measurement has reached the edge of the stream, the water can be diverted into the other channel and the apparatus pass over the dry bed, after which the stream can be turned back into its original course. Colonel Everest adopted this expedient twice at the Dehra Dún Base.

In the case of large rivers which can neither be bridged nor turned in their course, the ground must either be abandoned as impracticable or there must be a break in the line to be filled up by triangulation. This plan is considered by some geodesists a defective arrangement, as it destroys the unity of design. This objection, however, is rather theoretical than practical, but to avoid cavil, an interrupted line should not be resorted to, unless there is no alternative. In general, the best ground for bases will be found in a direction parallel to the course of rivers, in which position they are only liable to interruption from subsidiary transverse drainage.

Marshes should be avoided, because such ground is always yielding or elastic and very inconvenient. When they are unavoidable, an attempt should be made to drain them, but if that is impracticable, the apparatus, both registers and trestles, must be placed on strong pickets or piles driven firmly into the bed of the marsh. Such a proceeding, however, will necessarily be dilatory and inconvenient.

The above description of some of the impediments to measurement, as well as the arrangements usual for surmounting them, will enable a person selecting a base to judge of the practicability of the ground.

A minute examination over a large extent of country is requisite before it can be determined that the best selection has been made. The site of the new Bidar Base, for example, is about 9 miles south of Colonel Lambton's and on the opposite side of the Manjira river. It is more favorable both for measurement and connection, but was only discovered after an exploration occupying a week at least. The ground consisted of long transverse undulations, extending from the foot of the Bidar hills to the Manjira river. In each intervening hollow flowed a stream, of which four had to be crossed, and their beds varied from rocky shallows to deep muddy pools and marshes. The object was to select a line which should cross all the ridges in their lowest parts and all the furrows as high as practicable, so that the deviations from perfect level might be a minimum as far as the nature of the ground permitted. When the position of this line had been approximately established, another week was occupied in shifting the ends, until the trace ran clear of wells (which were numerous) and crossed the streams at hard places favorable to measurement. The latter were bridged by means of boulder embankments covered with earth, and several elephants were employed, a considerable time, in treading down these artificial parts of the line. One marshy part was successfully drained.

Having considered the style of ground suitable for a base, the next condition to be attended to is its symmetrical union with the series of triangulation.

The connection should be as simple and direct as possible, avoiding supplemental stations. The most satisfactory arrangement is when a base enters symmetrically as one of the sides of the regular series of triangles, either as a side of a well-conditioned polygon or quadrilateral. If a direct connection cannot be formed in this manner, supplemental stations must be resorted to, but it is desirable that they should be as few as practicable. For instance, one end of the base may be an extra station, and the other belong to the regular series of triangles. The annexed series of diagrams (Fig. 15), are given as practical examples of the actual transfers of several bases. Other arrangements will readily suggest themselves according to the character of the country, but the principle must be borne in mind that the connection should be direct and accomplished with the fewest number of stations.

A base-line being generally shorter than the usual sides of great triangles, the length of the lines derived from it should gradually expand in dimensions without violating the rules of symmetry. The transfer point or station forming the first triangle, is usually selected in such wise as to form an isosceles triangle with sides nearly double the length of the base. The angle subtended by the latter will then amount to 30°, which is the minimum admissible, but it is better that this angle should be not much less than 40°.

Scientific men entertain various opinions regarding the proper length for bases. Continental geodesists of the greatest celebrity are in favor of short lines from 1½ to 3 miles in length and have practically carried out this principle in modern operations. English base-lines, on the other hand, have always been of considerable length, varying in fact from 5 to 10 miles. Nothing seems to be gained by very short lines except a trifling saving of time and labour. It is clear that the short bases in fashion on the continent cannot be connected with great triangles without several supplemental stations, which is an evil, because the stations of a series should be as few as possible, and the length of the sides of triangles ought only to be limited by considerations connected with distinct vision of the signals. The chief part of the expense, difficulty and delay, attending the measurement of bases, consists of preparatory arrangements common to short as well as long bases; such as transport of apparatus to the spot, assembly of establishment from distant parts of the country and training them to the duties. The measurement of the first mile always occupies a considerable time, but after facility has been acquired by practice, the work proceeds rapidly at an accelerating rate. After the first two or three miles, the measurement usually proceeds at the rate of 4 days per mile or even less according to the length of daylight available. Two or three additional miles seem therefore to be a matter of small importance, as the time occupied in measurement will not be extended thereby beyond 8 to 12 days.

In India 7 miles is considered an average length of line, and as nothing can be gained by departing from the example of our English predecessors and running after modern continental fashions, it appears desirable that a base should not fall short of 6 miles nor exceed 8 miles. The character of the ground will generally give limits to the length of the base, for it is always difficult to obtain unexceptionable ground averaging 7 miles in length.

If sufficient practicable ground is not available to give an entire or unbroken line, it may be indispensable to resort to a partial system, the base being composed of measured portions and others deduced by triangulation. It has already been remarked that this expedient should never be had recourse to, unless every effort to establish a continuous measurement fails. In such cases, if the line be intersected by a river or other impracticable space, the base may be divided into three or more sections connected by minor triangulation Fig. 13. The 1st and 3rd sections being measured, the central one may be computed from the other two, whereby two values will be obtained and the deduction become verified. It must be admitted that the results given by minor triangulation of the Dehra Dún, Bidar, Sonákhoda and Chach Bases, indicate that the values thus obtained are as trustworthy as the measurement itself. The Lough Foyle Base, measured by the Ordnance Survey of Ireland, was extended by the addition of a portion to one end by means of triangulation, while at Cape Comorin, in Southern India, the central section only was measured with the Colby apparatus and the base extended North and South by triangulation on both flanks.

The line having been chosen and connected according to the principles which have been explained, the following preparatory arrangements require to be made:—

If the great triangulation has been carried up finally to the vicinity of the new base, the length of the latter may be deduced in terms of the linear value brought up by triangulation (which will always be within a small fraction of the truth), and an opportunity will thus be given for limiting the length of the line so as to include a definite number of entire sets of the compensation apparatus. That is to say, the base may be made equal to $n \times 63$ feet at the surface of the ground, n being any number fixed on and 63 feet the length of the apparatus. This expedient is not indispensable, although it is convenient. In taking approximate observations for this purpose, if the ground is unsteady, the stand of the theodolite may be placed on pickets firmly driven into the ground. As one end, however, of the base may be considered fixed and the other indeterminate, the platform at the former may be built first and rendered available for the approximate determination.

It is obvious that the intermediate or section stations may likewise be fixed so that each section may consist of a definite number of sets.

If the final triangulation has not been brought up to the new base, or if time will not admit of its length being regulated, the stations may be built and left to settle. In this case, the greatest supplemental quantity to be measured off cannot exceed 63 inches, being the distance from the centre of any one bar to the centre of the adjacent microscope.

It must be understood that in every case a supplemental quantity greater or less according to circumstances but not exceeding 63 inches, will have to be measured off, because it is very improbable that the length of the line will amount to a precise number of complete sets.* Provision must therefore be made for observing the fractional remainder.

The termination of a set is defined by a dot on a register head. The fractional part will therefore be comprised between a dot of this kind and the mark at the end of the base, and it is clear that it may be a quantity either in excess or defect according as the termination of the last set of bars falls beyond or short of the end of the base. It is also obvious that these two marks, *viz.*, the end of the base and the end of the last set of bars, should be on a level or reducible to a level.

The easiest practical way is as follows:—The upper markstone, at the terminal station of the base-line, should have a narrow groove running across it in the direction of the line, into which groove a slip of brass (Fig. 14) must be firmly fixed by lead or type metal or some suitable cement. The mark defining the end of the base will be made on the centre of the upper surface of this brass, which should be filed smooth and level. It will now be clear that, if the termination of a set of bars falls within the limits of this piece of brass, a corresponding dot can be engraved thereon, and the distance between it and the station mark can be measured with a pair of compasses and a scale.

The termination of the last set may, however, fall exterior to the slip of brass, and either short of, or beyond, the station mark. In this case, a small iron pin with a brass head may be driven into the masonry, and brought to an exact level with the station mark. On this brass head a dot can be engraved to define the end of the last set, and the distance between that dot and the station can be measured off by a beam compass and scale. To facilitate the driving of the iron pin or nail, it is necessary that the upper tier of bricks in the platform should not break bond across the line, but a seam of mortar must be left in the direction of the line, into which seam the pin can be securely driven. This can be very easily arranged when building the platform.

If the intermediate or sectional stations are built beforehand, they should be treated precisely in the same manner as the terminal station of the base, provision being made for measuring any supplemental quantity by means of the slip of brass and seam of mortar already described.

The measurement should commence at that end which is most favorable for work. If the

* Unless as at the East End of the Debra Dún Base, which was built after the measurement, the centre of the station being made to correspond with the last plain register.

line runs due east and west*, a commencement may be made at either extremity with equal advantage as regards solar influence, for the tents will remain open to the north, and in the cold weather the line will not be enfiladed by the sun. In this case, the choice of commencement will depend on local circumstances, such as healthiness of the country, dryness of the ground or the direction of the slope, because it is most favorable to commence at the lowest end to give the leading microscope the advantage of short focal lengths in viewing the registers.

On the other hand, when the direction of the base declines from east and west, it is considered most favorable to begin at the southern extremity, because the boning instruments will not then be enfiladed by the sun. If the south end is also the lowest and all other circumstances are favorable, there can be no question of the advantage of beginning at that end.

When it is decided from which end the measurement is to commence, that end can be marked by a platform and dot without any provision for marking the termination of the last set of bars.

The platforms which mark the ends of a base, as well as its section stations, should be as low as may be consistent with other considerations necessary to be attended to, because any extra elevation would only augment the natural inequality of level. Platforms 18 inches high are generally sufficient. In this case, if the rear bar be placed on trestles 6 inches high, the advanced bar will require trestles of 24 inches, which is about the usual height of trestles employed on level ground. When circumstances require that the platform should exceed 18 inches, the difference of level may be provided for and dispersed over three or more sets by trestles of suitable height. In the plains, however, towers will be required at the ends of a base, to connect with the triangulation, as at the Calcutta and Sonákhoda Base-lines (Fig. 15). When towers are used, they must have a vaulted passage† corresponding to the direction of the base, so as to admit of the apparatus being brought up to the basement mark. This mark can be placed at the ordinary height of a platform, that is to say, 18 to 24 inches or as much higher as may be necessary to protect it from inundation.

The lower mark should always be let into the rock *in sitû*, or, if there be no rock, the soil must be excavated to a sufficient depth for good foundation, and a mark-stone buried therein. It is usual to sink a plug of brass or copper into the centre of the upper surface of the stone, on which the ordinary concentric circle, which is the characteristic of the G. T. Survey station, should likewise be carved. In the centre of the metal plug, a small silver or platina wire should be screwed and filed flat. In the centre of this wire, a well-defined dot is to be drilled to mark the station. Over this mark-stone there should be a dry cavity formed by a small earthen pot or bricks, and this cavity will be an appropriate place for any inscription or record‡. The usual pillar and isolating annulus may next be built of the strongest masonry so as to ensure permanency. There ought to be one intermediate mark at least and as many more as the height may indicate to be necessary, and these marks should be of precisely the same character as the lowest one.

The upper mark will also be of the same kind for the first or commencing station, but for the other end, will consist of a silver or platina wire let into the centre of the brass slip, and on this wire the dot will be engraved. The upper marks are further to be protected from injury by a thin plate of brass fixed by two screws and two steady pins. On this plate a coarse dot is to be drilled, for the use of the heliotrope and lampmen, and care must be taken that this mark corresponds with the one below, as well as that all the marks are accurately adjusted to the lowest one.

* A north or south direction is reckoned unfavorable, because, morning and evening, the sun will either shine on the bar or there will be want of light. These evils may be modified by placing the tents at one side during those periods, so as to throw a long shadow over the apparatus.

† The vaulted passage must be closed up with walls of masonry at each end, after the work is done, so as to protect the marks effectually. In the case of simple platforms, the marks should be protected by mounds of earth or piles of stone.

‡ The inscription or record is usually written with Indian ink on parchment placed in a bottle well corked and sealed.

When the section stations are built beforehand, they must be accurately aligned. The boning instrument is the most convenient for this purpose. It is placed in the line 20 feet in rear of one end, and being levelled and adjusted, the telescope is to be directed upon the heliotrope at the other end and clamped in azimuth. It is then brought to view the near mark and adjusted laterally till it is placed truly in the line by successive trials, viewing alternately the further and near ends. The telescope having thus been adjusted to range accurately along the base, it is obvious that an object, placed at an intermediate section station, may be aligned.

The proper object to be used for this purpose is a small referring sight-vane with a heliotrope aperture of ¼ inch. This being brought into line by signals with flags, a picket must be driven nearly flush with the ground, and into the head of this picket, a small wire or nail must be driven to mark the exact position of the line.

When a base is subdivided into three sections by two intermediate stations, each should be aligned from the end of the base nearest to it; but if there be more than two stations, those nearest each end must first be fixed and from them the others successively, care being taken to verify the alignment.

On account of the distance of the section stations and the delicacy aimed at, the operation of alignment can only be satisfactorily performed about 4 o'clock in the afternoon during fine weather. In general, the mark can be satisfactorily fixed by direct observation from the end of the base, but should circumstances prevent it, then one or more intermediate points of alignment may be used.

At the Bidar Base, after the section stations had been established as above described, the Great Theodolite was set up over them to verify and correct the line by angular measurement. No particular advantage was gained by this expedient, and it appeared that direct vision with a powerful telescope is the best means of aligning.

When the boning instrument is not available, the Great Theodolite may be set up over the ends of the base and its telescope used to align the section stations.

The most favorable soil for measurement is a light sandy loam, which, being free from tremor, admits of pins and pickets being driven to a sufficient depth. Clay, being apt to crack in dry weather, cannot be considered immovable. Black cotton soil is so unsteady that pin registers must be used when it occurs, and also pickets for the trestles when needed. Rocky ground is perhaps steadiest of all, but pins cannot be conveniently driven into it. No base has been measured at any time over sand, but it would no doubt be practicable to work over it by the aid of pickets sufficiently long to ensure stability.

When a line has been finally chosen, it must be carefully traced along the ground by pins at short intervals, say 100 yards apart, and a space of 10 feet being marked off on either side by a slight trench, the intermediate ground, 20 feet broad between the lockspit lines, must be cleared of all obstructions. The earth from the trench marks should be cast off the line. Turf must be removed from a space 6 feet broad or 3 feet on each side of the line. All rat holes or other burrowed ground, within the 6 feet space, must be dug up, filled and rammed hard.

The person, who selects the line, should take a sufficient number of elevations to give a rough section of the ground, and the greatest ratio of slope or difference of level should be ascertained as an element for arranging the height of trestles required for the base measurement.

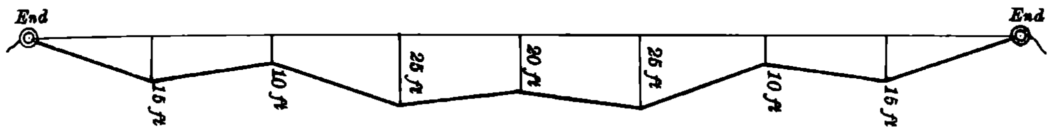


Fig 11

Fig 12

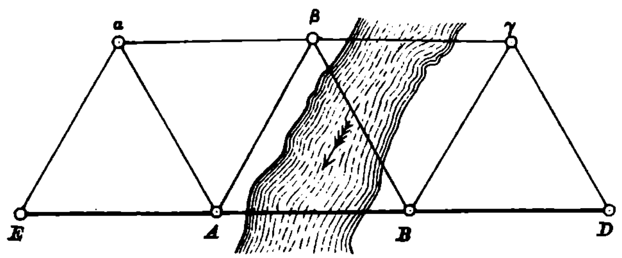


Fig 13

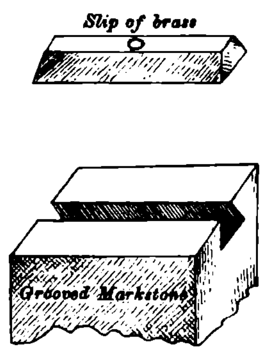


Fig 14

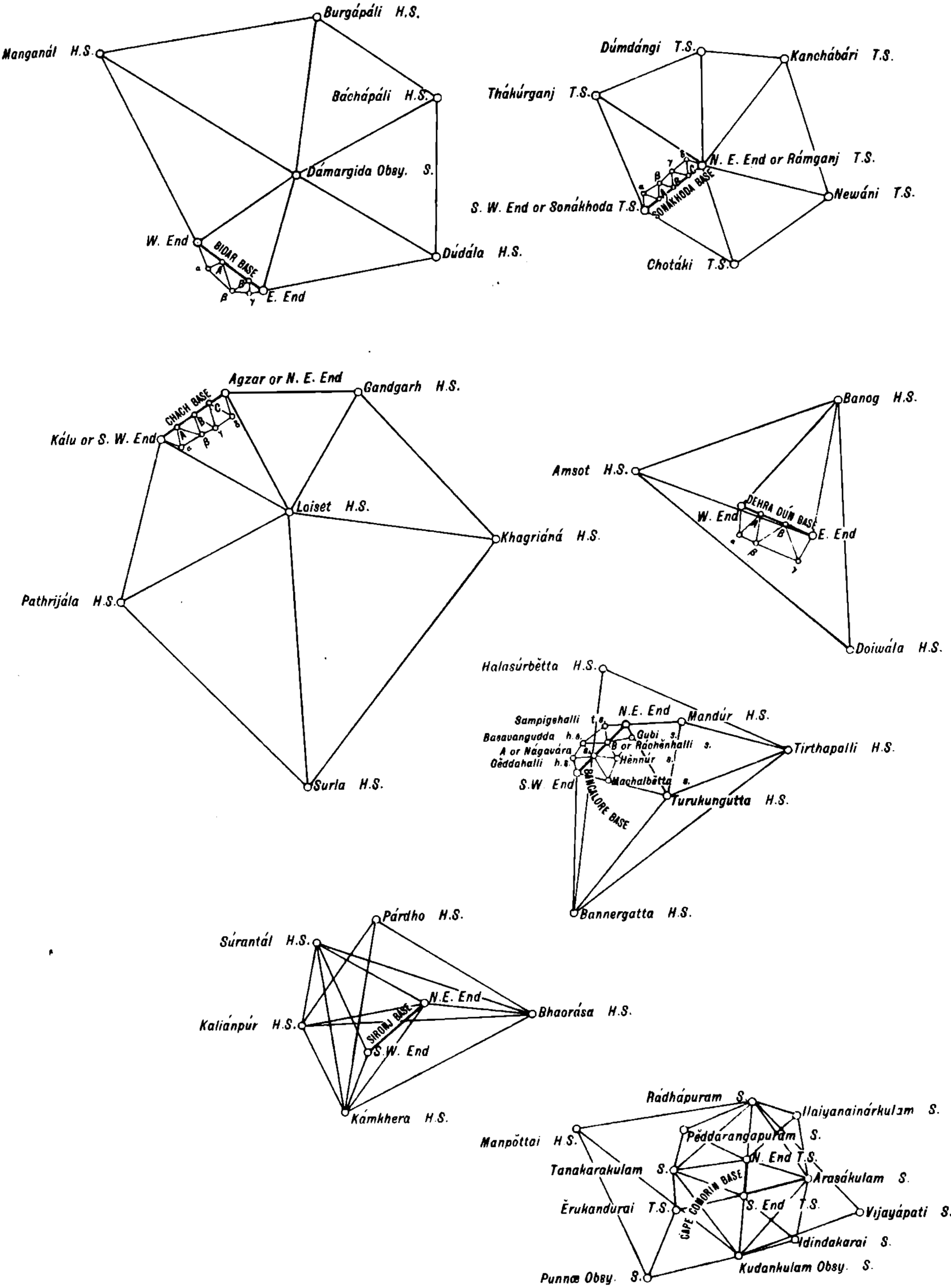
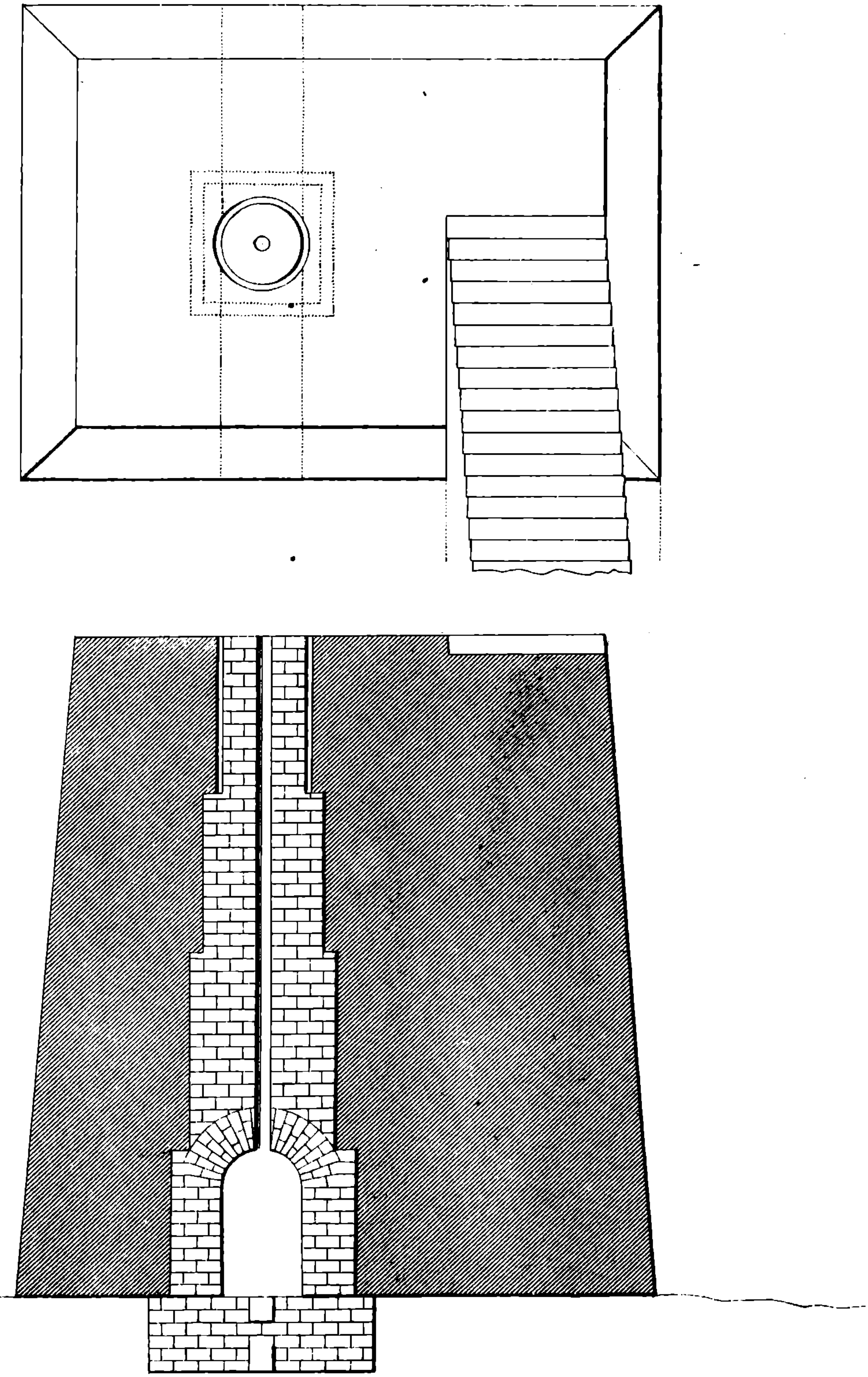

Burgápáli H.S.
Manganál H.S.
Báchápüli H.S.
Dámargida Obsy. S.
W. End
BIDAR BASE
Dúdála H.S.
E. End
Dúmdángi T.S.
Kanchábári T.S.
Thákurganj T.S.
N. E. End or Rámganj T.S.
S. W. End or Sonákhoda T.S.
SONÁKHODA BASE
Newáni T.S.
Chotáki T.S.
Agzar or N. E. End
Gandgarh H.S.
CHACH BASE
Kálu or S. W. End
Loiset H.S.
Khagriáná H.S.
Pathrijála H.S.
Surla H.S.
Banog H.S.
Amsot H.S.
DEHRA DÚN BASE
W. End
E. End
Doiwála H.S.
Halasúrbětta H.S.
Sampigehalli t.s.
N.E. End
Mandúr H.S.
Basavangudda h.s.
Gubi s.
A or Nágavára
B or Ráchěnhalli s.
Gěddahalli h.s.
Hěnnur s.
Tirthapalli H.S.
S.W. End
Machalbětta s.
BANGALORE BASE
Turukungutta H.S.
Bannergatta H.S.
Párdho H.S.
Súrantál H.S.
N.E. End
SIRONJ BASE
Kalianpúr H.S.
Bhaorása H.S.
S.W. End
Kámkhera H.S.
Rádhápuram S.
Ilaiyanainárkulam S.
Pěddárangápuram S.
Manpŏttai H.S.
N. End T.S.
Tanakarakulam S.
CAPE COMORIN BASE
Arasákulam S.
Ěrukandurai T.S.
S. End T.S.
Vijayápati S.
Idindakarai S.
Kudankulam Obsy. S.
Punnæ Obsy. S.

Fig. 15



Scale 6 Feet to 1 Inch.

Fig. 16.