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INSTRUCTIONS

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Topo GRAPHICAL SURVEYING.

BY

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RAL OF INDIA AND SUPERINTENDENT
OF THE
RIGONOMETRICAL SURVEY.

of the Survey Department.

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TOPOGRAPHICAL SURVEYING.

BY

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OF THE

GREAT TRIGONOMETRICAL SURVEY.

For the use of the Survey Department.

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INSTRUCTIONS FOR TOPOGRAPHICAL SURVEYING.

Proposed scope of these instructions.

1. In the Manual of Surveying for India ample instructions have been given for triangulation of the second order, and for detail surveying in general. It is unnecessary, therefore, to repeat here, what has already been completely described; but adopting the rules laid down in the Manual as a basis, it is intended in these instructions to recapitulate, with as much force as practicable, the great leading principles, which must not be departed from in extensive surveys, and to develope the system of internal detail best suited to surveys purely topographical in character.

Objects of a Revenue Survey.

2. The peculiar province of a Revenue Survey being to define boundaries of estates or properties, it is manifest that the principal operations of such a survey must be directed conformably to those boundaries; which require to be ascertained, and marked out before survey operations can commence.

Revenue Survey operations with Topography.

3. When the size of estates to be measured is considerable, as in Bengal, where the circuits are extensive, the operations of the Revenue Survey may obviously be made the basis of topographical delineations, whereby the expense of a separate basis is saved, and the districts can afterwards be incorporated by means of the great triangulation as described in the Manual. But when the size of the properties measured is so inconsiderable, as in the case of the Bombay Revenue Survey, and when they are further not included within principal circuits, those measurements cannot be combined to any extent, without running the risk of accumulating large errors, and therefore they cannot be made a basis for topographical operations, like the Bengal Surveys, in which field measurements, are strictly internal and subsidiary.

Definition of a special Topographical Survey.

4. The term "Topographical Survey" implies the measurement and delineation of the natural features of a country and the works of man thereon, with the object of producing a complete, and sufficiently accurate map. Being free from the trammels of boundaries of properties, the principal lines of operations must conform to the features of the country, and objects to be surveyed.

Orthodox basis for a special Topographical Survey.

5. The only safe basis for topographical operations is beyond all question or dispute a system of accurate triangulation, whereby undue accumulation of error is precluded in the extension of the work, and at the same time limits are set to the intrusion of the error in the internal details.

Brief description of the G. T. Survey of India.

6. The greater the extent of country to be surveyed, the greater will be the risk of accumulating error in the triangulation itself, and hence on account of the immense extent of British India, arises the necessity for superior accuracy in the Great Trigonometrical operations.

7. With the object of reducing the accumulating tendency within narrow limits, the Great Trigonometrical operations are carried on in principal series, proceeding in a straight course from one measured base to another, thus adopting the shortest lines of connection. The lines to which the series conform, are either Meridional or Longitudinal, or approximating to the boundaries of the empire. These principal series are now generally made double throughout, thus affording additional checks at every stage of progress. As their course is straight, and the size of triangles the greatest the country will admit of, without violating the principles of symmetry, it follows that the stations of observation are reduced to the minimum number practically attainable. The greatest care and attention can thus be bestowed (with all due regard to economy) on the few great stations on which accurate continuity depends, and those observations are always taken with instruments of the first order by experienced observers.

Methodical mode of procedure, the most correct as well as the most economical.

8. These principal series are further checked by measured bases, and Azimuths of verification. The accuracy of their sides being thus proved, those lines become fit to verify the next class of operations, viz., the subsidiary Meridional series by which the country is traversed (or intended to be traversed) at every degree of longitude apart.

9. Subservient to these great operations are the secondary and minor triangulations, by which places of major importance are fixed, and great rivers traced out.

10. This brief sketch of the system of the Great Trigonometrical Survey of India, though at first sight, it may appear foreign to the subject of this paper, is nevertheless essential, because those great operations afford the priamry basis for Topographical Surveys, which must either conform to the

great triangulation already executed, or be susceptible of easy incorporation with series hereafter to be carried on. It is indispensable also that the distinction should be fully understood between principal and secondary operations, the former being as rigorously accurate as human means can make them, while the latter being intended for limited purposes cannot, with propriety, be made a basis for extended operations.

Operations of extension are never to be based on secondary Triangles of intersection.

11. In commencing a Topographical Survey of an Indian district or territorial division, it will be generally found that some portion of it has either been traversed by one or more of the great series above described, or some of the great stations will be found sufficiently near to afford a convenient basis for triangulation of extension. These stations furnish at once to the Topographical Surveyor the four initial elements required for commencing a Survey, viz. 1st, a point of departure, the latitude and longitude of which are fixed; 2nd, a linear element or base of ascertained length; 3rd, an initial Azimuth or true direction of the meridian; and 4thly, the height above the sea level. The numerical values of these elements will be supplied on application to the Superintendent G. T. Survey.

Commencement of a Topographical Survey.

Initial elements.

12. As the great stations, however, are too far apart for immediate use in internal operations of detail, the great triangles may conveniently be broken down into smaller ones according to Colonel Everest's Ray trace system described in the Manual.* By means therefore of ray trace triangulation, and secondary points depending on the sides thereof, a sufficient number of fixed stations may be established in the immediate vicinity of the Great Trigonometrical series, and such points of reference should be about 3 to 5 miles apart, according to the nature and value of the ground to be surveyed.†

Internal triangulation

13. But this method is only applicable to ground covered by the great triangulation, or contiguous thereto. For other portions of the district or territory to be surveyed, provision must be made for extending additional large triangulations according to circumstances, viz.

Operations of extension described.

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* Paragraph 3rd, Chap. 20, page. 443.

† In the National Surveys of England, France and Bavaria, the internal triangulation was carried to a greater degree of minuteness than is here contemplated.

14. New points may be selected on the flanks of the great triangulation, so as to form an additional number of large symmetrical triangles, and in this way a breadth of 15 to 30 miles of hilly country may be embraced, or about 7 or 8 miles of flat ground.

15. Such additional triangles must be executed with the same rigorous precaution as in the Trigonometrical Survey. All three angles should be observed with an instrument, not less (if procurable) than 12 inches diameter, which should be duly isolated, and the signals should be luminous.

Extension by net-work.

16. If the space to be triangulated be greater than can be embraced by one set of these flank triangles, it will be proper in a hilly district to extend operations as far as the limits required, by means of a net-work of the largest symmetrical triangles that can be selected. These will arrange themselves into a succession of hexagonal or other polygonal figures, and it is to be remarked, that the care and attention which should be bestowed on this part of the work ought to be strictly proportional to the extent to which the additional triangulation may require to be carried, the main object being to exclude accumulated error in extending the work. Hence the number of times the observations should be repeated, the size of the instruments and every other element of accuracy should be in proportion to the distance to be triangulated. Manual of Surveying, Chap. 16, p. 384.

Extension by Series.

17. In a flat country, however, the method of net-work would be expensive and dilatory, as well as liable to accumulated error. In such if the area to be triangulated is large, it will be proper to carry a boundary series of triangles with sides as large as practicable along the outline of the district and perganas, or such internal boundaries, as are intended to be delineated. Minor series of this class should emanate from a *principal* side of the Great Trigonometrical Survey, and re-enter on another principal side, the former serving the purpose of an initial base, while the latter fulfils the object of verification. One flank of such a series should also conform sufficiently near to the boundary, so that the latter may be susceptible of easy connection therewith, while the course of the series should be as direct as circumstances will admit, because accumulation of error depends *cæteris paribus* on the length of the series, and number of stations employed.

18. It is to be understood, that a minor series of this class, must be conducted with the same rigorous precautions that have already been enjoined in the case of a net-work.

19. If the space included between the bounding minor series and great triangulation exceeds 20 to 25 miles, it may be desirable to break it up into smaller spaces by means of branch minor series, emanating from a principal side of the great triangles, and closing on a side of the bounding series.

Internal triangulation.

20. Having thus covered the whole field of Survey with a net-work of large triangles in the case of hilly country, or with connected series in the case of flat lands, it will remain to interpolate other stations by means of the ray trace system, aided by secondary triangles, whereby the whole country may be covered with fixed points 3 to 5 miles asunder, according to circumstances.

How to proceed when the district has been traversed by more than one Series of the G. T. Survey.

21. It may happen in some instances that a district to be topographically surveyed, may have been traversed by more than one series of the Great Trigonometrical Survey. In such cases, the interval between two series must be filled up, if the country be hilly, with a net-work of large triangles uniting symmetrically with the flank sides of both series; but if the country be flat, minor series should be run across the vacant space, from one Great Trigonometrical series to the other. The ray trace triangulation, before adverted to, will furnish appropriate bases for such minor series to emanate from, and close on.

Methodical arrangement of operations recapitulated.

22. From this description it will be apparent, that the principle necessary to be observed in triangulating a district is to divide the operations into three classes; viz. the 1st class, consisting of large symmetrical triangles of which all the angles are to be observed with peculiar care, as well as with the best means, and it is to be distinctly understood that the advantage aimed at by this class of triangles, is the prevention of accumulated error in extending operations to a distance.

1st Class triangles or operations of extension.

The 2nd class of operations consists of ray trace triangles, by means of which the larger triangles may be symmetrically subdivided into smaller ones. This class of operations is essentially internal, and therefore not productive of accumulated error; nevertheless all three angles should be well measured. The 3rd or last class consists of secondary triangles, whereby conspicuous existing objects or new stations may be fixed by intersections from the stations belonging to the superior classes of work. In fixing a secondary point by intersection, mistakes are liable to be committed, both in recognizing the object under different aspects, as well as

2nd and 3rd Class or internal operations.

Triangles depending on mere intersections liable to error.

ascertaining its name, more especially when the distance is great. Proper precautions must therefore be observed to insure identification in both those respects, and when practicable the same point should be intersected from more than two stations, whereby its position will become verified by common sides. If all due care be taken, these points will be sufficiently well fixed for topographical purposes, but they cannot be permitted to enter into any continued series or system of triangulation, of which the main object is accurate extension.

Triangles of intersection cannot be permitted to enter into operations of extension.

23. In all cases of net-work or triangles which combine into polygonal figures, the computations will not give consistent results, unless all equations of condition appertaining to the figures are previously satisfied according to Colonel Everest's method, described in his work page CXXI. or Professor Galloway's method, vide Royal Astrl. Society's Memoirs, Vol. 15. The calculations for this purpose are, however, so complex and laborious, as to be beyond the means and competence of topographical parties. It will suffice, therefore, for this class of operations to disperse triangular error by distributing 1-3rd of its amount to each angle of the triangle, after which the latter may be computed as plain triangles, and the Arithmetical means of common sides* should be taken for continuing the triangulation. If the observations have been carefully made, the discrepancies in the values of such common sides ought to be extremely small, and therefore of no great importance.

Computation of net-work.

24. Some system, however, must be maintained in the order of computation, otherwise the mean results will vary according to the order in which the computations proceed. The principle to be observed is this; the values given by the Great Trigonometrical Survey are to be taken as fixed quantities, and those sides which are deduced immediately therefrom are considered of next importance, while those which are deduced by the same number of steps from the Great Trigonometrical values, are reckoned of equal weights. Thus supposing in the diagram in the margin that *A B C D* are stations on the flank of a Great Trigonometrical series, the values of those sides are to be taken as unalterable.

Order of computation.

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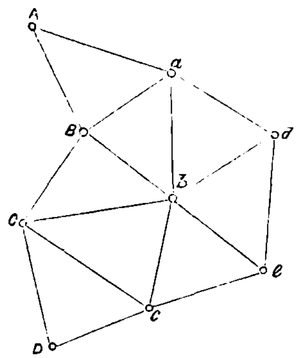
* When several independent values of the same quantity agree very nearly, it is sufficient to take the mean of the Logs of those values to represent the Log of the mean of the natural number answering thereto, but if the differences between the Logs affect more than the 7th place, the mean natural numbers should be used, and its Log taken out independently.

Let *a b c d e* be stations of an extending network. Then the sides *Aa* and *Ba* will be obtained by computing the triangle *ABa*. Similarly, *Bb* and *Cb*, will be derived from triangle *BCb*. But the value of *ab* will differ, according as *Ba* or *Bb* be made the base for computing triangle *Bab*. The values of *Ba* and *Bb* are, however, of equal weight being each derived from the basis by one step of computation. Hence *ab* will have two values of equal weight, the mean whereof should be taken for computing triangle *abd*. Similarly there will be two values of *bc*, and so on generally for all sides of these triangles.



25\. Any large portion of the Earth's surface, such as a district or province cannot, however, be treated as a plain surface. The spheroidal excess of the large triangles will have been dispersed by applying 1-3rd of the triangular error to each angle, which is strictly conformable to Legendre's rule; but with reference to the extension of the triangles over a spheroidal surface, together with the change in Azimuth or inclination of Meridians that takes place, this will be duly provided for by computing the Latitudes, Longitudes and reverse Azimuths, according to the methods explained in chapter 18, of the Manual, Part 3rd.

Spheroidal nature of the earth's surface to be taken into account.

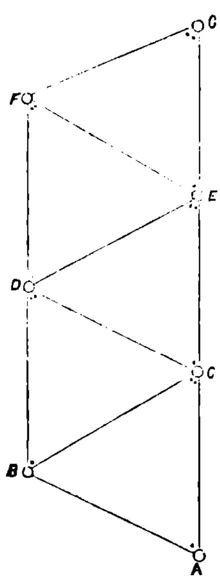
26\. In prosecuting these latter computations, it will be found that the results derived from different sides, will disagree by small quantities in the 2nd and 3rd place of decimals of a second. These discrepancies will be occasioned by the equations of condition not having been previously satisfied. The triangular correction being insufficient in complex figures, and the mean sides not corresponding with the angular elements with Mathematical precision, the figures become more or less dislocated. There is no remedy for this inconsistency, but to satisfy all the Mathematical Equations of condition, by corresponding corrections as has already been remarked. If however, the work has been executed with all due care and with good instruments, the discrepancies in Latitude, Longitude and Azimuth ought to be

Minute discrepancies in the common values of calculated position.

very minute, and barely appreciable.* To enable the Topographical Surveyor to form a proper estimate of the character of his work, discriminating between discrepancies due to want of refinement, and those errors which may arise from mistakes, it is to be remarked that 1″ of a great circle of the earth is very nearly 100 feet, and consequently 1 foot is nearly 0″·01 of Latitude or Longitude in India. The latter quantity would be an error totally inadmissible in great operations, but may be exceeded in subsidiary work, if the common sides differ more than two feet.

Linear discrepancy in verifying a Series, how treated.

27. It has been recommended to adopt minor series in flat countries in preference to net-work. Such minor series emanating from a side of fixed length, and closing on another of the same character, may be expected to exhibit a discrepancy of greater or less amount at the line of junction. Suppose $\delta\ L$ to be the Logarithmic difference on comparing the last computed side, and n to be the number of triangles in the series, then on the hypothesis of a gradual and equal rate of generation of error $\frac{\delta\ L}{n}$ would be a Log correction applicable to each side of continuation successively, and by applying such corrections to each triangle, the discrepancy at the line of junction would disappear; but the sides of the triangles, after being thus altered would not agree with the angles for computation, and therefore, this simple process would not prove satisfactory. To produce consistency between the angles and corrected sides, we may proceed in this manner. In any triangle ABC, appertaining to a series, if AB be the known side, and BC the next side of continuation for the series, then $BC =$ Log AB + Log sin A — Log sin C; but if it be required that Log BC should become Log $BC + x$ then this new value will be equal to the expression Log AB + (Log sin $A + \frac{1}{2} x$)—(Log sin $C — \frac{1}{2} x$). Hence if we take out the Log difference due to 1″ for each of these two angles in every triangle of the series, and call the sum of these Log difference S, then



* Another reason for such discrepancies, particularly in Azimuth, is the omission of spherical excess, in computing secondary triangulation. The angles used in deducing Azimuths should be spheroidal. To obtain these, $\frac{1}{3}$ the spherical excess requires to be added to each angle of a plane triangle. This should not be omitted by a careful computer, even in the case of secondary triangu-ation, when the sides exceed 8 miles.

$\frac{\delta L}{S}$ will be the angular correction in seconds due to each of the two angles of the triangles, which enter into the computation for continuation.

28. If the cumulative correction required at the side of junction be positive, then the angular correction will also be positive to all angles opposite the side of continuation in advance (which angles are marked with a single dot in the diagram), and negative to those angles which may be termed the apices being opposite to the known sides used as bases of calculation. These apical angles are marked with two dots in the diagram. The 3rd angle in every triangle, or that opposite the flank side will not need alteration. After correcting the angles in the foregoing manner, and recomputing the triangles (or correcting the sides in proportion to the angular corrections,) the discrepancy at the line of junction will be found to have disappeared, provided the calculations are carried to an additional figure of logs beyond the usual number of places.*

29. In this way consistency may be produced in the results of a minor series of importance; but it is not in general a matter of rigorous necessity, because the numerical discrepancies likely to occur in calculating Latitudes, Longitudes and reversed Azimuths appertaining to well executed operations, will usually be so minute as to admit of being considered unimportant for topography.

Remarks on the formulæ for computing terrestrial Latitude, Longitude and reverse Azimuths.

30. It is to be understood that our formulæ for computing Latitude, Longitude and reversed Azimuth are approximate, being in fact a series of terms not regularly converging. Of these formulæ, the two first terms only are given in chapter 18, part 3rd of the Manual, the other terms being insensible for short distances. In the principal operations of the Great Trigonometrical Survey, however, the computation is always carried to the 3rd and 4th parts, † and it may be remarked, that in distances of 30 to 40 miles, the 3rd part may amount to half a tenth of a second or thereabouts in Latitude or Longitude, and sometimes nearly as much in Azimuth.

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* Angular corrections of this kind ought to be very minute, and far within the probable errors of observation, otherwise the work is radically bad, and no system of treatment short of actual revision will do any good, vide Manual, page 559 on the subject of limit of error. In 1st class minor triangulation, the error should be less than half a foot per mile, and in secondary operations based on the former or inferior triangulation, one foot per mile or 1-5280th part may be reckoned about the limit.

† Special Tables for facilitating the Great Trigonometrical Survey computations have been printed and are procurable on application to the Surveyor General.

31. The Trigonometrical basis of a Topographical Survey, having been laid out in the manner, which has been here described, and the requisite computations having been effected, the next business is to plot the position of stations (by means of co-ordinates of Latitude and Longitude) on a skeleton chart, whereon the geographical lines have been previously correctly projected according to the rules given in chapter 26, part 3rd of the Manual.

Method of plotting triangulation.

32. The protraction by co-ordinates should then be verified by distances, *i. e.* by the length of sides of triangles, and lastly a comparison should be instituted with the angular readings or bearings in the field books as a check against errors of direction. A further test of the most satisfactory character will be obtained, when the skeleton chart is mounted on the plane table, and the principal stations are visited by the detail Surveyor, who will thus have an opportunity of verifying the accuracy of the plot in a few minutes.

Verification of the plot.

33. The precise part of those objects which have been fixed by intersection, such as temples, buildings, &c. should be briefly, but significantly specified on the chart, to prevent mistakes in identifying the exact points fixed.

Intersected objects to be specifically described on the chart.

34. The next question for consideration is the best method of filling in topographical details. There are three methods of procedure available; 1st, the method of measuring up the minor triangles on the principles of the Ordnance Survey, as described by Captain Frome in his work; 2nd, by traversing from trigonometrical point to point, and taking offsets and intersections; 3rd, by means of the plane table.

Topographical operations, various methods of procedure.

35. The two first methods being purely mechanical in principle, and susceptible of easy check, may readily be carried out by native agency, if it can be procured sufficiently cheap. However, as all surveying comes ultimately to sketching in the ground, provision must be made for performing this part of the duty artistically, unless indeed the contour-system be adopted, by which means the character and configuration of the ground can be accurately delineated mechanically, without the aid of any artistical talent whatever. A contoured Trigonometrical Survey, however, would be extremely costly as well as slow in progress,* for

Mechanical operations.

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* Contouring costs about 40 Rupees per mile, and prolongs the time occupied in completing the maps nearly three fold. The last Parliamentary Report on the Ordnance Survey of Scotland, has pronounced the contouring system unadvisable, on the evidence of the most celebrated Civil and Military Engineers of the day.

which reasons that system of internal survey is hardly applicable to the circumstances of India in the present day, and certainly totally inapplicable to the Native States, or to the mountainous and jungly tracts, belonging to the Government of India. These two classes of country form the only field for surveys purely topographical, all the rich districts coming specially within the scope of the Revenue Survey system.

Plane Table surveys, or the method of the Bavarian cadastre & Madras surveys.

36. An inexpensive and rapidly conducted but perfectly complete survey, is what is urgently required in India, and these objects can most effectually be attained by plane table surveys, based on the trigonometrical operations before described. This method however requires able and practised draftsmen.

Cautions in using the Table.

37. The principle of the plane table is that of trigonometrical intersection, and demands the same caution as has been already enjoined in the case of secondary triangles. Accumulation of error cannot take place in such a survey, as limits have already been set to it, by the fixed points trigonometrically established. The accuracy of the internal detail within these limits, will, on the other hand, depend on the shortness of the distance from which the ground is sketched up, as well as on the care with which points are intersected from the Trigonometrical stations, and the necessary offsets measured up and plotted on the board.

Trigonometrical marks and flag stations.

38. All Trigonometrical stations must first be marked in some conspicuous manner, such as is described in the Manual at pages 393 and 396, and flags or other marks should be planted at those additional points where the table is required to be set up. Such plane table positions being fixed *á priori* from the Trigonometrical stations, render the Surveyor independent of the magnetic needle, in the use of which much caution is requisite on account of hourly variations and liability to disturbing attractions. It is reckoned that the compass may be trusted for distances on the board, less than the needle's length, but not for distances exceeding that length, for obvious reasons. To set up a table at an unfixed station, the needle and two visible fixed stations are the least required, but a careful Surveyor would not be satisfied with less than the needle and three visible stations, which proves the work. To enable this method to be practised on such occasions as it is applicable to, it is necessary at the outset on commencing a new board, to set it up at a great station, and after rectifying and proving its position by observations to the circumjacent great stations, the magnetic compass should be placed on some convenient part of the board. The table being fixed and the needle adjusted to the North mark and standing

quite steady the Surveyor will proceed to draw the outline of the box on the board and to make marks corresponding with those on the box, which may be either circular with 4 marks or square or oblong. The needle should be strongly magnetized and play quite free in the box. Its indications should also be tested by comparison with a standard needle occasionally, or with the true meridian, and if found to differ, and particularly if it hangs back, giving different indications according as the box is turned from the left or right, then the point of suspension will be found to be bent and should be rectified. The other method of interpolating stations is by observations to three known points, a problem equally unsatisfactory in plane tabling as in trigonometry, and which should never be resorted to in accurate surveys. A practical solution of this problem is given in Appendix marked A, but more as a matter of curiosity than utility. All young hands are fond of interpolating stations, but it is an inadmissible principle except for very subsidiary details. The accuracy of the work depends on drawing true rays from the Trigonometrical stations, and by that means fixing a number of plane table stations. This rule cannot be too strongly insisted on.

Advantageous conditions.

39. A hilly country offers the fairest field for the practice of plane table surveys, and the more rugged the surface the greater will be the relative advantages and facilities this system possesses over the methods of actual measurement. On the other hand, in flat lands the plane table works at a disadvantage, while the traverse system is facilitated. Consequently in such tracts, the relative economy of the two systems does not offer so great a contrast as in the former. In closely wooded or jungly tracts, all kinds of survey operations are prosecuted at a disadvantage, but in such localities, the commanding points must be previously cleared for trigonometrical operations, which facilitate the use of the table.

Scale of survey will be ordered by the Surveyor General.

40. On a scale of 1 mile to an inch a district can be completely surveyed by means of the plane table, at a cost of 6 to 8 rupees per square mile, including the expense of minor triangulations. On this scale, all those objects should be delineated which are essential in a map for Political and Military purposes, as well as for those of local improvement.* The scale of 1½ inch per mile is to be resorted to only in very dense jungly countries containing a scanty population and little cultivation, with a dangerous climate, rendering it desirable to accelerate progress.

* This opinion, which I have held for years, is perfectly conformable to the last decision of Parliament on the Ordnance Survey; which decision was based on the evidence of eminent Civil and Military Engineers, whose opinions were taken.

Rate of progress in proportion to scale, and not including field measurements.

41. On the scale of 1 mile per inch a practised draftsman can execute about five square miles per diem, while on the ½ inch scale 16 square miles may be accomplished, in each case supposing the detail to be minutely drawn, and nothing omitted which the scale admits of being represented. Thus on the 1 inch scale, any natural feature, such as a ravine or water-course less than ⅛ of a mile in length, cannot well be shown; and if the country be intricate and full of detail, objects less than ¼ of a mile cannot easily be represented without creating confusion and destroying the unity of the general effect. On the half inch scale, the limits to the power of representation appear to be double the above quantities, between which they will vary according to the nature of the ground. All these rates refer to ground of ordinary character. In easy country, open and nearly level, or hills of simple outline, the work will be done cheaper and faster—but in ravines and intricate ground or hills of irregular formation and difficult to travel over, the cost may be enhanced considerably. It must be recollected, however, that such tracts are generally of little value and do not demand so much precision and minuteness of detail as other valuable lands. In such wild tracts it is sufficient that the character of the ground should be correctly represented and its prominent features distinctly shewn, in which case water-courses of ¼ of a mile would hardly attract attention. If the greatest precision and minuteness is aimed at, none but skilful draftsmen can be expected to survey 5 square miles a day independent of the triangulation which must be previously plotted on the board. The rate of 6 Rupees per square mile, over all, is derived from the Hydrabad survey, but will vary in proportion to the salaries and the number of subordinate Surveyors employed under one Superintendent. Allowance must also be given for the determination of elevations which, if numerous, and extended to all obligatory points for roads, draining and canals as hereafter explained, will considerably enhance the cost.

42. Whether the details be taken up in the first instance on the principle of the plane table, or by traverse operation carefully plotted, the work will have to be mounted on the boards for examination in the field and to enable the configuration of the ground to be sketched up in a characteristic manner.

Delineation of the configuration of the ground.

43. In delineating a corrugated surface, the rule to be attended to, is, first, to draw in carefully, the arterial drainage system or water-courses, constituting the outfall of the country

and next the watersheds or ridges of hills must be traced. * Having thus outlined the highest and lowest levels of the ground, the subordinate features can be put in with great precision, but as these require to be generalized in proportion to the scale, an operation depending entirely on judgment and coup d'œil, a considerable degree of artistic talent and practice is necessary to ensure success. † The outlines of table land should be well defined and ranges of hills pourtrayed with fidelity, carefully representing the water-sheds or divortia aquorum, the spurs, peaks, depressions or saddles, isthmuses or connecting links of separate ranges and other ramifications. The depressed points and isthmuses are particularly valuable as being the sites of ordinary passes or points which new roads should conform to. These are the chief heads to be attended to, as regards physical relief; but the water system or drainage and depressed features, such as ravines, are also of the greatest importance. Every bend or angle of a stream or streamlet should be accurately fixed; whereby a true representation of its course will be given, and not a mere similitude or rough likeness depending on vermicular contortions, with which common Surveys are disfigured, but which are totally unlike nature. The general outlines of ground as defined by ridges, water-courses, and feet of hills must absolutely be fixed by actual survey, otherwise the work would be mere reconnoisance and no two Surveyors working independently would produce the same results. This is the distinction between survey and reconnoisance, the delineation of the Artist being in the first case rendered accurate by the precision with which the outlines are fixed, whereas in reconnoitering, more is trusted to the eye. The rest is a matter of shading, and there are three modes of execution, viz. 1st, by brush shading or general washes, varying in intensity with the steepness of the slopes; 2nd, brush shading relieved by contour touches, sketched on the ground; 3rd, vertical hatching similar to engraving. The last method however, depends on the 2nd, because contour lines must be drawn to regulate the vertical strokes, each row of which should conform to a contour, while the direction of

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* Since the above was written, it has been pointed out to me, that the same rules very nearly are given in the masterly paper on Field Sketching in the Aide Memoire to the Military Sciences, Vol. 2, page 523, published by Weale, viz.

"On whatever scale the subjects of study may be, the master lines of ground are,—

1st. The main or summit ridges of the mountain or hill.
2nd. The water-courses.
3rd. The coast or horizontal contour lines.

The subordinate lines are those more or less oblique contour lines, defining the minor features and generally called feature lines."

The Surveyor is recommended to refer to this admirable paper for further information and illustration of the method of delineating and shading the natural forms of ground.

† Care should be taken to avoid the opposite error of suppressing the minor features entirely: because their omission produces a monotonous effect, nothing helps to work out the main features so characteristic, as a clear representation of minor features within due limits.

each stroke is to indicate with precision the direction of the declivity, otherwise the configuration will not be truly expressed. The object of all shading is to depress the furrows and elevate the ridges or intumescent forms. This can be done with best effect by the 1st method for small scale manuscript maps, such as $\frac{1}{4}$ inch scale geographical maps, et infra : by the 2nd method for 1 inch scale maps, and by the 3rd method for larger scale plans, for which a combination of all three modes is generally necessary to work out the effect, and this also is sometimes necessary for the one inch scale, when the relief requires to be picked out. The hypothesis of vertical illumination is here supposed to regulate the shading, because it is the only method by which relative commands and intensity of slope can be expressed on the usual scales of maps. For plans on large scales, the artistic effect produced by oblique light is an advantage, which is unattainable on the small scales of maps.

Large rivers to be triangulated by minor series with stations on both banks.

44. Large rivers are fit objects for triangulation by minor series, by which means their general directions can be accurately traced. After which their special features can be drawn characteristically, viz. their margins or banks, breadth of water and sands in the dry season ; ferries and fords (with the depth of water thereon to be recorded) and the outline of floods.

Statistics.

45. The one inch scale admits of villages, towns and cities being represented in a general way according to their relative sizes, with the principal streets or roads by which they are intersected, and the outlines of fortifications. The number of houses should be estimated and recorded in the register. To prevent omissions, lists of villages should be obtained in the first instance from the civil authorities and a copy of these lists should afterwards be returned to the same authorities, with the estimated number of houses for examination. Trial should then be made of the number of inhabitants per house in various parts of the district, by which means data will be forthcoming for a tolerable approximate estimate of the population of the district, vide chapter 6, part 4 of the Manual. Whatever be the scale of the Survey, a register is to be kept of the latitude and longitude of every village taken by admeasurement from the map, as soon after the field plot has been made as practicable. By means of these numerical data, the map can always be projected on any scale, and errors arising from shrinking or other alterations in the paper of the original map, will be guarded against. The register also admits of corrections in orthography being introduced into the fair copies, which cannot be done on the original maps without injury to the drawing. Names also can thus be restored if obliterated and omissions be checked. This register will likewise

exhibit the number of houses, and the height above sea level where it has been determined. By this means the importance of the village or town can be duly estimated and the style of printing made to conform thereto. Vide Manual, page 536.

46. On a scale of 1 inch per mile the general figure and extent of cultivation and waste, and forest tracts can be delineated with more or less precision, according to the size of the masses in which these distinctive features occur, distinguishing especially irrigated rice lands which generally display the contours of the ground. The areas of these several portions can be estimated from map measurement, and thus will be obtained further elements for the statistical information required in the chapter last cited. Historical enquiries should also be prosecuted and information collected, regarding the staple agricultural productions, geological formations, mines, and mineral resources, and all other items of interest suitable to a statistical memoir * to accompany the map. In prosecuting such enquiries application should be made to the Civil Authorities to supply information, or verify the researches of the Survey Department.

Orthography.

47. Great care is requisite in the orthography of native names, regarding which the rules of chapter 6, page 629 of the Manual, are to be scrupulously adhered to. In verifying the names of places, assistance may also be expected from the Civil Authorities, and it is to be considered one of the main objects of a Surveyor's duty, that his map should fully satisfy the wants of those authorities.

48. The means of communication, whether by roads or minor tracks are important, both for civil and military purposes, and should be carefully inserted in the map. This can generally be done with facility in a hilly country, as the fixed marks will be visible in sufficient number along the road, so that the latter may be drawn in at once by plane table operations along the line of communication to be surveyed. In flat countries, or where the view is circumscribed, it may be necessary to resort to measurements and plotting, but should any case occur where the fixed points of reference are far apart, the traverse system must be resorted to as described in chapters 14 and 15, part 3rd of the Manual, and the road should be plotted from computed co-ordinates.

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* For heads of this Memoir, vide chapter 6, page 926, Manual of Surveying for India, and also Memorandum (I) Appendix.

49. The supposition has been hitherto made, that before taking up any part of the details, the whole district should be triangulated, the computations effected and the fixed points carefully projected. This principle is undoubtedly correct, but in practice it may be desirable to aim at a division of labor and saving of time by setting the plane tables to work as soon as a sufficient portion of the district has been triangulated, &c. and the points projected on the tables. It is however clearly to be understood, that no detail should be taken in hand until a sufficient number of fixed points have been satisfactorily established, and the whole area to be surveyed should be methodically apportioned into a convenient number of plane table sections, in such wise, that they may readily be incorporated without overlap or hiatus. In arranging this distribution, the whole area of a board should not be considered available, but a margin of 2 or 3 inches or more ought to be left all round for external fixed points, which are required for working upon near the edges of a section, vide Memorandum G.

Order of procedure. Topography not to be commenced until sufficient triangulation has been executed, plotted and projected on the table.

50. It will be indispensable to lay down the boundaries of the principal territorial subdivisions on the map; and to prevent mistakes in defining their limits, every care and precaution, ought to be taken to ascertain them with all due precision, timely application being duly made to the proper authorities on this subject.

Principal territorial boundaries where any doubts exist, to be drawn on a separate chart and referred to the Civil power for orders.

51. The relative heights of hills and depths of villages are facts of importance coming within the scope of a Topographical Survey. These vertical ordinates may be determined geometrically or barometrically, or by a combination of both systems. The Barometer is more especially useful for determining the level of low spots from which the principal Trigonometrical stations happen to be invisible. In using this instrument however in combination with the other operations, the relative differences of heights are to be considered the quantities sought, so that all the results may be referrible to the original Trigonometrical station. The height above the sea level of all points coming under any of the following heads are especially to be determined for the purpose of illustrating the physical relief of the country, viz.

Elevation and depression of ground.

1st. The peaks and highest points of ranges.

2nd. All obligatory points required for Engineering works, such as roads, drainage and irrigation, viz. the highest points or necks of vallies,—the lowest depressions or passes in ranges; the junctions of rivers, and debouchements of rivers from ranges; the height of inundation level at moderate intervals of about three miles apart.

3rd. Principal towns or places of note.

52. The methods of determining heights geometrically has been fully explained in chapter 19, part 3rd of the Manual, and it is only necessary in this place to add, that in using those instruments of the minor class which have two vertical arcs with a pair of Verniers regulated by a level, the observation will be facilitated as well as improved in accuracy by applying a scale to the level. The angular value of the divisions of this scale can be ascertained by experiments with a good instrument, and thus corrections may be applied to the vertical angles for those small deviations in the indications of the level which it is difficult to eliminate practically, but very easy to correct theoretically. The principles of procedure in such cases are very fully explained in the annexed Memoranda marked B and C, but it is utterly impracticable to impart by means of written instructions, a thorough knowledge of the use of instruments and more especially of the vertical apparatus, the principles of which vary in different instruments, and are always more or less complex. For these reasons the Surveyor should learn these parts of his duty practically at head quarters or with the nearest party of the G. T. Survey. Vide additional Memorandum marked H.

Level corrections.

To teach the use of instruments by written instructions, impracticable.

53. To enable a sufficient check to be exercised during the progress of the work, the following returns are required to be periodically forwarded to the Surveyor General of India, viz.

Periodical returns made to the Surveyor General.

1st. A Monthly Progress Report exhibiting the distribution and employment of each Surveyor and the quantity of work executed, whether in field or in office.

2nd. An annual narrative of operations to be sent in on the conclusion of each field season.

3rd. An annual Tabular return of progress and expenses, exhibiting the cost of Survey per square mile.

4th. An annual return of instruments and Government property, specifying the depôt from which received, and date of receipt, as well as their state of efficiency.

54. It is to be distinctly understood that the officer in charge of a Survey is responsible for maintaining the instrumental equipment in efficient order. All requisite repairs are to be made during the recess, and those instruments which require repairs beyond the competence of the Surveyor to execute, should be sent to the Mathematical Instrument Maker's department or to the nearest magazine as circumstances may render advisable, or should be returned into store and replaced by efficient instruments. Timely application must be made to the Surveyor General for orders on this subject.

The officer in charge responsible for the efficiency of instruments and equipments.

55. The mapping must on no account be allowed to fall into arrears. The following plans are therefore to be brought up season by season.

Mapping.

1st. A skeleton chart of triangulation on the one inch scale (scale of survey), for the use of the Surveyor's office.

2nd. A reduced copy of the above on $\frac{1}{4}$ inch scale (4 miles to the inch), for the Surveyor General.

3rd. Plane table sections on the one inch scale (scale of survey), for the Surveyor General, vide Memorandum G.

4th. Fair compilation map on the one inch scale (scale of survey), vide Memorandum G, for the Surveyor General.

5th. Reduced compilation map, scale $\frac{1}{4}$ inch to the mile, Memo. G, for the Surveyor General.

6th. Skeleton progress map, on a scale of 8 or 16 miles per inch, vide Memo. G, to accompany narrative report.

56. Maps. plans, &c. should not be mounted on cloth, because it renders the tracing of copies for Lithographic or other purposes, a matter of difficulty.

57. The following office books should be kept up and not suffered to fall into arrears.

Official records.

1st. Letter book for correspondence with the Surveyor General, his deputy and other professional Officers.

2nd. File of letters received from above parties.

3rd. Miscellaneous letter book.

4th. File of miscellaneous letters received.

5th. Pay abstracts and acquittance roll book.

6th. Contingent bill book.

7th. The usual field books and computations which are to be kept in duplicate, one copy to be forwarded to the Surveyor General.

58. All these office records are to be legibly written in a neat style and kept clean. The duplicate field books and computations are to be rigorously compared and must on no account be suffered to fall into arrears, nor be daubed with blots or written illegibly. Neat clean writing, and well formed figures, methodically arranged, are in fact essential elements of accuracy in elaborate computations, and as this is entirely a matter of habit it must be insisted on from the beginning. Observations and memoranda are never to be recorded in pencil, or on loose scraps of paper, but entered at once in ink in the proper books kept for the purpose.

Range of duty expected of the head of the party.

59. Although operations of extension may be considered the peculiar province of the head of the party, he should also take a leading share in every part of the duties, never expecting more from his assistants than he can do himself, and showing by personal example, how their several duties are to be performed.

Sanatory cautions.

60. The officer in charge should be careful of the health of his followers and himself, for the due preservation of which in jungly tracts, separate medical instructions have been issued.

The true principles on which celerity of progress depends.

61. It is in vain to expect rapidity of progress from hurrying on the work, the effect of which is only to produce confusion and mistakes. Celerity will naturally follow that facility and skill which are acquired by long practice, combined with an undeviating system of order and method.

Disputes to be avoided.

62. The officer in charge must also be careful to prevent disputes between his people and the inhabitants, with whom he should endeavour to establish friendly relations, and acquire the confidence and support of the local authorities. He should be

chary of the expenditure of public money, and by precept as well as example should encourage his followers in the manly discharge of their public duties; the acquirement of a high professional reputation, and a character for respectability and cheerfulness of spirit.

63. Instructions, however elaborate and minute, cannot supersede the necessity of judgment and discretion on the part of the Executive Officer, who is strictly responsible for the success of the work. If doubts or difficulties arise, immediate reference is to be made to the Surveyor General.

Doubtful points to be referred for orders.

64. On the conclusion of the Survey a professional report on the operations and construction of the map is to be drawn up and submitted. The memorandum marked I. in the Appendix contains the heads of the subjects proper to be discussed iu this final professional report.

Final professional report.

A. S. WAUGH, *Lt. Colonel,*

Surveyor General of India.

LIST OF APPENDIX.

A. Problem for fixing a station on the plane table, by means of intersections to three known points.

B. Rules for determining the value of the division of a level scale.

C. Rules for correcting vertical angles for level errors.

D. Description of a new Theodolite Stand and Plane Table in use with the G. T. Survey.

E. Blank forms of returns.

F. Estimate for a Topographical Survey party.

G. Memorandum on Mapping, illustrated with a specimen of a plane table section.

H. Additional remarks on vertical angles, for determining terrestrial heights.

I. Heads of final professional report.

K. Despatch of the Hon'ble the Court of Directors on Statistics.

Fig. 1.

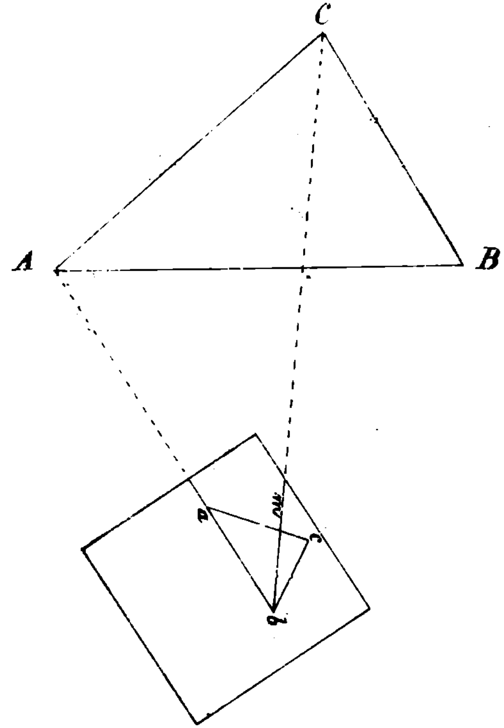


Fig. 2.

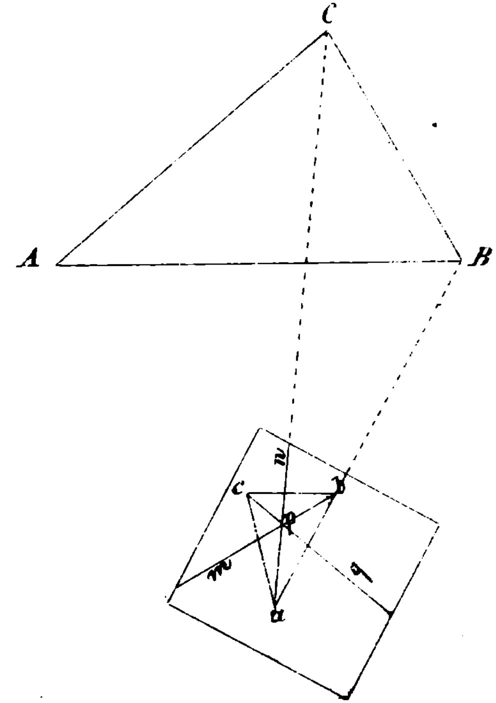
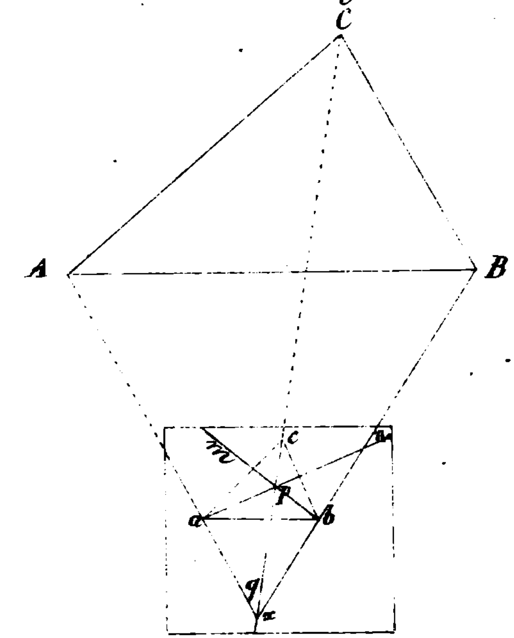


Fig. 3.



A.

To fix a plane table in position at an unknown point *x*, by means of three points *ADC*, whose positions are laid down on the plane table, and represented by *abc* respectively.

Fix a pin in the point *b* on the plane table, and placing the ruler against it and the point *a*, with the object and sight towards *a*; turn the table about, until the point *A* is intersected, then clamping the table in this position, turn the ruler and intersect the point *C*, with the edge of the ruler still against the pin at *b*, and draw the line *bm*;—now remove the pin to the point *a*, and unclamp the table,—place the ruler against the pin at *a*, and the point *b*, and turn about the table until the point *B*, is intersected (vide fig. 2); clamp the table again and having intersected the point *C* as before, draw the line *a n* through the intersection *p* of the line *a·n* and *b m*; draw the line *c p q* passing through the point *c*, and placing the edge of the ruler against this line, unclamp the table once more, and turn it about until the point *c*, is intersected (vide fig. 3); now clamp the table, and it will be in position and the unknown point *x*, will be situated on the line *c p q*; to find this point it is merely necessary to intersect either of the points as *A*, and draw the line *A a x*, and the accuracy of the operation is tested by intersecting the other point *B* and drawing the line *B b x* which should intersect the line *A a x*, on the line *c p q*, thus giving the position of *x* on this line.

Vide Fig. I.

The demonstration of this problem is evident to those acquainted with the same problem in plane trigonometry, it only remains to be remarked, that when the point *c* with regard to the point *x* is situated on the other side of the line *A B*, or below it, the lines *a n* and *b m* will intersect on the opposite side of the line *a b*, to that on which *c* is; and if the point *x* be situated within the triangle *A B C*, these lines (*a n* and *b m*) will diverge instead of converge, in which case they must be prolonged on the opposite direction, until they intersect for the point *p*.

N. B. The accuracy of the result depends on the length of the line *c p*.

Remark. The problem for fixing an unknown station by observations thereat to three known ones, is only applicable to reconnoissance, and totally inadmissible for accurate surveying. The rules for trigonometrical operations prescribe symmetry and the measurement of every angle at accessible stations. Plane tabling is perfectly similar and the points at which the table is to be set up should first have rays drawn to them from the trigonometrical stations. Interpolated stations are inadmissible except for very subsidiary details, and should, for such purposes only, be fixed by the needle and three known points at least.

B.

G. T. SURVEY.

Rules for the determination of the value of a level scale.

The value of the divisions of the scale of a level may be ascertained, by affixing the level to the frame of the vertical circle (or making it ride parallel to the telescope) and then taking readings of the microscopes in two positions of the bubble, whence comparing the number, of divisions of the level scale run over by the bubble, with the corresponding angular motion of the vertical circle, as measured by the microscope, the value of one division of the level scale will be obtained by simple proportion as shown in the following example.

Experiments made at Kalianpoor, January 1840, *to determine the value of the divisions of the axis level appertaining to the circle Troughton.*

Temperature.	Microscope readings.					Level readings.					Computed value of one division of level scale.
	D.	Diffce.	E.	Diffce.	Mean Diffce.	L. end	Diffce.	O. end	Diffce.	Mean difference.	
70°7	7°25′47″.0	″	′25″41 0	″	″	85 6		48.4			″
	7 26 20 .5	33.5	26 14 1	33.1	33.3	50.9	34.7	83.0	34.6	34.65	0 9610
	7 26 12 .1	8.4	26 6 0	8.1	8.25	59.9	9.0	73.9	9.1	9.05	0.9116
	7 25 62 .1	10.0	25 56 2	9.8	9.90	70.1	10.2	63.8	10.1	10.15	0.9754
	7 25 52 .2	9.9	25 45 0	11.2	10.55	81.0	10.9	53.1	10.7	10.80	0.9769
	7 25 44 .2	8.0	25 37 3	7.7	7.85	89.9	8.9	44.3	8.8	8.85	0.8870
	7 26 11 .1	26.9	26 4 9	27·6	27.25	61.2	28.7	73.0	28.7	28.70	0.9495
											5.6614
	Mean value of one division of the level scale.										0.9436

The above form exhibits only a few of the experiments necessary for determining the value of a level. For the azimuth level of an astronomical circle, not less than 50 to a 100 observations should be taken; for the azimuth level of the Great Theodolite about 30 observations will suffice; for transit axis levels about 15 to 20 observations, and for inferior instruments about the same number. These observations should not be taken at one time, but under as great a range of temperature and circumstances as practicable; some in the hot, some in the cold weather, morning, noon and evening and with various lengths of run, taking special care to avoid allowing the bubble to approach too near the end of the scale on the one hand and on the other avoiding small runs. The run to be measured should not in any case be much less than 10 divisions, because the uncertainty of reading arising from indefinitude in the bubble, partial expansions and other sources of error, produces a proportionally greater effect on a small run. Supposing for example in a fine level, that the uncertainty in two readings, *i. e.* on a run may be 2-10ths of a division (which is a moderate assumption,) then the uncertainty in 10 divisions will be 1-50th part of the whole quantity. In small common levels, the uncertainty will be much greater, perhaps as much as ½ a division. A good level should be sensible in every sense of the term; viz. both sensitive and steady. This happens when its internal surface has been ground to an arc of a perfect circle, but as the instrument-makers have no certain means of grinding to a perfectly circular figure, the requisite conditions are in a great measure a matter of chance, and a good level a matter of selection.

In circles, equal parts of the circumference subtend equal angles, which is not the case with elliptical or other geometrical curves, or with an irregular curve. If the internal surface of a level were perfectly cylindrical, the bubble would remain at any part when the cylinder was level, and would run up to one end or the other on the slightest inclination, so that the quantity of angular deviation could not be measured. If the internal surface were convex the bubble would run on to one end, and there would be no indication of the true level or of the amount of deviation therefrom. If the surface be concave, but of elliptical or any other curvature excepting circular, equal parts will not subtend equal angles but the indications would otherwise be steady Lastly, if the surface is irregular the bubble will be liable to fits and starts and irregular indications. A good 10 or 12 inch ground level generally runs 30″ to 40″ in the inch, although they sometimes run as fine as 20″ to 25″ but the latter are generally unsteady. Common short levels run from 40″, to 100″ in the inch, 80″ being not an unusual value. Supposing the internal surface to be a true circular arc, the radius of that circle for a level having 30″ in an inch will be 573 feet, because, $\frac{\text{cosec } 1''}{12 \times 30} = \frac{206264.8}{12 \times 30} = 573$ feet. For 40″ to the inch, the radius is 430 feet, and for 80″, 214 feet.

As the grinding does not extend to the extremities of the glass, and no readings are ever taken near the ends, it is necessary when measuring the runs to be careful not to make the bubble approach too near the ends, as has been already remarked.

If the runs of a level vary under different temperatures, the internal surface is most likely an elliptical or some other geometric curve. A mean value derived from experiments under various temperatures should in such cases be used, provided the variations are minute, but if they are large, it

D

may be necessary to use a different value for different temperatures, as shewn in the annexed memo. of experiments.

Memo. on the level experiments at Kalianpoor 1839-40.

The run of the level is apparently very much affected by temperature as will be seen from the following statement:

Temperature	74°.8	value of 1 division		0″.7871
„	72 .4	do.		0 .7594
„	70 .5	do.		0 .7478
„	66 .45	do.		0 .7317
„	60 .27	do.		0 .6858
Mean	68 .9		Mean	0 .7424

This indicates a correction of 0″.00698 nearly, for the value of the level for every degree of the thermometer, on which assumption the computed values for the other temperatures, are as below:

Temperature.	Computed values of one division of the level.	Difference from observation.
74°. 8	0.7836	− 0.0035
72 . 4	0.7688	+ 0.0094
70 . 5	0.7535	+ 0.0057
66 .45	0.7392	+ 0.0075
60 .27	0.6821	− 0.0037

In applying a level to a vertical circle for the purpose of measuring the angular value of the scale, the best plan is to fix on the bars or on the telescope, 2 *Ys* of wax, in which the level can be made to sit firm, taking care to secure it from accident by tying it on. The level must be accurately cross-levelled, so that it may occupy the same position under trial, as in actual use. If there be no cross-level attached, one may be temporarily fixed on with wax, before dismantling the level, but if means are not available for this purpose, then before taking the level off for trial, mark with pen and ink on the glass, the outline of the bubble. This will give the means of approximately cross-levelling, and however rough the device may be, it is infinitely preferable to trusting to chance.

Besides this mode of determining the value of a level scale, there is another method applicable to levels of azimuthal instruments which may be called an examination in *situ*, as it does not require the level to be detached nor fixed on to a vertical circle. The method is as follows.

Bring the object or eye end of the telescope plumb over a foot screw. Turn the whole instrument till the telescope is directed on the referring mark at a time of day when the altitude is steady.* Now level the instrument.

* About 3½ hours p. m.

It is clear that if the screw under the telescope end be raised and depressed the amount of dislevelment so occasioned may be measured both by the level and by the apparent change of altitude in the mark, consequently the deviations of the former may thus be compared with the divisons of the vertical circle. This method can only be practised at one period of the day, but as that period is most favorable for vertical angles, it is not unsuitable for obtaining a value for correcting those observations.

N. B. Levels being very sensitive thermometers, care must be taken not to influence them by breathing, or too near an approach of the body.

Experiments taken at Masuri Observatory to determine the value in seconds of the Divisions of the vertical Axis Level attached to Simms' 24-Inch Theodolite No. 2, by Captain Thomas Renny Tailyour, Astronomical Assistant Great Trigonometrical Survey.

Temperature and date.	MICROMETER READINGS.					LEVEL READINGS.					Computed value of one division of Level Scale.
	A.	Diff.	B.	Diff.	Mean Diff.	L. end.	Diff.	O. end.	Diff.	Mean Diff.	
1853						d.	d.	d.	d.	d.	
71°2	85°56′ 25″.2		56′ 44.″8			90.5		40.2			
	57 15 .2	50″.0	57 34 .4	49″.6	49″.80	40.6	49.9	90.4	50·2	50.05	0″.9950
31st Aug.	56 35 .4	39 .8	56 54 .6	39 .8	39 .80	80.0	39.4	51.0	39.4	39.40	1.0102
	57 3 .3	27 .9	57 23 .3	28 .7	28 .30	51.7	28.3	78.5	27.5	27.90	1.0143
	56 43 .8	19 .5	56 63 .2	20 .1	19 .80	70.0	18.3	60.8	17.7	18.00	1.1000
71°2	56 54 .7	10 .9	56 73 .9	10 .7	10 .80	60.7	9.3	70.2	9.4	9.35	1.1551
70 1	57 17 .3		57 38 ·6			87.4		43.2			
	58 3 .1	45 .8	58 23 .8	45 .2	45 .50	43.5	43.9	87.6	44.4	44.15	1.0306
	57 30 .3	32 .8	57 51 .7	32 .1	32 .45	77.0	33.5	53.8	33.8	33.65	0.9643
	57 52 .9	22 .6	57 73 .7	22 .0	22 .30	53.4	23.6	77.6	23.8	23.70	0.9409
70 1	57 38 .8	14 .1	57 59 .2	14 .5	14 .30	67.8	14.4	62.8	14.8	14.60	0.9795
71 2	56 29 .7		57 49 .8			85.0		47.2			
	57 8 .3	38 .6	56 26 .7	36 .9	37 .75	47.3	37.7	84.9	37.7	37.70	1.0013
1st Sep.	56 39 .0	29 .3	56 58 .4	28 .3	28 .80	75.0	27.7	56.4	28.5	28.10	1.0249
	56 57 .8	18 .8	56 77 .0	18 .6	18 .70	55.8	19.2	75.6	19.2	19.20	0.9740
71°2	56 47 .0	10 .8	56 65 .4	11 .6	11 .20	66.0	10.2	64.8	10.8	10.50	1.0667
71 2	56 31 .8		56 51 .2			82.3		48.5			
	57 4 .8	33 .0	57 23 .4	32 .2	32 .70	49.1	33.2	81.9	33.4	33.30	0.9820
	56 40 .3	24 .5	56 60 .1	23 .3	23 .90	72.7	23 6	57.9	24 0	23.80	1.0042
71 2	56 56 .0	15 .7	56 74 .2	14 .1	14 .90	58.8	13.9	72.2	14 3	14.10	1.0567

By 10 previous measures at Temperature 46°.8, ...	1″.1639
By 10 ditto ditto 47 .2, ...	1 .1743
By 10 ditto ditto 50 .8, ...	1 .1527
By 10 ditto ditto 53 .6, ...	1 .1563
By 10 ditto ditto 55 .3, ...	1 .1205
By 16 measures at Temperatnre 70°.9 as shown above 70°.9, ...	1 .0187
General Mean of 66 measures at above Temperatures, ...	1.1311

Remarks.—The azimuth level was examined in *situ*, by bringing the eye end of the telescope immediately over one of the foot screws, and at the same time intersecting the wires of a 30 Inch Transit used as a Collimator.

The runs of the transit axis level of the same instrument were determined by fixing it on the vertical circle. The mean of 50 observations at temperatures 47°4 to 56°5 gave 0″.71859 for the value of one division of the Level Scale.

C.

RULES FOR CORRECTING VERTICAL ANGLES FOR LEVEL ERROR.

Extract from Circular Order, Department G. T. Survey, Surveyor General's Field Office, Dehra Doon, 1st September 1849.

2nd. The reading of each end of the level is to be registered in two columns marked "object end" and "eye end." The object end readings are to be marked + and the eye end readings marked —. The Algebraical sum of the whole will be divided by the number of level readings, each end being considered an independent observation. The quotient will be the level error in terms of the level scale, which multiplied by the angular value of the divisions of the scale, will give the angular correction with its proper sign, to be added algebraically to altitudes, and subtracted from depressions.

D

(EXAMPLE 1st.)

NORTH EAST LONGITUDINAL SERIES.

Vertical angles taken at CHANDIPAHAR HILL STATION with Lieut. Colonel Waugh's 24-inch Theodolite No. 1.

Object.	Face.	Time of observation.	Micrometer readings. G	Micrometer readings. H	Level readings. Object End.	Level readings. Eye End.	Mean vertical angles. One face	Mean vertical angles. Both faces.	Mean vertical angles. General mean and level corrn.	Height of object.	Barometer reading.	Thermometer. Attached.	Thermometer. In the air Dry.	Thermometer. In the air Wet.	Remarks.
					+	−									
Afternoon Vertical Angles 19th November 1850.															
		h. m.	° ′ ″	° ′ ″	d	d	° ′ ″	° ′ ″							
Roorki Station Heliotrope.	L	2 40	D 0 43 25·5	D 0 43 43·6	82·0	65·0	D 0 43 34·55	D 0 43 37·98	D 0 43 37·89	0·6 feet above the station mark.					Value of one division of level scale = 1″·164. The station mark is on the highest part of the roof of the College, 27 feet above the ground. Height of eye = 5·4 feet.
" " "	R	44	D 0 43 54·8	D 0 43 28·0	74·5	72·0	D 0 43 41·40		Corn. = −5·69						
" " "	R	50	D 0 43 55·0	D 0 43 28·8	73·0	72·6	D 0 43 41·90	D 0 43 37·80	D 0 43 32·20						
" " "	L	3 0	D 0 43 27·0	D 0 43 40·4	83·4	64·2	D 0 43 33·70				Ins. 27·926	66°·0	69°·8	58°·3	

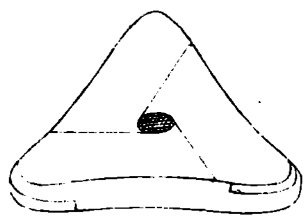
Calculation of level error $(+\ 312^{d}\cdot9 - 273^{d}\cdot8) = +\ 39^{d}.1$ hence $+\ \frac{39^{d}\cdot1 \times 1\cdot164}{8} = +\ 5''\cdot69$ subtractive from depressions.

D

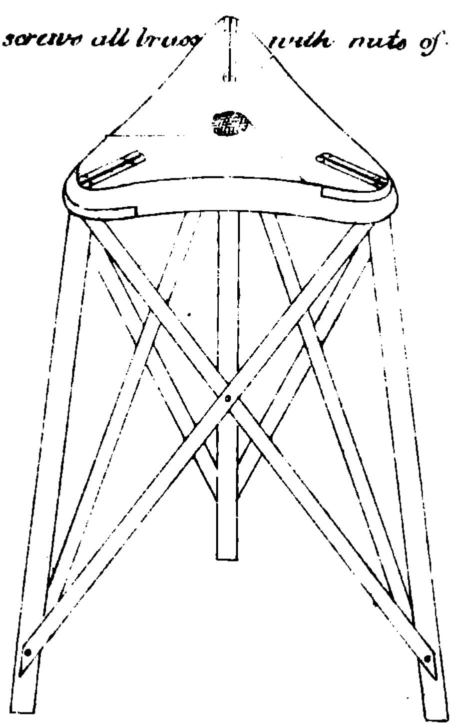
DESCRIPTION OF A NEW THEODOLITE STAND

in use with the G.T. Survey.

Plan showing the head of a trestle composed of 3 solid pieces notched down on each other. Diameter 8 inches, thickness 2½.

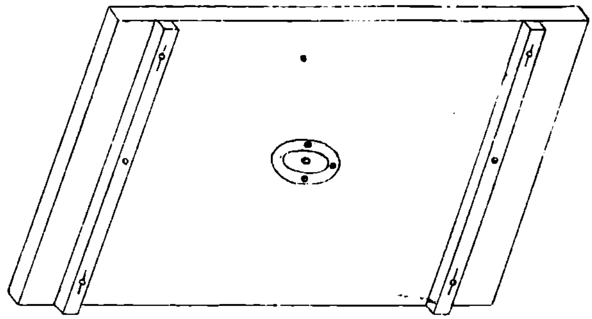


Plan of trestle head showing the brass grooves suited to Theodolites of 5 inches to 12 inches.



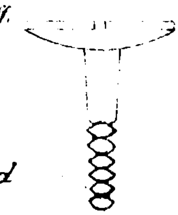
DESCRIPTION OF A NEW PLANE TABLE

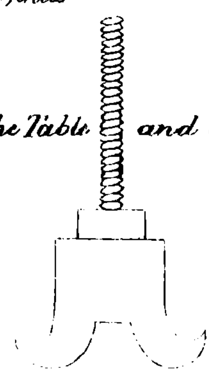
in use with the G. T. Survey.



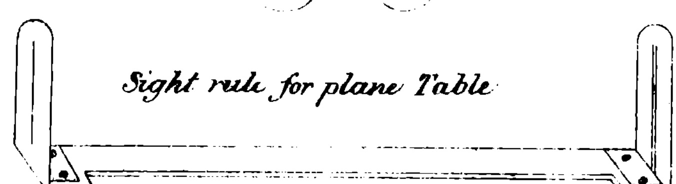
Sketch showing the under part of a Plane Table, with the brass Socket screw in its center countersunk and fixed by 4 screws. The board is made of planks of well seasoned Toon or Deal wood one inch thick. To prevent warping, edge bars are attached across the grain. These edge bars are to be fixed firmly by one screw in the middle. There is also one screw at each end, passing through a long hole, so as not to impede expansion and contraction. These latter screws should have broad heads, and should not be screwed too tight. Moreover a piece of brass or tin should be placed between the shoulders of the screw and wood, to prevent countersinking, which would prevent the expansion & contraction of the wood. After being made up and well aired and seasoned, the surface of the Board should be planed true and smooth.

The shoulders of these screws should be slightly bevelled, or turned off, so as to offer the least possible resistance, thus





Screw for fixing the Table and the Stand



Sight rule for plane Table

GENERAL REMARK *Iron is inadmissible on account of the Compass*

(EXAMPLE 2ND.)

NORTH EAST LONGITUDINAL SERIES.

Vertical Angles taken at GHOONGTI HILL STATION with Lieut. Colonel Waugh's 24 inch Theodolite No. 1.

Object.	Face.	Time of observation.	Micrometer readings.		Level readings.		Mean vertical angles.			Height of object.	Barometer reading.	Thermometer.			Remarks.
			G.	H.	Object end.	Eye End.	One face.	Both faces.	General mean and level corrn.			Attached.	In the air. Dry.	In the air. Wet.	
					+	—									
Afternoon Vertical Angles 20th December 1860.															
		h. m.	° ′ ″	° ′ ″	d	d	° ′ ″	° ′ ″	° ′ ″						
Saonchalia H. S. Heliotrope.	R	2 0	E0 23 30·7	E0 23 14·3	95·5	102·0	E0 23 22·50	E0 23 28·00	E0 23 28·20	1·67 feet.					Height of eye = 5·40 feet
„ „ „	L	3	E0 23 22·3	E0 23 44·7	98·5	98·5	E0 23 33·50		Corn. = —2·62						
„ „ „	L	8	E0 23 23·2	E0 23 45·0	99·0	98·0	E0 23 34·10	E0 23 28·40	E0 23 25·58						
„ „ „	R	10	E0 23 30·6	E0 23 14·8	92·0	104·5	E0 23 22·70				Ins. 23·347	55°·2	56°·4	49°·0	

Calculation of level error $(+385^{d}\cdot0 - 403^{d}\cdot0) = -18^{d}\cdot0$ hence $-\frac{18^{d}\cdot0 \times 1''\cdot164}{8} = -2''\cdot62$ additive to elevations.

Observed by Thos. Renny Tailyour, Captain, Astronomical Assistant G. T. Survey.

E

REPORT PROGRESS of the __________________ *Survey for the Month of* __________________ 18 .

Name and date of Appointment.	On what duty employed during the past Month.	Progress and present state of the Work.	On what duty proposed to be employed during the ensuing Month.	Remarks.

Date. **Annual Narrative of operations to be in letter form.** **Signature.**

ANNUAL RETURN of Instruments, &c. the Property of Government in use with the ________ Survey ending 1st September 18____.

Names and description of Instruments, &c.	No. or Quantity.	Maker's Name.	Whence received.	Date of receipt.	Remarks.
(In exact Alphabetical order.)					

Date. Signature.

________ SURVEY.

ANNUAL RETURN of Expenses, ending 31*st August*, 18___

Names.	Staff Pay.	Salary.	Amount drawn in each Month.												Total.
			Sept.	Octr.	Novr.	Decr.	Jany.	Febry.	March.	April.	May.	June.	July.	Augt.	

Abstract of the Cost of the Survey ________ Total of Expenses,

Area surveyed ________ Square miles.

Rate per square mile.

Date. Signature.

*REPORT PROGRESS of the*____________________*Survey for the year ending 31st August 18*____.

Names and Dates of Appointment.	On what duty employed during the last year.	Progress and present state of the Work.	On what duty proposed to be employed during the ensuing year.	Remarks.
Surveyor, ...				
Sub-Assistant Surveyors,				

Date. Signature.

F

ESTIMATE FOR A TOPOGRAPHICAL SURVEY PARTY.

Instruments.

Theodolites. One large Theodolite for operations of extension, viz. a 14-inch, 12-inch, 10-inch, or 7-inch, according to the distance to be triangulated. One 7-inch or 5-inch for each Assistant Surveyor employed on internal operations.

Signals. Ten or twelve Heliotropes, large and small, for operations of extension; eight flags with bamboo staves, &c. for each Surveyor employed. In hilly countries, poles and brushes can be used extensively and flags will not be much required.

Plane Tables. One for each Surveyor employed, including the officer in charge.

Magnetic Compasses. Two box needles for each board, two prismatic compasses with stands for the party.

Magnets. One pair, for remagnetizing needles.

Measuring Apparatus. One iron chain to be used as a standard of comparison; one 5-foot standard iron bar; one measuring chain for each Surveyor, or one or more perambulators in lieu of chain, according to the nature of the Survey.

Barometers. Two, previously compared with the Surveyor General's standard, for determining the altitudes of places inaccessible to trigonometrical levelling

Office Instruments. One box of mathematical instruments each; one box of colors,* &c. each; one Gunter's scale; two beam compasses, large and small; one straight-edge flat ruler; one T square; one parallel ruler for each Plane Table Surveyor.

Books. Manual of Surveying for India; Logarithms; 1 Bagay; 1 Shortrede; 1 Hutton; 1 Babbage Numbers; 1 Babbage Sines and Tangents (Callets.)

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* 1 Cake Prussian Blue, 1 Cake of Indigo and 1 Cobalt,
1 „ Lake or Carmine, and 1 Cake Light Red,
1 „ Gamboge, and 1 Cake Yellow Ochre,
1 „ Burnt Sienna, and 1 Cake Burnt Umber,
1 „ Indian Ink, and 1 Cake Sepia,
} with 2 pairs hair pencils.

Native Establishment.

Permanent Establishment. 12 Heliotropers, Flagmen and Chainers at 6 Rs. each, ... 72 Rs.

12	Lascars, @ 5, ...	60	„
3	Do. for each Assistant Surveyor, @ 5,... ...	15	„
2	Hurkaras, @ 5, ...	10	„
1	Guard Military,		
1	Native Doctor, at 25 or 30 Rs.		

Temporary Establishment during the Field Season.—4 to 10 men extra fer each Assistant Surveyor according to the nature of the Work, at 5 Rs. each.

Camels,	3	for Office Tent.
„	1	„ „ Records.
„	1	„ Tools, &c.
„	1	„ Medicine Chests.

As many of the Permanent Establishment as can be spared, are allowed leave on half pay during the recess.

Stationary.

Foolscap Paper, ...	1	Ream.
Country do.	1	„
Quills, ...	100	
Steel Pens, ...	2	Gross.
Blotting Paper, ...	1	Quire each.
Atlas Drawing Paper, ...	6	Sheets.
India Rubber, ...	2	Pieces.
Pencils Drawing, ...	1	Dozen.
Antiquarian, ...	3	Sheets.
Tracing Linen, ...	6	Yards.

Books, 2 Letter Books, 3 quires Foolcap,
1 Pay Book, „ „
1 Contingent Bill Book. „
1 For each Assistant, „
4 Memo. Books for each, one Quire.

Lithographed Forms, Angle Books, &c., to be indented for as required.

G

1. The whole district to be surveyed should be apportioned off in sections to the Assistants by the head of the party, who is responsible for the combination of the different parts.

2. On the one inch scale, the most convenient size for a plane table section is fifteen minutes of a degree or about 17.2 inches in Latitude by 17 to 14 inches in Longitude, according to the parallels. Such a section will require a board at least 22 inches square, so as to give room for external points as adverted to in para. 49 ; but boards of 26 × 30 inches would answer better, because room would be given for additional tiers of sub-sections to assist in protracting external points. It is to be understood, that the lines defining sections are to be set out to correspond with the geographical degrees and quarter degrees, and they may be projected by doubling the tabular quantities in Table XI. of the new Geodetical Tables,* taking due care that the central meridian of each section intersects the parallel at right angles. Vide Example G′.

* New diagonals will require to be computed, or protraction will answer, proving by the two diagonals agreeing.

3. The sections may, for convenience, be subdivided into sub-sections of 5′, and the Trigonometrical points will be projected by the use of appropriate scales.

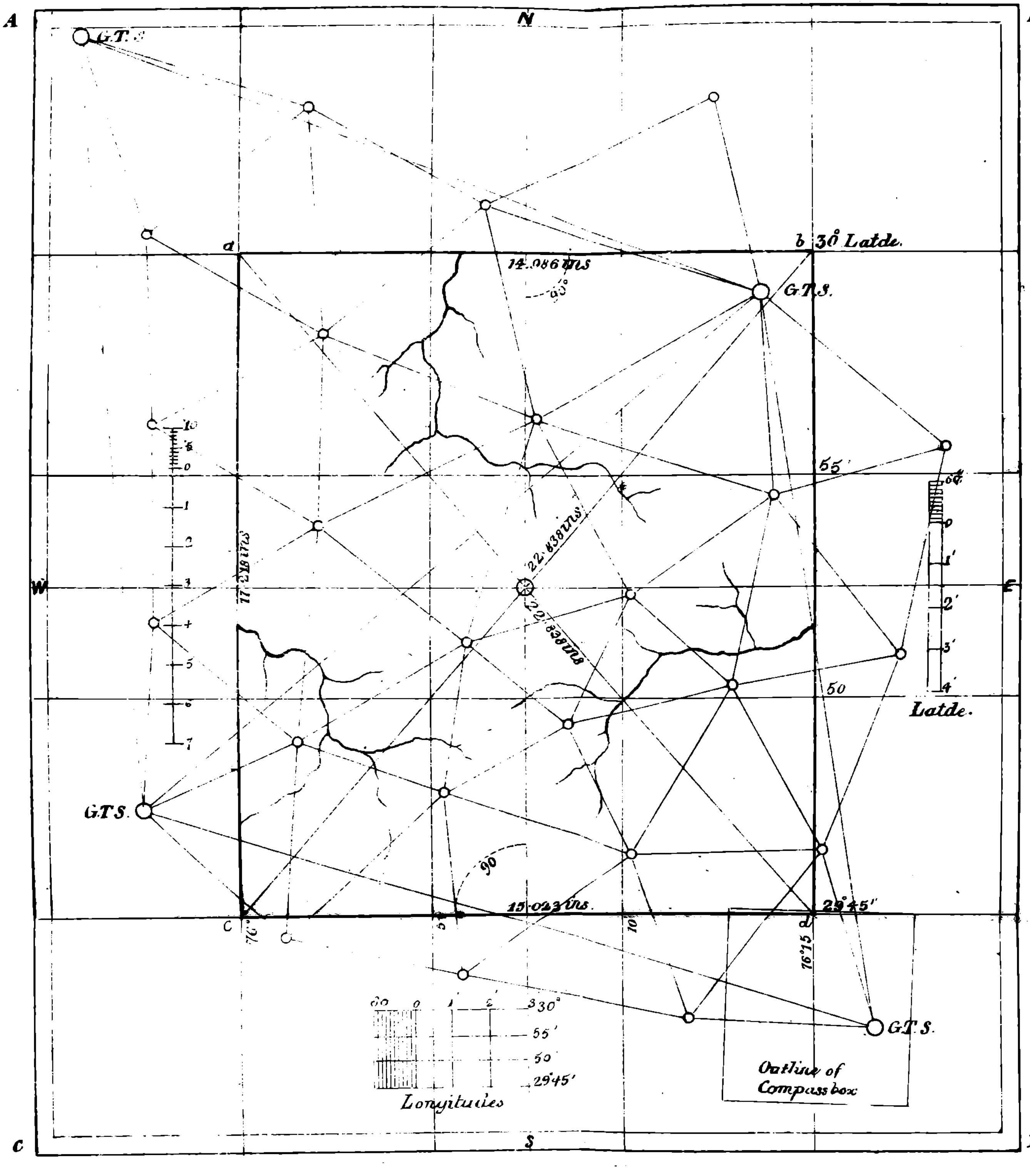
4. The section lines define the limits to be surveyed up to, so that when all the sections are placed side by side they are intended to produce a complete map. When any portion of a district occupies a part only of a section, it will nevertheless require a full sectional sheet for its survey, however small the portion surveyed may be, so that every field sheet will be of uniform size. The assistants should work together in the first instance at their common boundaries to such extent as will ensure agreement on the lines separating their respective portions. To effect a general agreement and consistency of style, the head of the party should be competent to direct and instruct his subordinates in every part of the work.

5. These sectional sheets are the field books of the Survey and must be preserved accordingly. They are therefore intended to be sent to the Surveyor General, by whom they will be placed in a book or portfolio duly indexed previous to despatch to the India House.

6. The meridian and parallels, defining the sections are to have their Geographical values carefully printed whether they be degrees or quarter degrees, for on this depends the due incorporation of the sheets without mistake. As a further precaution against confusion or omission, each sheet is

G′

TYPE OF A PLANE TABLE SECTION FOR THE ONE INCH SCALE ¼ FULL SIZE.



EXPLANATION.

Let *ABCD* be the Plane Table, which bisect with the central Meridian *NS* and central parallel *EW* intersecting each other exactly at right angles. The accuracy of the projection depends on the precision of these lines. A Meridional arc from 29° 45′ to 30° measures on the one inch Scale 17·218 inches. Lay off half this quantity on the central Meridian on each side of *O*. Draw the parallels *ab* and *cd* parallel to *EW*. An Arc of 15′ of Longitude in Latitude 29° 45′ is 15·023 inches and in Latitude 30° it is 14·986 inches. *Vide* Table XI of the new Geodetic Tables. Lay off half of these quantities on their respective parallels, and on each side of the central Meridian. Prove the equality of the diagonals *ad* and *cb* which should measure 22·838 Inches. If they are correct, the quadrilateral *abcd* will define the Section and may be inked in accordingly. Now trisect each side of the quadrilateral and draw corresponding lines which will form the subsections of 5′ each. Produce the subsectional lines to the Margin, and if there is room on the board prove the external subsections by their diagonals. Draw the requisite Scales, and then project all the Trigonometrical points by co-ordinates of Latitude and Longitude, and prove them by their distances. The thick lines represent the parts to be inked, and the thin lines those in pencil only. When the Table is set up at the first G. T. Station, and rectified, the compass box is to be adjusted, and its outline drawn.

On so small a Scale, the convergence of Meridians in 15′ is not perceptible to the eye, but on the full one Inch Scale, it is appreciable.

to be endorsed on its back, with the Nos. of the meridians and parellels by which it is bounded.

7. For the half inch scale, the sections should be ½ a degree in latitude and longitude, and to them the other rules above given equally apply.

8. The names should always be printed to the right of the villages or towns to which they belong, and on a line of parallel, *i. e.* due east and west. The names of rivers, parallel to their courses, and the same as respects those of mountain ranges. With regard to the size of print applicable to these names, and to those of territorial divisions modern or ancient, reference may be made to the Manual, chapter 25, page 515.

9. After the field sections have been fairly copied into the general compilation map on the same scale, they are to be carefully packed in double tin and a wooden case and forwarded season by season to the Surveyor General with a copy of the register.

10. The compilation map is intended to incorporate the field sections into a district map, in which unity of style is particularly to be attended to. This compilation is to be forwarded to the Surveyor General (carefully packed as above) after the receipt of the field sections has been acknowledged. This is in accordance with a general rule, not to entrust the original and duplicate of any work to the post at one time, thus the means of replacing a lost document will always remain in hand.

11. No specific rules seem necessary for the preparation of the fair compilation map. The projection of the geographical lines on which it depends will be based on the Geodetical Tables, and care is requisite in proportion to its superior size, so that the projection may not accumulate error. The projection of the Trigonometrical stations must be carefully done by appropriate scales and duly verified by linear distances, after which the easiest way is to trace in the details of each section consecutively from the glass. Great care and precaution will be required in preserving the compilation map from injury and hygrometic changes. When the size of the district requires that the one inch scale compilation should be got up in sheets, then each sheet when finished is to be sent to the Surveyor General.

12. The same rules apply precisely to the reduced ¼ inch scale map.

13. The skeleton map is to be a mere outline, shewing the extent surveyed by each individual, distinguishing the same by a wash of color and the season of survey recorded thereon, which with the geographic lines will serve to illustrate the Narrative Report and show the progress achieved.

II.

VERTICAL OBSERVATIONS.

Extract from Instructions for a Trigonometrical Survey.

1. Every exertion should be made to enable you to observe verticals at minimum refraction, for those taken later are worthless—about half past 3 P. M. or as soon as objects begin to steady for horizontal angles, they rise at the rate of 1″ per minute, or even more rapidly. Thus a few minutes difference of time will cause greater error, than observing unsteady objects. As a general rule, it is better to observe verticals too early than too late, for even at noon the uncertainty in the mean of several intersections to an undefined dancing object, would not much exceed 2″, an error which at a later period of the day might be occasioned by about 2 minutes in the time of observation.

2. If your sides in the plains do not exceed 11 miles, your stations always on high ground, the towers sufficiently high and due care taken to avoid intermediate obstacles such as can neither be removed nor surmounted, there will be no difficulty in getting verticals at minimum. The period of minimum refraction lasts a considerable time, probably from noon to the epoch of maximum temperature, which is generally reckoned to occur about 3 P. M. As soon as the thermometer begins to fall, objects begin to rise, and it is the evil effects of this uncertain change in altitude which it is desirable to avoid. When verticals are observed before 3 P. M. in the cold, and say half past 3 P. M. in the hottest weather, identical times are of less importance, because in several minutes there will be no change of altitude, but still it is a good habit to observe reciprocal verticals at exactly similar times, for if from circumstances, the observations should in the least degree overstep the limits of minimum, then perfect equality of time is an essential condition of success. To ensure this requisite identity of time in reciprocal observations, a well regulated watch is necessary. In the plains, time can be ascertained with sufficient exactness by observing sunrise and sunset (noting the same in the angle book,) the half interval between which will be apparent noon; or apparent noon can be estimated from sunrise or sunset alone, by means of a table of the sun's rising and setting, such as is published in the Bengal Almanac. In hilly countries this simple expedient cannot be

practised for want of a natural horizon, but time can always be ascertained with sufficient exactitude by equal altitudes of the sun, taken with the small Theodolite. By any of these means, you can regulate the observations of reciprocal verticals, so that they may correspond exactly in regard to equal apparent times after noon, and it is the time from apparent noon which should be recorded in the angle books, not watch times which give vast trouble afterwards.

3. I would advise your having small sight vanes attached to the top of your lamp boxes, with trestles of sufficient height to raise the centre of the Heliotrope aperture to the usual height of the axis of your large Theodolite. By this means you will gain the following advantages:—

1st. Your Heliotrope and lamp will be raised above the tower and the additional height will improve the appearance of the object.

Lamps not being used in Topographical surveys, these remarks are so far inapplicable, but the height of the centre of Heliotrope or other object observed may be made equal to the height of the transit axis of the Telescope, so that the eye and object corrections may cancel each other by being equal.

2nd. The sight vane, being attached to the heavy lamp box, will be steadied thereby.

3rd. Both being in perfect adjustment simultaneously the lamp can be lit exactly at sunset, and all hurry and confusion in setting the lamp box avoided.

4th. The height of eye and object being identical, you can without any trouble calculate, in the field, the height of your stations and satisfy yourself of their correctness on the following principle. In any triangle *ABC* if you take the height of *A* as zero and the comparative height of *A* to *B* and *C* to *B* and *A* to *C*, the result of levelling round the circuit should reproduce zero for the height of *A*. Good observations should not give an error of more than 1 or 2 feet in a circuit of 3 sides. To carry out this principle efficiently you should have heavy well-made plummets, which you must provide yourself with in due time.

4. Heavy plummets are also necessary for plumbing towers where reference is made to the lower mark. You can either make this reference the usual practice, or place a temporary well centered mark at top, taking care to ensure identity and measuring the height of towers yourself, so that the results may all be referrible to the mark at the ground surface.

5. It sometimes happens that the height of an inaccessible point is required to be derived from a vertical angle observed to it from a great station

The principle of computation in such cases is explained in the Manual at page 435, and requires no further elucidation except as regards terrestrial refraction.

6. There are no certain rules for estimating terrestrial refraction, but with care and attention a much nearer approximation may be made than if all consideration of circumstances was neglected. Reciprocal observed verticals, compared with the contained arc, give the true sum of the refractions at each end of a ray, which sum divided by two is the mean refraction deduced by observation. Dividingthis mean refraction by the contained arc we get the ratio of mean terrestrial refractions in terms of the angular distance or contained arc, but as the value of this term differs according to the radius used in computing it, the ratio of refraction will also vary accordingly. Due discrimination must therefore be used in applying such ratios to single verticals, for the same kind of radius of curvature must be used, as was employed in deducing the ratio, viz. either the normal, the meridional radius, the mean radius, or the true radius of curvature, due to the oblique arc.

7. At the northern extremity of the great arc, the mean terrestrial refraction was found to be nearly $\frac{1}{15}$th of the contained arc, computed with the normal as radius, but this ratio is applicable to dry weather, and peculiar local circumstances.

8. In the Darjiling operation on the other hand, the mean terrestrial refraction was found to be $\frac{1}{13.2}$ of the contained arc, similarly computed or $\frac{1}{12.8}$ of the same arc computed by the true radius of curvature. These ratios are, however, applicable to a very moist climate and the months of October and November.

9. In the mountain operations crossing the Himalaya, all the stations of which series were greatly elevated above the sea, some of them attaining an altitude exceeding 17,000 feet, the mean terrestrial refraction was found to vary with the season, as will be seen from the following statement, the ratios in which were computed with a mean radius of curvature equivalent to the radius of an oblique arc of 45° azimuth :

March.	*April, May, June.*	*July, August, September.*	*October.*
0·06	0·07	0·08	0·06

10. The annexed memorandum exhibits the mean terrestrial refractions given by great Trigonometrical operations in the Jhelum and Rawulpindee

districts, the contained arc being computed with a mean radius of curvature, *i. e.* mean between normal and meridional radius.

11. This table exhibits the mean ratio for terrestrial refraction proper to be used in the locality indicated, and similarly, the proper ratio should be deduced for every other locality and season from the principal operations.

12. It will, however, sometimes occur that an inaccessible point has been observed from a great number of stations at very different distances, varying perhaps as 2 to 1 or upwards. Such single vertical angles repeated at variable distances, will furnish a most satisfactory check, for it is clear that all the values of the height of an object should be identical. If, however, the greater distance gives the greater height, than two little correction has been applied for refraction. On the other hand if the greater distance gives the lesser height, then too much correction has been applied and the ratios may be altered judiciously to produce consistent results. On finishing the back observations to towers or other stations, a tumulus of earth or pile of stones should be made at top, so as to prevent rain getting down the central aperture or isolating annulus and thus speedily destroying the tower. The vault of access to the basement mark, should also be closed and the ramp cut away. These precautions have been mentioned before in my paper on towers and previous instructions, but still I find they cannot be to strongly insisted on.

APPENDIX TO H.

Memorandum of Mean Terrestrial Refractions in the Jhelum and Rawulpindee Districts—Season 1851-52.

Eye Station.	Object Station.	Ratio of mean terrestrial refraction to contained arc, computed with a mean radius of curvature.	Month in which observed.
Jogi Tila,	Mongri,	·068	Novr. and Jany.
	Jaolee,	·066	Novr. and Decr.
	Kundi,	·071	April and Novr.
	Kudiali,	·070	Do. and do.
	Daolatnagar,	·067	November.
Jaoli,	Mongri,	·069	Decr. and Jany.
	Soorla,	·070	Do. and do.
	Kundi,	·071	April and Decr.
	Khagriana,	·074	December.
	Nerh,	·076	Do.
Nerh,	Kundi,	·072	April and Decr.
Khagriana,	Nerh,	·074	December.
	Soorla,	·082	Decr. and Jany.
	Loiset,	·078	Do. and do.
	Gandgarh,	·074	Do. and do.
Loiset,	Gandgarh,	·083	January.
	Adjar,	·069	Do.
	Kaloo,	·068	Do.
	Pathrijala,	·072	Jany. and Feby.
	Soorla,	·070	January.
Adjar,	Gandgarh,	·084	Do.
	Kaloo,	·076	Do.
Kaloo,	Pathrijala,	·050	February.
Pathrijala,	Jhamut,	·069	Feb. and Mar.
	Pari,	·065	Do. and do.
	Soorla,	·070	Jany. and Feby.
Soorla,	Sidhr,	·070	February.
	Pari,	·066	Do.
Taman,	Pari,	·060	Feb. and Mar.
	Jhamut,	·064	March.
	Bani,	·066	Do.
	Sakesir,	·062	Do.
	Jatla,	·046	Do.
Jatla,	Sidhr,	·063	Do.
	Sakesir,	·065	Do.
Sakesir,	Bani,	·069	Do.

Remarks.

Abstract of the Mean Terrestrial Refraction in the Jhelum and Rawul Pindee Districts.

	November.	December.	January.	February.	March.	April.	Remarks.
Mean,	·069	·073	·074	·065	·063	·071	The ratio for April seems doubtful, depending on 4 results only and those mixed up with November.

These are minimum terrestrial refractions.

Observed by Geo. Logan, Esq. 1st Assistant G. T. Survey.

FINAL PROFESSIONAL REPORT OF THE SURVEY, AND CONSTRUCTION OF THE MAP.

Heads of subjects to be discussed.

1. The orders and instructions for the survey to be briefly referred to.

2. The instrumental equipments of which a return should be made, particularizing their values and condition at the outset and termination of the work.

3. A nominal statement of the Surveyors employed, the quantity of work achieved by each, their length of service, &c.

4. Area surveyed, with cost of execution and rate per square mile.

5. A narrative of the operations describing the date of taking the field, and time occupied in field work. Method of procedure, value of the unit of measure whether derived from the G. T. Survey or from independent bases. Determination of point of departure, if fixed independently, how? or the precautions taken to have it fixed hereafter by the Great Trigonometrical Survey. The steps taken to form a connection with the great triangulation by using its marks or leaving marks for future reference. The termination of initial azimuth if not derived from the G. T. Survey. The verification processes followed, such as angular proofs:—

1st. By Geometrical conditions.

2nd. By verificatory azimuths.

Linear proof:—

1st. By verification measurements.

2nd. By errors on closing.

The result of these checks to be stated.

6. An account of the office duties, specifying hours of business; whether all arrears have been brought up, or how much remains in hand. Whether the field books have been brought up in duplicate, so as to be ready for submission.

7. Whether the survey is complete in all topographical details, or only partial, and what precautions have been taken to prevent omissions.

8. Remarks on the details, drawing, projection and construction of the map, and how far the character of the country has been successfully represented.

9. An account of the boundaries, general and subsidiary.

K.

DESPATCH OF THE HON'BLE THE COURT OF DIRECTORS ON STATISTICS.

Copy of a Letter from the Hon'ble the Court of Directors (Statistical) No. 6 of 1846, dated London, the 3d June 1846.

1. The great practical importance of Statistical enquiries and the attention which they now receive from the most enlightened European Governments, have induced us to take measures for investigating the Statistics of the countries under our administration, and for arranging and preserving in a form convenient for reference, the information which may be attainable.

2. With the view of accomplishing these ends, we have formed a Statistical Department in our Home Establishment, in which the requsite enquiries will be conducted, and the materials thereby obtained classified and compared.

3. The voluminous Records and Documents in our possession, contain a vast amount of Statistical information, and the labors of the new Department will in the first instance, be directed to extracting and rendering it available for reference; these duties, which have already commenced, will continue for a long period to claim a large share of the time and attention of the Department, but the results will be imperfect, unless by the co-operation of our Governments in India, in collecting and transmitting Statistical information, we are enabled to remedy the defects, correct the inaccuracies, and as the condition and circumstances of all countries are in many respects constantly varying, to note the changes which time or other cause may produce.

4. We do not doubt that our servants will cheerfully afford their assistance for these purposes, and as the aid which they may render in this respect is not intended, and must not be permitted to interfere in any degree, with their ordinary duties, no detriment will arise to the public service, but on the contrary much advantage may be expected from the transmission home of such information as to local details, which so many of our servants cannot fail to possess.

5. Information will be most desirable on such subjects as the following—

LAND. Area
Geological structure.
Natural aspect.
Soil.
Atmosphere and climate.
Productions.
Modes of cultivation.
Prices of principal products.
Tenure and occupation.
Modes and rate of assessment.
Labor employed and its remuneration.

WATER. Navigable Rivers.
Description of.
Length of.
How far navigable.
Vessels employed on them.

LAKES. Description and situation.

CANALS. Their purposes.
Length and depth.
Vessels employed on them.
Cost and return on the outlay.
Wells and Tanks.
Means of irrigation in each district.
Harbours, and shipping frequenting them.

CITIES. Towns and Villages.
Situation and general description.
Number of Houses and whether Pukha or Kucha.

POPULATION. Numbers of people of different descriptions.
Employment.
Languages.
Condition.
Health and Disease.

HEALTH. of Troops, especially with presumed causes of health, or diseased state, and the treatment (not strictly medical) found to be useful.

WEALTH. Education, and method of pursuing it.
Charitable Institutions not Educational.
State of litigation and of crime.
Police, number, remuneration and efficiency.

COMMERCE. Manufactures.
Capital employed.
Imports and Exports from official sources.
Exchange.
Weights and measures.
Coins.
Banking operations.
Lending and borrowing.
Modes of transit and communication.
By Land.
By Water.
Impediments, and their duration.
Fords, Ferries and Bridges.
Postal Arrangements.
Taxation.
Sources of Revenue, and produce of each Tax.
Mode of collection.
Number in Sebundy or other corps, engaged in collecting revenue.
History and Antiquities, facts illustrative of more recent history, and of changes, Political or Agricultural.
Public Buildings.

6. We need scarcely observe, that in Statistical investigation, the most rigid accuracy as to matters of fact is indispensible. Erroneous information will be worse than none, because it can but tend to mislead.

7. There may be some subjects, especially those relating to Physical Science, with which our servants generally may not be minutely acquainted, and no statement on these or any other matters of enquiry, will be of any value, unless they be both precise and accurate. Where the requisite measure of scientific knowledge is not possessed by others, it may perhaps, in many cases, be supplied by our Medical officers, and their aid will, we doubt not, be cheerfully rendered whenever required.

8. In conclusion, we direct attention to the following general instructions.

9. In all cases, where practicable, reports should be the result of the personal knowledge of the officer reporting, and where such is the fact it should be mentioned.

10. Where from any cause the personal knowledge of the officer cannot be extended to any object of enquiry, the authority on which the reported facts rest, must invariably be stated, either in the margin, or in the body of the report.

11. When estimates only can be furnished, the grounds of each estimate must be stated, and the reason for adopting it.

12. Where information is orally given, it should be committed to writing at the time, in like manner personal observations should be recorded at the moment of making them.

13. In addition to the names by which places are known among Europeans, it would be desirable that the original names should be given, both in in the Devánágari * and Urdu character, according to the best authorities, especially local and native.

* The proclamations and state advertisements in the Calcutta Gazette are usually printed in the Devánágari as well as in the Urdu or Arabic character.

14. In regard to coins, weights and measures, care must be taken to preserve uniformity as to valuation, comparison, and conversion, and to ensure this, Prinsep's Useful Tables may be taken as a guide.

15. Where any material variations exist in different parts of any country or divisions of a country reported on, the nature and limits of such variations should be precisely pointed out.

16. It will be observed, that the greater part of the instructions above, are designed to ensure accuracy, the importance of which we have already adverted to. It is the more necessary to dwell upon this point, inasmuch as some previous attempts to afford Statistical infomation are unsatisfactory, because obviously incorrect.

ON THE VERNIER CLASS OF THEODOLITES.

AMPLIFIED FROM THE HEADS OF A LECTURE,

BY

LIEUT. COLONEL A. SCOTT WAUGH,

BENGAL ENGINEERS, F.R.S. F.R.G.S. SURVEYOR GENERAL OF INDIA, AND SUPERINTENDENT GREAT TRIGONOMETRICAL SURVEY.

BY

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1ST ASSISTANT GREAT TRIGONOMETRICAL SURVEY OF INDIA.

For the use of the Survey Department.

Distinction between Vernier and Reading Microscope Theodolites.

1. The Theodolite or Alt-Azimuth Instrument is constructed of various dimensions and according to different designs, but the chief distinction which may be firstly and most suitably noticed, is that which is comprehended between the Reading Microscope and the Vernier Theodolite. In the former instrument, its Readings are obtained by means of Reading Microscopes. In the latter, a most useful invention of Peter Vernier's, is employed to encompass the same end. The Vernier Theodolite, forms the subject of this paper.

How Theodolites are characterized.

2. It is customary to characterize a Theodolite according to the diameter of its horizontal circle, so that when the latter measures (n) inches, the former is called an (n) inch Theodolite. Thus there are the 5, 7, 8, 12 and 14 Inch Theodolites, all of which are usually read by the Vernier. The Reading-Microscope Theodolites are the 15, 18, 24 and 36 inch.

Special subject of this paper.

3. Of the Vernier Theodolites enumerated, the 7 inch (Everest's) may be fitly taken as a type or representative in general. The following remarks therefore apply in particular to this instrument, and in those cases where illustration

makes it necessary to adopt Theodolites of other dimensions or pattern, the digression from the text will be duly noticed.

Notes for packing and general remarks on contents of Box.

4. Supposing then that a 7 Inch Theodolite locked in its case has been placed before us, that we have opened the Box and turned back its lid, thus exposing to view the Instrument and its appurtenances as they are packed for travelling. The first step to be taken is, to examine the position of these contents, and to make suitable notes of the same; so that hereafter, in putting the Instrument back into its case, one of the most serious sources of accident, arising from the want of such notes, may be avoided. In the present instance we find the Telescope occupying one of the diagonals of the box, the "object end" being in the right hand corner, while the "Face" stands next to the hinged side of the case. It is sufficient to define these two conditions, by making the letters *O* and *F* respectively on those parts of the boards near which the object end of the Telescope and Face rest. Besides the Instrument itself, the following will usually be found in the box.

I. Magnetic Needle and two mill-headed screws for fixing it to the Telescope.

II. Direct (so called) Eye-piece.

III. Plummet.

IV. Ordinary turn screw and pin.

Of these No. II need rarely if ever be used, for by reason of its four lenses, less light is refracted to the eye than with the inverting (so called) eye piece, which latter contains only two lenses. (1.) The plummet on the other hand is absolutely necessary, but occupying as it does a higher place in the box than the Theodolite, care should be taken when placing it in its travelling socket that it does not fall on the Instrument. No. IV is a very indifferent screw driver, whence every careful Surveyor should provide himself with both larger and smaller turn screws of better pattern and temper.

A most important caution.

5. Having enumerated the contents of the box, we proceed to place the Instrument on its stand. But before doing so we must gravely caution the surveyor against ever employing violent force in the manipulation of a Theodolite. It is a caution as easy as beneficial to remember, and one which the construction and purposes of the Theodolite peremptorily forbid a violation of. No man yet

Note 1. The weight of the direct Eye-piece overbalances that end of the Telescope. This Eye-piece is sometimes useful as a finder for indistinct objects.

observed truthful angles or kept his Instrument in working order, who employed violence to effect his purpose. When a screw works stiff, or a slide cannot be moved, when the Theodolite itself will not settle into its appointed recesses for travelling, or the lid of the box does not close. In all these, and every other similar case, be patient, let your movements be gentle. More than one valuable Instrument has been irretrievably damaged through a neglect of this fundamental maxim, viz. *never to employ violent force in the manipulation of a Theodolite.*

Placing the Instrument on its stand.

6. Now draw the slides which hold the Instrument down, lift the Theodolite and place it on its stand. In performing this process, there is no choice but to hold the Instrument by what are termed its *Ys*. This mode of lifting is evidently objectionable, and the heavier and larger the Instrument the greater the objection. The most correct way of raising a Theodolite, is clearly by holding its foot screws; (1.) but these latter are inaccessible in the case of a 7 Inch and the small size and weight of the Instrument make the objection named comparatively trivial.

Naming the various parts of a Theodolite.

7. But before proceding further, (2.) it is essential that the various parts of a 7 inch Theodolite should be duly named. To this end we begin with the "Foot screws" of which there are three, working in a "Tribrach." The "Boss" of this Tribrach is pierced with a "Female Axis," in which the the "Lower Vertical (or Azimuthal) male axis" works, and attached to the Boss of the Tribrach is an arm carrying a "Clamp and Tangent Screw." This brings us to the "Horizontal Plate" of the Instrument, which bears the "Graduations" marked on silver; the silver circle being termed the "Limb." The graduations again are read by means of the three "Verniers" and the moveable "Lens" above them; and the fourth arm projecting from the Boss of the "Upper Female Vertical Axis" carries a second clamp and tangent screw. This last mentioned Axis encloses the "Upper Male Vertical Axis." So in succession we arrive at the "Azimuthal Level," from thence to the "*Ys*," within which the "Pivots" of the "Transit Axis" work. Between the Pivots lies the "Telescope," carrying with it two segments of the vertical circle denominated the "Face" of the Instrument. The "Verniers" which appertain to these segments carry their clamp, tangent screw and the

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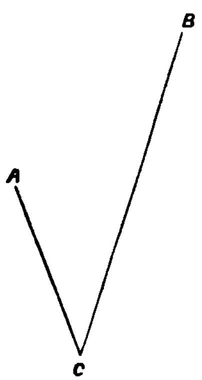
Note 1. The large Theodolites are always raised by the feet, and for Troughton's great Theodolite a lifting apparatus was applied in this country.

Note 2. At this stage, in addition to the notes in para. 4, record the position of the clamps; which, in this class of instruments, defines that of the feet screws. In larger instruments, the reading of the circle when packed requires to be noted, and in some cases, a foot screw and its place in the box should be similarly marked.

"Vertical Level" with them, the whole being fixed in position by means of a couple of antagonistic screws, usually termed "clips," which work against a shoulder between them. As in the case of the Azimuthal verniers, the "Vertical verniers" are read by means of two "Lenses." In the Telescope, we observe the "Eye piece," the "Object Glass" and its "Cap," as also the large "Milled-head," which carrying a "Pinion" and working in a "Rack" attached to the "Sliding Tube" of the Telescope, affords the means of nice adjustment for "Focus." Finally if the eye piece and the tube within which it fits were removed, there would be exposed to view a "Diaphragm" carrying three "Wires," whereby a point within the "Field" of the Telescope becomes defined. The Diaphragm in turn is held by means of four screws whose Capstan-heads appear around the sliding tube of the Telescope. These four screws are termed the "collimating screws."

Measurement of Horizontal Angle illustrated.

8. We may now consider generally in what manner an azimuthal ∠ is measured with the Theodolite. For this purpose, see that the Lower Horizontal clamp is clamped, and that the upper clamp is released. Also, since the assumption will probably simplify a rough illustration, let us imagine the pivots of the Transit Axis raised sufficiently high and the telescope capable of reading its own Horizontal Limb when depressed thereto. (1.) Now let it be required to measure the Horizontal angle at *C* between *A* and *B*.



Move the telescope until it intersects *A*. Then depress the telescope and read the Limb, obtaining by this means a reading of (say) 17°. Next move the Telescope until it intersects *B*, obtaining by a similar process a reading of say 33°. Now since the Horizontal readings of most modern Instruments increase from left to right, or as an ordinary screw is turned in driving it home; that is *increase* in the order South, *West*, North, East; the $\angle\ ACB = 33° - 17° = 16°$. Hence, it is by a comparison of *non simultaneous* readings that the Theodolite measures Horzontal angles; so that, if intermediate to the two intersections *A* and *B*, the Limb of the Instrument happened to undergo movement, then the readings obtained would be vitiated by this movement, and would be no longer comparative. In other words, if after intersecting *A* and reading it at 17°, the Limb moved in such wise that the line *AC* would

Note 1. Of course this supposition is entirely theoretical.

now cut the 19° division, then would the reading of B become 35° and the $\angle ACB = 35° - 17° = 18°$ instead of the real $\angle$ 16°.

Planes in which the Theodolite measures angles.

9. Thus the Theedolite cannot observe two points simultaneously, as for instance is done with the Sextant; nor yet like the latter Instrument can it measure oblique angles. Its measurements can be made in only two planes, vizt. A plane perpendicular to the Normal and the planes perpendicular to that plane. In other words, its measurements can only be made in the horizontal and vertical planes to any point on the Earth's surface.

Stability.

10. The inability to observe two points at the same instant creates this indispensable condition, that no movement shall occur in the limb of a Theodolite, while the Telescope is being moved. To ensure this end, it is essential to secure stability of

(1) Ground or site of observation.
(2) Theodolite Stand.
(3) And of the Theodolite.

Stability of ground.

Stability of ground. It is rarely necessary to adopt any extraordinary precautions for 7 inch Instruments with the object of securing this end. Usually, the paring of the turf under the legs of the stand is found sufficient. But when the site of observation is artificial, and perhaps composed of both straw and earth; or yet again, when observing on dry sand with a strong wind undermining the legs of the stand, it is occasionally found necessary to isolate the Instrument. This may be done by driving three ordinary tent pegs nearly flush with the ground and resting the stand on them, since the vibrations of the pegs in driving them home necessarily causes the isolation required. If required, strike the pegs laterally before driving home, so as to ensure isolation. Tremor and instability of the ground are widely different. The first is momentary and makes no alteration in an intersection. The second leaves permanent displacement.

The Stand and its stability.

11. The stand and its stability. There are three descriptions of Stand used in the Great Trigonometrical Survey of India. Two of these being provided with moveable legs, and the third having its legs rigidly fixed in position. For sketches of the two former, see manual of Surveying page 115. The fixed Stand is probably peculiar to the Department, and besides being the most stable of the three, it is furnished with three long radiating grooves on its

surface, of such length as to accommodate any of the Vernier Theodolites. But in a hilly country, the fixed stand causes considerable delay, since it is necessary to roughly level a plot of ground capable of receiving the legs of the stand. The stands with moveable legs may on the contrary be readily put up under almost any circumstances. To secure the stability of any of these stands, it is only necessary to drive their screws tightly home.

Stability of Theodolite.

12. Stability of the Theodolite. Depends chiefly on the foot screws, the clamps and tangent screws, but as it is intended to offer a few remarks on each of the parts composing the Theodolite, the stability of the above mentioned portions will be commented on in due course.

The Foot Screw.

13. The foot screw should on the one hand have no sensible shake in its socket, and on the other it should admit of being turned by a force short of what would displace the Instrument. This is effected by a slit made horizontally across the female screw, which slit being opened as required, its elasticity keeps the threads in close action with the foot screw. This adjustment will be found much improved in the 8 Inch and other Theodolites recently constructed.

Similarity of Axes.

14. The Upper and Lower Vertical Axes are so precisely similar in construction that it will be sufficient to consider only one of them viz.

The Upper Vertical Axis.

15. The Upper Vertical Axis. This Axis is the frustrum of a cone, the centre portion of which is relieved, so that contact between the male and female Axes (1.) exists along the ends of the Frustrum only. These two Axes are necessarily similar, the female Axis being simply a male one introverted. The male Axis is relieved, to induce a constancy in the bearing surfaces and hence in their centres. Friction is not lessened by this condition, for since friction varies as weight, it is immaterial what amount of surface is in contact so that the pressure is unchanged. The base of the frustrum is provided with a flange, which shares the superincumbent weight with the cone, and it is one of the essentials of stability, that the axis of revolution should in every case work glibly. (2.) To this end, take out the screw and nut at the upper extremity of the axis, also remove the clamping screw and its nut, having previously taken off the Telescope from its *Ys*. Now raise the Instrument

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Note 1. Also called Axis and Socket. Note 2. But of course be free from shake.

by the *Ys*, and the upper portion will lift readily with the hand. Clean the male and female axes with soft cloth, employing some pure olive oil for the purpose. (1) It is at this stage of the operation, that the Limb, Verniers, Clamp and Tangent (1). Screw should be examined and cleaned.

Of the Limb, Verniers, Clamp and Tangent screw.

16.—The Limb and Verniers should be very carefully brushed free of dust and grit, next washed with a little soap and water and finally rubbed over with a cautiously prepared mixture of lamp-black, (2) and oil. In these processes the tip of the finger alone should be employed. It is extremely sensible of grit, and its superior capabilities of polishing are well known. The clamp and tangent screw are of considerable moment in a Theodolite. They are peculiarly liable to be the seat of instability, and on the other hand without their assistance, it would be a tedious and unsatisfactory process to make an intersection at all. The Tangent screw at one of its extremities works in a collar and at the other extremity in a female screw. The collar (in the case of the *Upper* Horizontal Clamp) may be called the "moveable point" and the female screw the "fixed point." This female screw is cut in a stud fixed to a brass plate carrying a shoulder, which plate works in its appointed slide in the lower surface of the fourth arm projecting from the boss of the female-axis. Again through this arm are cut two slots, in one of which the stud before mentioned moves, while through the other the clamping screw passes perpendicularly. This last screw next passes through the brass plate, and attaches to a nut which also carries a shoulder so that when the clamping screw is clamped, the shoulder of the brass plate, and the shoulder of the nut, pinch the upper rim of the Horizontal Circle and hold it firmly. Whence it will be perceived, that a fulcrum is furnished for the tangent screw to act on. Now since turning the tangent screw varies the distance between the fixed and moveable points, and since the former is rendered immoveable by reason of the Lower Horizontal Clamp; the movement created occurs at the collar, and is communicated through the arm, axis &c., to the Telescope. But by reason of their being constantly used, both tangent screw and shoulders be come worn in time, and when this happens, what is termed "lost motion" occurs. Otherwise, the screw being loose, it may be sensibly turned before its threads come in contact with the female screw. Or, the bearing surfaces of the shoulders being wider apart than the thickness of the rim of the Hori-

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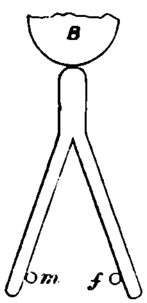
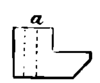
Note 1. Salad oil is frequently adulterated with Linseed oil which latter being a drying oil, soon leaves a gelatinous deposit.

Note 2—Made by holding an oiled plate over the flame of a wick dipped in oil. The more smoke the better. The Lamp Black should be made as required so that it may be fresh and free from grit.

zontal Plate, they are no longer capable of pinching the latter, and thereby furnishing the necessary fulcrum for the tangent screw to act on. In both these cases instability would result. Such sources of instability are occasionally created in the field, at a time perhaps when the Surveyor is entirely dependent on his own resources. It may therefore be useful to mention some of the remedies which fall within his reach. In the case of the tangent screw, the object to be attained is to keep the fixed and moveable points constantly pressed either together or apart (1), whereby the lost motion will become eliminated. To this end take an ordinary bit of bamboo, slit it partially, and adapt the two legs thus produced, to the required thickness. Now if *B* be the boss of the female axis, *(f)* the fixed and *(m)* the moveable point, it is clear that the required object may be temporarily obtained, by fixing each leg of this bamboo spring without *(f)* and *(m)*; the head of the spring being conveniently placed inwards towards the boss of the female axis. Other temporary remedies may also be named (2), but being uncertain and dangerous experiments it is wiser not to resort them. The Clamp on the other hand is both readily and permanently cured. Take out the nut and grind the surface *(a)* until the shoulders bite. This remedy merely requires ordinary caution in application. Returning to the tangent screw, its worm or thread being rather delicate, there is some risk in parting the male and female screws for the purpose of cleaning them. To an unpractised hand, they will be found difficult to fit together again, and being as remarked, of a delicate formation, it is likely that the union will be imperfectly effected and the screw destroyed. It is therefore a wiser plan to clean the screw by repeatedly moving the female screw as required. There is yet another caution which may be useful to note. The tangent screw is taken to pieces by removing a minute screw which will be found in the centre of its (tangent screw's) head. This little screw serves the important purpose of preventing lost motion between the shoulders in which the collar or moveable point works. If screwed at all





NOTE (1) In several modern Theodolites, this pressure will be found effected by means of a spiral spring.

NOTE (2) Such as taking out the Tangent Screw, passing a coarse thread over it longitudinally and then introducing the screw into its female screw. Another method is to take out the Tangent Screw, and holding it perfectly perpendicular, head downwards, to give it a suitably strong tap on its point. Whereby the angle of the spiral becomes slightly altered. This latter is a very dangerous expedient, for it may bend the screw and so render it useless.

too tight, the tangent screw can hardly be turned; on the other hand, any looseness between the shoulders and collar creates an equal amount of instability in the telescope. The tangent screw and clamp play an important part in the manipulation of the Theodolite, and are deserving of proportionate attention. The latter should bite fairly, and the former ought to move glibly and effectually. This last condition cannot be secured unless lost motion be eliminated (if necessary) in the fixed and moveable points and in the clamp.

The upper Vertical Axis resumed.

17. Returning now to the axis. We have supposed that it has already been cleaned, every precaution to avoid the entrance of sand and grit having been carefully adopted. There now remains to oil the axis before closing it, and for this purpose the best lubricating matter will, it is believed, be found in pure olive oil. The most suitable oil for the axis of an Instrument probably depends on the weight (so to speak) to be floated. For a large weighty instrument thicker (though not much more gelatinous) oil may be more suitable, but in the absence of more positive evidence, pure olive oil filtered through blotting paper, will be found to answer for the axis of every instrument, from the 7 to the 36 inch.

The Verniers and general remarks on foregoing.

18. It is objectionable to clean the Limb and upper surface of the Verniers of a Theodolite frequently, because the friction must necessarily produce some amount of abrasion. Once a year is generally found sufficient. The adage that "prevention is better than cure" is well suited to these surfaces, for they may be long kept in good and workmanlike order, by brushing them free from dust and grit with an ordinarily soft camel's hair brush. Indeed the habit once acquired, Surveyors may be seen brushing the Limb almost unconsciously as they walk round and round the Instrument. On the other hand the Upper Vertical Axis, and the lower surfaces of the Verniers require frequent cleaning. The latter is easily effected by holding a piece of thin soft cloth on the Limb and making the Vernier pass over. But on this and every other occasion, when the Vernier is being cleaned, it must be remembered, that its sharp silver edge is very soft and that a trifling force will injure it. Verniers should always be wiped *with* the edge, not against it. There are three Verniers in this Instrument as already mentioned, and in all cases, whether of Verniers or Reading Microscopes, the number will be found to be an odd one. One of the reasons for this condition may be thus stated. As far as the very rough measurement of an angle is concerned, one Vernier

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will evidently serve the purpose as well as a larger number, but owing to the imperfections of graduation and errors in estimating minute quantities, a mean reading from three or more Verniers will obviously be more accurate than the reading from one such Index. Now by a process to be hereafter described (technically termed "changing face") the *reading* of any object *A* becomes altered by 180°.—Whence it follows, that were there an *even* number of Verniers, "changing face" would simply make the opposite Verniers exchange places without the desired alteration of reading being produced. The Vernier should neither press on the Limb, nor yet rise above it. In the former case the graduations on the Limb must become worn, and since the Verniers are generally minutely unequal in distance from the axis of motion, a space will be created between the longest or the shortest Verniers and the Limb, according as the Verniers form an external or internal circle to the Limb. The internal Vernier is preferable, because it can be better illuminated and is less liable to become raised above the Limb, an evil already alluded to and which creates an uncertainty of reading according as the lens is normally under the eye or otherwise.

The Azimuthal Level.

19. The Azimuthal Level is suspended by two drawing screws working in collars, and it is desirable that the Level should be fixed as high up on these screws as practicable. That is to say, when adjusting the Level in its place, always raise the required end in preference to lowering the other. For it is evident, that the longer the lever the more liable will the level be to shake and derangement. Analogous remarks apply to the Level employed in observing Vertical Angles.

The Clips.

20. The Clips, should furnish *points* of contract with their appointed shoulders, not surfaces, and they ought to work antagonistically in the same straight line. When the circumstances existing are contrary to these conditions, the clips have a tendency to raise or twist the Pivots of the Transit Axis.

The Pivots and Cleats.

21. The Pivots of the Transit Axis should always be wiped clean before being placed in their *Ys*, for the interposition of grit must necessarily wear them away. The same precaution of course being observed with the *Ys*. The cleats should neither press on the Pivots, nor yet should there be an intermediate space between the former and latter. In fact there should be contact, without pressure on the one hand, or room for the Pivots to rise on the other. In larger Instruments the Cleat sometimes carries a small piece of cork at-

tached to its under snrface, which cork furnishes a point of contact between the Cleat and Pivot.

The Vertical Verniers, Clamp and Tangent Screw.

22. The Vertical Verniers, clamp and tangent screw are similar in all essentials to those appertaining to the Horizontal Circle already discussed. It only remains to add, that the plane of the Vertical Verniers should be parallel to the plane of the Vertical Circle. The segments of the latter admit of depressions and elevations of about 35 and 30 degrees respectively. They are fixed to the Telescope by means of two screws which appear about the imaginary line connecting the zeros of the Vertical Arcs; and of these screws it is to be noted, that they should never be moved. In the original putting together of the Instrument, the plane of the Vertical Circle was placed perpendicular to the transit axis, and the line joining the zeros on the Vertical Circle put parallel to the optical axis of the Telescope. At least these conditions were then secured within small limits. There is no object to be attained by opening the screws, while the only probable result obtained will be a general and perhaps permanent derangement of the Vertical Apparatus. The numerals on the Vertical Arcs increase from their zero or 0°, both upwards and downwards, thereby furnishing direct readings of elevations as well as of depressions.

Of the Telescope.

23. The Telescope should define sharply and without color *i. e.* the light refracted should be white light. Its object glass is composed of two lenses, the outer being of double convex form and of blue crown glass, the inner lens is concavo-convex and made of white flint glass. In 7 inch Theodolites these glasses are usually fixtures, but with the larger class of Instruments, they can be taken out of their cell on removing a ring which screws against them. The object glass should always be fairly screwed home in the telescope, as any rotary motion alters what is termed the "line of collimation," a technicality to be hereafter explained. (1) To the same end, the cap of the object glass must always be both put on and taken off by the screwing (not unscrewing) motion, since it is usually too tight to be moved without turning it round. The power of a Telescope is measured by the quotient, obtained from dividing the focal length of the object glass by the focal length of the eye piece.

The Eye pieces.

24. There are two eye pieces to the telescope; the shorter one with two lenses, and another with four. The first of these shows objects direct, but since the image formed in the focus of

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Note 1. The object glass should also be firmly fixed in its cell.

the object glass is an inverted image, objects seen in the telescope with this eye piece appear inverted; and hence it is called an "inverted eye piece." By reason of its fewer glasses, it refracts more light and is the more suitable one to use. The eye piece with four lenses is called a "direct eye piece" for similar reasons. It is the one mentioned at paragraph 4 as not usually wanted. The object glass very rarely requires internal cleaning, indeed as already implied it is objectionable to unscrew the object glass, since doing so deranges the line of collimation. The eye piece however requires frequent cleaning, chiefly of the outer surface of its outer lens. Glasses should not be opened in damp weather, for the efflorescence which is some-times found to settle on a lens and dim it, is probably attributable to a neglect of this precaution. It may be readily ascertained which of the two is not clean, the object glass or the eye piece. To this end look into the sky and at the same time turn the eye piece in its cell. If the little specks which appear in the field revolve with this motion, the eye piece is at fault. When necessary, select a dry day and clean the glasses with spirits of wine and a soft handkerchief.

The Diaphragm and how to wire it.

25. The Diaphragm will be found nicked for two systems of wires, one comprising a horizontal and two diagonal wires cutting each other in nearly a common point, and another in which a vertical and a horizontal wire may be employed. The latter is most suitable for luminous signals, which furnish discs for intersection. For ordinary objects, such as poles, brushes &c., the system of three wires is preferable. To wire the Diaphragm, remove the 4 small screws which hold the eye end of the Telescope to the sliding tube. Draw out this end with the eye piece, and remove three of the four collimating screws. Then turn the fourth a quarter of a revolution and the Diaphragm will necessarily turn with it and protrude. The latter may now be laid hold of conveniently and removed, and the object in describing this part of the process in detail is, that unless the diaphragm be similarly handled in replacing it, the chances are that the wires will meet with accident. The wires employed in Theodolites are either silk fibres or Spider's lines. The former is the stronger of the two, and wiring may be rapidly effected with it. The spider's web however furnishes the more even wire. Opinions differ on the question of preference between these two, but the silk fibre is probably more suitable to Vernier Instruments. (1) In wiring, clean the surface of the Diaphragm and the nicks on it, with spirits of wine. The Diaphragm may next be laid on any

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Note 1. That is, to Eye pieces of low powers.

slightly raised surface. Now select a silk fibre, append a small ball of wax to each end, and fitting the fibre into two opposite nicks, let the balls of wax hang free to tighten the fibre. When the required member of wires are thus placed, fix them to the diaphragm with drops of laudanum, or any other adhesive liquid. A better method of tightening the wires is to open the legs of a hair spring compass sufficiently, first releasing the spring, attach the wires to these opened legs with some wax, and then by drawing the spring, tighten the wire to the required tension. This process may however be overdone, in which case, while avoiding the evil of festooning, a contrary evil will have been incurred; the wire will then be found jagged and as if twisted. A wire should be even edged, of equal thickness, and covering, says Mr. Troughton, two thirds of the object.

Of the Magnetic Needle.

26. The Magnetic Needle has a positive and a negative end, of which of course the latter flies from the Magnetic Pole. The positive end will generally be found marked. It should be fixed towards the object end of the Telescope. There is always some little play in the perforations, through which the screws attaching the Needle box to the Telescope, pass, so that to obtain comparative bearings, the needle box should never be moved intermediately. On the other hand it is not possible to "change face" with the needle on, since this process brings the box into contact with the nut of the Vertical axis. When packing for travelling, the needle should always be thrown off its centre by means of the small lever provided for this purpose.

Of the Milled-head for adjusting focus.

27. There remains the large milled-head attached to the side of the Telescope to notice. By means of this screw the adjustment for focus is made. It carries a pinion at its inner extremity, which acting on a rack attached to the sliding tube at the eye end of the Telescope, pushes out or draws in the eye piece. The pinion and rack hardly ever require cleaning, but should this become necessary, the milled-head may be removed by opening the four little screws which fasten it to the Telescope. As in the case of the tangent screw, the small screw in the centre of this head should be tightened no more than necessary. If this small screw be removed before withdrawing the four little screws above-mentioned, the pinion may drop into the Telescope, and rolling down it to the eye piece, break the wires.

How to "Change Face."

28. The face of the Instrument it will be observed stands over Vernier *A*, a condition which is always to be secured when replacing the pivots in their *Ys*. To change face signifies to turn the Telescope 180° vertically, that is on its transit

axis. In those Instruments which have complete Vertical Circles, the process comprises a literal following of the above definition; but for obvious reasons a 7 inch requires a somewhat different manipulation. Suppose the Instrument to stand at face left, which implies, that standing at the eye end of the Instrument its face falls to the observer's left hand. Now let it be required to change face. The manipulation is as follows. Open the cleats and release one of the two clips, the upper Azimuthal Clamp being free to avoid strains from accidental jerks. Raise the Telescope out of its *Ys*. Hold its object end with the left hand, and it is useful to remember that this end should never be held uppermost, or any dust within the Telescope will fall on to the wires. Now unclamp the Vertical Clamp and turn the Verniers 180°, whereby they will change places; clamp, change the Telescope end for end in the hand. Replace in *Ys*, keeping the face over Vernier *A*, and make the released clip pinch. The object and eye ends of the Telescope will thus have exchanged positions, and if as before, the observer stand at the latter end, the Face will now fall on his right hand. Before this procses was gone through, the Instrument was said to be at "face left" It now reads "face right."

The principle of the vernier.

29. We may next proceed to the principle of the vernier. Let it be supposed that the limb is divided to 20′ as is usually the case with 7 inch Theodolites. Take off a distance = 39 such divisions on the vernier plate (which we will suppose for illustration not to be graduated) and thereon divide this distance into 40 parts, numbering every fifth alternate line thus, 5, 10 &c.

then	39 divisions on limb		=	40 divisions on vernier
whence	$\frac{39}{40}$,,	,,	=	1 ,,
but	1 ,,	,,	=	20′ of arc
∴ 1 division on vernier =	$\frac{39 \times 20'}{40}$,,	,,	=	$19\frac{1}{2}'$,,

And 1 division on limb − 1 Division on vernier = 30″ ,,

Generally if (a) be the arc measure of one division on the limb, and the united distance of n such divisions be taken off on the vernier, then

$$\text{One division on limb} - \text{one division on vernier} = \frac{a}{n+1} \text{ in arc,}$$

wherefore, if the zero or arrow on the vernier be coincident with the 0° division on the limb, and it be required to increase this reading by 30″, we must turn the Telescope until the first division on the vernier, counting from its zero, coincides with the 0°20′ line on the limb, when, the Instrument will evidently read 0°0′30″. So if the zero be pointing to some undefined point on the limb lying between the 27°20′ and 27°40′ lines, while *the* line on the vernier coincident with one on the limb is the 17th from the vernier zero, we have for reading.

From the indication of vernier zero, ...		27°20′
From coincidence of the vernier 17 × 30″,	= +	8-30″
Wherefore the Instrument reads, ...		27-28-30

30. The principle and practise of the vernier will be sufficiently clear from the foregoing; it only remains to notice, that a vernier can always, when necessary, be read by estimation to half the arc for which it is divided. Thus in a 7 inch, whose limb is graduated to 20 minutes, and when $n = 39$ such divisions sufficient nicety of reading may be attained to, to estimate such readings as 27°28′15″ or 27°28′45″. In these cases the estimation is made from the *deficiency* of coincidence.

Estimating reading of vernier.

31. Further there will be noticed, that this difference exists between the numbering of the horizontal and the vertical verniers. In both cases the numerals will be found marked at every 5th minute, but in the case of the vertical verniers there appear two sets of numbers, such that the sum of the two numerals at any given line is always = 20. Thus the coincidence may indicate a vernier reading of 7 or 13 of 4 or 16 minutes, &c. The internal numbers or those nearest the transit axis are intended for reading elevations. At least this is usually the case. But the observer may readily decide for himself by this Rule, the truth of which is apparent. In any given position of the vertical circle, adopt that set of numbers on the vernier which *increase* in the direction *from* the zero on the limb *towards* the zero on the vernier. Thus let the Instrument be pointing to an elevation. Then 0° on the limb at the object end of the Telescope will be above the zero on the vernier, and the direction from the former towards the latter is a downwards direction. Whence that set of numbers should be adopted, which increases numerically in a downwards progress. Finally on that segment of the vertical arc towards the object end of the Telescope, there will be seen certain graduations on brass marked as " difference of Hyphothenuse and Base". Which in other words means, when the index of this graduation reads the number 2, it is signified

Of the vertical arcs and verniers.

that the Hypothenusal length at that inclination minus its corresponding horizontal length, is equal to 2 links per chain.

32. We may now consider the adjustments of the 7 inch Theodolite, which are both included in the following and performed in the order therein enumerated.

The adjustments.

1. Centering over a given point.
2. Setting the vernier lenses.
3. Obtaining distinct vision of wires.
4. Eliminating parallax, commonly called " finding focus".
5. Setting to zero.
6. Levelling, otherwise making the vertical axis perpendicular to the horizon.
7. Collimating in azimuth.
8. Making the vertical and horizontal wires respectively vertical and horizontal.
9. Setting the level of the vertical arcs to their zero of altitude. To these may be added a tenth, which is however only applicable to those Instruments provided with the means of changing the height of one of their pivots.
10. Levelling the transit axis (1).

33. In considering these adjustments, (7) (8) and (10) will not be noticed in the first instance. The intention being to return to these processes so soon as a more intimate acquaintance with the Theodolite has been made.

Prefatory.

34. Centering. The Theodolite being placed on its stand, suspend the plummet from the former or the centre of the latter, according as the Theodolite is provided with a hook for the purpose or not. Now move the stand until the point of the plummet is immediately over the given point of observation. The nicety to which this process should be performed, depends firstly on the

On centreing over a given point.

NOTE (1.) The instrument herein especially commented on, viz. the 7 inch altitude-azimuth is not provided with the means of levelling its transit axis, and hence this adjustment is mentioned last in the enumeration made. In fact, as completing the list, when however the means of doing so exist, the transit axis should be levelled *before* collimating the Instrument in azimuth, unless the object observed in collimating be situated exactly in the horizon.

powers of the Instrument, and secondly on the distances of the objects observed, generally, in an Instrument reading to (n) seconds, it is probable without the limits of accuracy to estimate any angle measured by it as true to $\frac{n''}{2}$; always provided that the Telescope is sufficiently powerful to appreciate the $\angle \frac{n''}{2}$ on its Limb. Now, one second of arc at a distance of 43 miles subtends one foot of linear measure nearly. Also in a 7 Inch Theodolite $\frac{n}{2} = 15''$. So that if A be the station of observation, and B and C the objects for intersection, such that $AB = AC = 1$ mile (nearly,) then we have $\frac{12 + 1 + 15''}{43} = 4{\cdot}19$ Inches as the limit of uncertainty under the assumed circumstances. But however this may be, the observer should accustom himself to far greater nicety in all his operations especially when that end may be attained without any serious sacrifice of time. As a general rule, the 7 inch should be centered true to 0·2 of an inch, and this may be effected in half a minute.

Setting the Vernier Lenses.

35. Setting the Vernier Lenses is an apparent process. Raise or lower the Lens until distinct vision of the Verniers is obtained. Otherwise, place the given Vernier in the focus of its Lens. When the Vernier happens to be raised above the Limb, the most suitable focus then to be found will evidently bisect the space between the Vernier and Limb. In such cases there will unavoidably result what is termed "parallax," an expression to be considered presently in connection with the Telescope.

Prefatory on obtaining distinct vision of the wires, and eliminating parallax.

36. Processes (3) and (4) may be profitably considered conjointly, especially as any *great* change in the focus of the object glass necessarily produces a sensible difference in the focus of the eye piece. In the large and more powerful Theodolites, adjustment (4) is rarely if ever required to be altered, and it is to be remembered that such alteration in Instruments of all dimensions, affects the line of collimation. Owing however to the variability and shortness of distances appertaining to secondary operations, it is ordinarily required to perform adjustment (4) at every station of observation. This however is no reason why the object glass and eye piece should be pushed back to their normal position before packing, and since most 7 inch cases will not admit the Telescope as it stands elongated for observation, a suitable recess should be made in the box for this purpose.

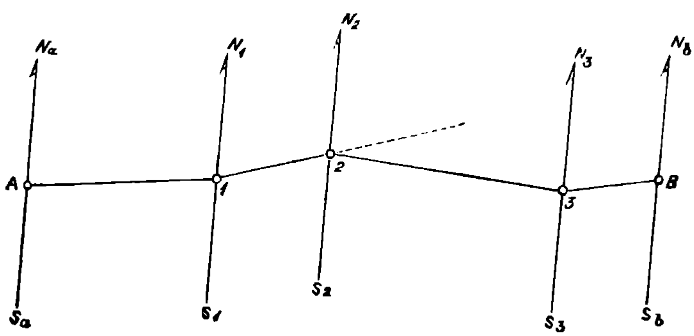
37. To perform (3) turn the Telescope until it looks into the sky, or any other field of vision, devoid of such terrestrial objects as are likely to distract the eye from the wires. Push in or draw out the eye piece until the wires are most distinctly visible. Now perform (4) and if so doing has deranged (3) re-adjust the latter finally. The object of the wires is clearly to define a point in the field of vision. Adjustment (4) serves to form the image, refracted by the object glass, in the plane of these wires; while by means of adjustment (3) the focus of the eye piece is made to fall in this common plane. In other words, the focus of the eye piece, the wires and the image refracted through the object glass, must all lie in the plane of the wires. Wherefore to perform (4) direct the Telescope to any object which admits of accurate intersection, clamp and intersect. Now imagining the wires to be fixed, move your head laterally as far as the field will admit, while your eye is intently watching the intersection of the object by the wire. According as the object appears to move, or otherwise, so is it said that there is, or is not, "Parallax." In the former case, the image must be formed either between the wires and the eye piece, or between the wires and the object glass. The first is distinguished as near, and the second as distant parallax, and the respective adjustments are evidently these. In the first case elongate by means of the milled head, the distance between the wires and object glass. In the second case the same distance requires to be shortened, until no parallax is perceptible. As a further assistance in remembering the distinction between near and distant parallax, the following familiar illustration, may be useful. Imagine to the east of your position, a Church steeple in the distance and a tree in the foreground, on the line drawn from your eye to the former. Let the Church steeple represent the wires. Now if you move to the North, the tree will appear to the South of the steeple, in other words the object will move against the eye as in near Parallax. On the other hand, the tree being in the distance while the steeple occupies your foreground, if now you move to the North, so will the tree appear to the North of the steeple, illustrating the case of distant parallax when the object moves with the eye. It is only necessary to remember, that it is the *wires* which represent the fixed object, and the foregoing familiar illustration will always readily show whether the distance between the object glass and wires should be elongated or diminished. Also, adjustment (3) will be found to vary for different eyes, while (4) should be found suitable to all observers. Adjustment (4) varies rapidly for near objects, owing to the variability in their angles of incidence, which rays from such objects undergo. But so soon as such rays become parallel, or nearly so, the point of no parallax will be found

The same two adjustments continued.

constant for all objects more distantly situated. For instance the point of no parallax for the sun, any Planet or Star, and for all terrestrial objects 10 or 15 miles distant, will be found to be identical. The condition implied by the technicality " Solar focus" is this, that the rays of light emerging from the given object, and impinging on the object glass, shall be parallel to one another.

Setting to Zero and the same in connection with the Needle.

38. Setting to zero requires, that any given point shall read a given reading on the Limb, or nearly so. For this purpose, set vernier A to the given reading, unclamp the *lower* clamp and turn the Telescope by the Horizontal plate, until the given object is nearly on the wire. Now clamp the lower clamp and intersect with its tangent screw. To perform this process effectually, the Instrument should be first roughly levelled. The object to be attained in setting to zero, is to observe the required angles at certain readings and changes of reading, in pursuance of an established system of observation. These readings (in all cases of the left hand point) being technically termed " zero" or origin. Otherwise, in the case of the 7 inch and when carrying on a route survey or traverse, setting to zero combined with the use of the magnetic needle is of considerable utility in checking gross errors of observation. Thus let the following be a route survey.



In which N_a S_a, N_1S_1, &c., denote the Meridians respectively at stations A, 1, &c. Now since the distances involved, A to 1, 1 to 2 &c. = 1 mile or there abouts, and the 7 inch Theodolite is not capable of measuring angles true to less than 15″ of probable error, it follows that the convergency of these Meridians may be neglected under the circumstances. Whence N_a S_a, N_1S , &c., may be taken parallel to each other. And if N_1 at 1 read $A°$, and 2 read $A° + a°$, then it is evident, that at 2, if 1 be set to zero = $A°$ —

$N, 21 = A^\circ + a^\circ - \pi$, the reading of the Magnetic North Pole will remain, constant, provided the bearing at 1 of 2 was correctly read. Generally if any forward bearing $= F^\circ$, then while the reading of the Magnetic North Pole remains invariable, the back bearing will always $= F^\circ - \pi$. When this equality is found not to exist, it indicates some error of observation at the preceding station.

On Levelling the Theodolite.

39. Levelling. As already indicated, this requirement consists in placing the Vertical Axis truly perpendicular to the Horizon. Which may be done thus,—place the level parallel to any two foot screws, and by suitably turning these latter bring the bubble into the centre of its tube. Then turn the Telescope 180° in Azimuth, observing that the same direction of motion is adopted on every occasion of Azimuthal motion. Supposing the bubble now to occupy a different place from what is did before, move it by means of the two foot screws into the mean of these two places, and it is evident that if the Telescope be further turned 180° in Azimuth, *i. e.* into its original position, the bubble will still continue to occupy that mean place into which it has been moved. This mean place is called the zero of the level. Next turn the Telescope 90° in Azimuth, and by means of only the third and hitherto unused foot screw, move the bubble into the mean place already indicated. The instrument is now level or approximately so, and in the latter case, the foregoing process must be repeated until the bubble continues in the same place, however the Telescope may be made to point. This mean place should not necessarily be the central one in the tube, but in case the deviation is much more than a sensible quantity, move the bubble as required by means of the two drawing screws which hold its tube. These two processes, viz., that of finding the zero of the Level, and of correcting that zero, have been intentionally kept apart in the above discussion. But they may be readily performed together. Place the level parallel to any two foot screws, and by means of the latter bring the bubble into a central place. Now turn the Telescope 180° in Azimuth. Half the error lies in the foot screws the other half in the drawing screws before mentioned. The zero of the level is not constant throughout the day, varying as it does with the Temperature. And since the expansion of the Liquid contained in the glass tube, (spirits of wine) is greater than that of the glass, it follows that the bubble will vary in length inversely with the Temperature. So, the bubble is shorter at noon than it is of a morning; and from the latter period to the hottest time of the day, its zero will continue to recede towards the centre of the glass tube. For further remarks regarding Levels in general, as also

on the determination of the value of a level scale, see appendix *B* to " Instructions for Topographical Surveying."

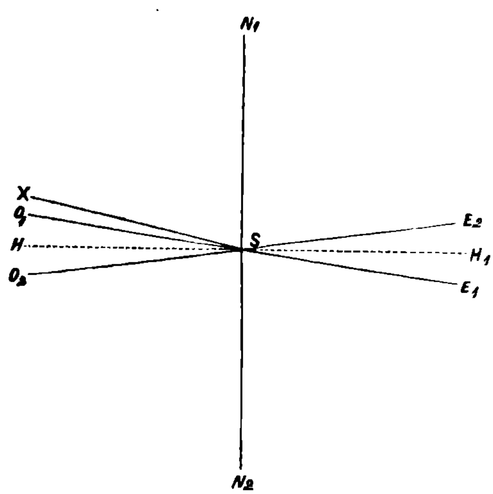
40. Setting the Level of the Vertical arcs to their zero of Altitude.

Prefatory.

Before considering this adjustment, it is proposed to give a definition of the expression " Line of Collimation."* Thus, the imaginary straight line joining the intersection of the wires and the optical centre of the object glass, is called the line of collimation.

On setting the level of the Vertical arcs to their zero of Altitude.

41. Now adjustment (9) secures the following conditions. When the bubble of the Vertical Level stands in the centre of its tube (or run) and the Verniers stand at zero, if the Telescope be made to describe an Azimuthal circle, then the plane thus generated by the line of collimation, should be at right angles to the axis of motion, otherwise the Vertical Axis. In other words, when the Vertical Axis is perpendicular to the Horizon, and if there be imagined a point *X* situated exactly in the plane of that Horizon, then set the vertical arcs to zero or 0° 0′ 0″ and intersect the object *X* on the Horizontal wire with the *Clips*. Now bring the bubble of the Vertical Level into the centre of its run by means of its adjusting screws, and it is evident that adjustment (9) will have been performed. But in reality no such point as the imaginary one *X* exists, whence the process becomes as follows. Let N_1N_2 be the Normal to *S*, HH_1 the Horizon, and *X* any point whose true elevation is $a°$. Level the Instrument. Fix the bubble of the Vertical circle in the centre of its run by means of its clips, and let the erroneous horizon thus indicated be represented by O_1E_1. Also let the Instrument be now standing at face left, then the measured altitude of $X = a° - O_1SH$. Next change face, setting the bubble by its clips as before. Whence if the Telescope be again directed to *X*, it is evident that the erroneous horizon will be represented by O_2E_2, such that $O_2SH = O_1SH$, Wherefore the measured altitude of *X* at face right $= a° + O_1SH$, and the mean altitude by face right and left

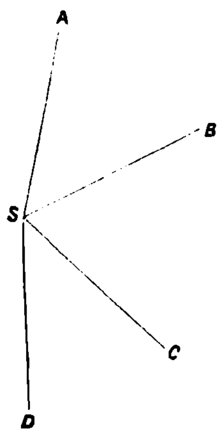


* Collimatio, an aim or Level; from Collineo, I aim in a straight line.

$= \frac{(a^\circ - O_1SH) + (a^\circ + O_1SH)}{2} = a^\circ$ the real altitude. So that, having found the actual Elevation, the procedure becomes the same as that already described in the case of an imaginary point situated in the horizon. Thus set the Vertical arcs to read an elevation of a°; intersect X by means of the clips, and while maintaining these conditions, bring the bubble of the Level into the centre of its run or glass tube. It is also evident from the foregoing, that provided the position of the level bubble be constant at faces left and right, any error in the assumed Horizon will become eliminated in the mean value of the two vertical angles.

On the process of observing Horizontal Angles.

42. We may now proceed to observe with the Theodolite thus adjusted, reserving as already remarked, adjustments (7), (8) and 10 for subsequent notice. Let it be required to measure on zeros 0° and 180° the angles at S, between A, B, C and D, two measures of each angle being taken at each zero. Here A, is the left hand point, and in compliance with the foregoing conditions we will suppose it to have been set to $0^\circ - 1'$ on Face left. Bring the Telescope up from left to right until it nearly intersects A, clamp and intersect, read and register the verniers, taking the degrees from vernier A. Now examine the intersection, and if found good unclamp and turn towards B preserving the same direction of motion, clamp, intersect, read, register and examine as before. Similarly proceed to C and then to D, when one round will have been completed. This round will thus have been observed throughout with a similar motion from left to right, and it is required to be noticed, that in such cases when a point is overshot accidentally, the Telescope must be turned back well past the point, before bringing it up again for intersection with the original direction of motion. Now find the mean reading for each intersection, and the differences $B-A$, $C-B$, $D-C$, will be the angles sought. But as two measures are required at each zero, turn the telescope well past to the right of D, and repeat the round in the order D, C, B, A. In this latter case the motion will be from right to left, In other words the circumstances of the second round will be contrary to those of the first, and therefore, the mean angles of the two rounds, are calculated to be free from such errors as may be especially engendered by either circumstances. This completes the two required measures at zero 0°.



43. Next change face, which will now become right, and proceed as before. In changing face it will be observed, that the place of every vernier for the same intersection has been altered by 180°, and that this result has been obtained without the necessity for re-levelling. But here it is to be remarked, that in changing face, the same Pivot is always returned into the same *Ys*. It is true, that were the pivots alone changed and the Telescope inverted as before but without any manipulation of the vertical arcs, the readings would be altered by the required angle π, while the face of the Instrument would still remain at the observer's left hand. This process is sometimes adopted in route surveys checked by the Magnetic needle, for the reason that the face cannot be changed without the objectionable step of removing the needle, and because it is a highly desirable check to measure the required angle at different parts of the Limb. But to change pivots, the vertical arcs must be placed over verniers *B* and *C*; when the weight of the vertical apparatus, generally without a counterpoise, becomes transferred from one to the other side of the Instrument. As a consequence verniers *B* and *C* are found difficult if not impossible to read, while the transfer of the weight above noticed throws the vertical axis out of verticality. Besides, by changing pivots results of error in Azimuthal collimation (to be hereafter discussed) are not eliminated in a mean of the two zeros. Whereas, by changing face, this elimination is effected. Whence it is undesirable to change pivots at all, and decidedly objectionable if the change be made unintentionally. It is a convenience in observing, that the upper clamp and tangent screws should admit of the Lens passing over them, because when this is the case the Lens is readily carried round by the shortest route.

Horizontal observations continued.

44. Azimuthal angles should be measured with the vertical clamp free; and it is to be remarked, that if *A*, *B*, *C* and D are at different altitudes, the principal enunciated of retaining similar circumstances throughout any given round, should not be lost sight of, in depressing or elevating the Telescope for the horizontal Intersection. That is if *A* reads an altitude, *B* a depression, *C* another altitude, and so on; then if in intersecting *A*, the Telescope was raised to the object, so ought it to be depressed below *B* and raised to it in proceeding to its intersection, and so on. When turning the Telescope horizontally or vertically the force respectively employed should be in those planes; and in the manipulation of the tangent screws, the motion imparted should be truly rotatory without pressure in any direction.

The same.

45. Vertical angles must be observed with the horizontal clamp free, for it will be found that the contrary condition dislevels the Instrument. The intersections for these angles are of course made with the horizontal wire, a little on one side of the bisection of the wires for the sake of clearness, but whichever part of the wire be selected for this purpose, it should constantly be adhered to. The process of observing these ∠ s may be thus described, and in so doing it will be useful to imagine that the level is furnished with a scale. Let the Instrument be at face left, intersect, note time, read and register verniers and level scale (1), the Bubble of the latter being stationary. Now change face, which will thus become face right, and proceed as before. A mean of the two mean values, one at face left and the other at face right, will evidently be free from collimation error (also called Index error) as already shown, and in order to find the true observed elevation of the given object, it will only be necessary further to correct this mean result for "Level error." See appendix *C* and *D* to "Topographical Instructions." The mean of one observation at face left and one at face right constitutes what is known as a "collimated observation;" it is usual to take at least two such collimated observations on each day of observation.

On observing vertical angles.

46. To find the amount of collimation error, take the difference between the two faces and halve it. Thus in example 1st Appendix *D* to "to Instructions for Topographical Surveying," the collimation error is as follows.

Of collimation or Index error.

by first collimated observation $\frac{6''\cdot85}{2} = 3''\cdot425$

by second „ „ $\frac{8\cdot20}{2} = 4\ \cdot10$ Mean $3''\cdot76$

Additive in this example to face left, when the observed vertical angle (at one face only) is a depression.

47. As already remarked, the standard number of vertical ∠ s to any given object is two collimated observations, otherwise two pairs, but in those cases when an observer is detained at a station, it is advisable to repeat the angles daily. Vertical observations with Instruments which

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Note (1) Theoretically the level scale should be read at the instant of making the intersection for it is required that the conditions existing at that instant should be indicated. But in practice, the movement in the Bubble occasioned by changing face and turning the Instrument horizontally, generally continues for a minute or so after intersection, and hence it is advisable to read the verniers first and let the Bubble have time to steady. In taking the meridional altitudes of the zenith stars at Banog H. S., it was found indespensable that the level scale should be read instantly after observation and before reading the Microscopes.

have only segments of the Verticle Circle, should be taken in rounds. That is to say if there be objects *ABCD* visible at *S*, the order of observation in rounds would be

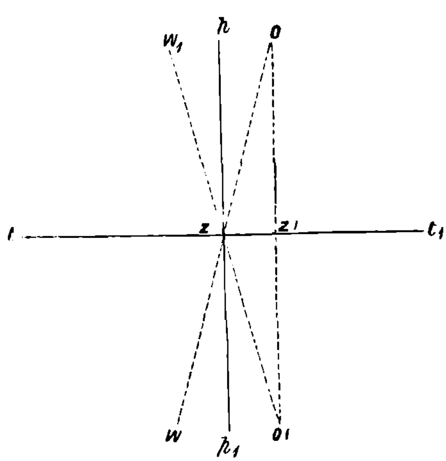
Face Left *A,B,C,D,*
Now change Face, and observe
Face Right *A,B,C,D.*

Rigorously speaking, these observations should be taken between the hours of $1\frac{1}{2}$ and 3 P. M. of apparent time, which are about the limiting periods of minimum Refraction. Also if at *A* the object at *B* be observed at say 1 h. 47 m. P. M., then at *B* the object at *A* should be observed at the same hour or nearly so. The reason for this last condition may be stated thus. In computing the angle which subtends the difference of height between *A* and *B*, it is assumed that the terrestrial refraction at one station is equal to that at the other; and similarity of circumstances between these reciprocal observations is most likely to produce equality in refraction. The foregoing remarks apply more especially to Vertical angles measured with the superior classes of Instruments, but they cannot be seriously neglected even in the case of a 7 inch Theodolite; for other reasons excepted, objects may be seen to rise after the period of minimum Refraction at the rate of 1 minute of arc in each minute of time, and even more rapidly. But whatever the class of Instrument employed, it is obvious that the height of eye and object are essential Elements, as without these, the results cannot be reduced to the levels of the stations observed at.

Of Collimating in Azimuth.

48. We may now return to adjustments (7) (8) and (10).

49. A Theodolite is said to be collimated in Azimuth when its line of Collimation, cuts its transit axis or axis of motion at right angles. Thus let $t\,t_1$ denote the Transit axis. Then when the line of collimation (which for shortness sake call (*c*) coincides with the perpendicular to $t\,t_1$ or $p\,p_1$, the Instrument is in collimation. And if now it be made to describe a semicircle in its *Ys*, it will pass through the zenith, *describing* a *great* circle. But if *c* be represented by *OW*, then will the semicircle traced out be represented by OO_1, the false zenith being Z_1, while the arc de-



scribed will be that of a *small* circle. In other words by changing face, the object end or O will arrive at O_1, while the wires or W will describe a similar *small* semicircle and reach W_1. Whence if any object in the horizon give a horizontal reading at Face Left of a°, and then the Pivots of the Instrument be changed and the Telescope turned sufficiently in Azimuth again to Intersect the given object, the two readings thus obtained will disagree from each other by OW_1 instead of exactly coinciding.

Wherefore the error in collimation at the horizon will $= \frac{OW_1}{2} = OP$.

Methods of collimating enumerated.

50. There are three methods of collimating in Azimuth.

1st. By changing Pivots. A process applicable only to small and light Instruments.

2nd. By changing Face. An unsuitable method where the Verticle circle is not a complete one.

3rd. By Gaus's, method. Which is applicable to all Theodolites.

Collimating by changing Pivots.

51. By changing Pivots. Throw open the cleats and see that the clips are just biting their shoulder and no more. Now intersect Azimuthally and note the reading of any fixed object, taking care that the clamps are holding firmly. Next release clips, raise the Telescope gently and turn its Verniers 180° to bring the clips lowermost, change Pivots, replace the Telescope without the smallest knock or violence of any kind, the object end still pointing towards the fixed object. The success of this process depends on the rigidity of the Instrument in Azimuth, intermediate to exchanging the Pivots. If the Telescope in its second position still intersects the fixed object, the Instrument is in collimation, otherwise perform the intersection with the Tangent Screw and note this second reading. Set the Instrument to the mean of these two readings, and then looking into the Telescope, move the Diaphragm by its collimating screws until the wires again intersect the object. Repeat the process, until the intersection remains constant on changing pivots, remembering that half the apparent is the real error, and that (with what is called an inverting eye piece) the diaphragm should be drawn in the same direction which is apparently indicated. In other words, if on reversing Pivots, the Instrument should prove not to be in adjustment, then set to the mean reading as above explained, and draw the wires *towards* the apparent place of the image.

52. It has been recommended in the foregoing that collimation error should be eliminated by finding twice its measure on the limb, and from thence to obtain the reading of the true line of collimation. But the same elimination may also be effected by estimating half the error as it appears in the Telescope, and dispensing with readings.

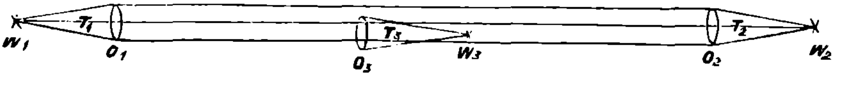
Continued.

53. Collimating by changing face is most suitable to weighty Instruments with complete vertical circles, in which the face can be changed without the necessity of lifting the pivots out of their *Ys*. In prosecuting this method, intersect and take the reading of any fixed object, change face (not pivots) and intersect and read again. The two readings should disagree by exactly 180°; otherwise correct analogously to the first mentioned method. It will be observed, that in collimating by changing face, such errors of graduation, as may exsit in the divisions of the Limb employed, are involved in the process.

Collimating by changing Face.

54. Gaus's method of collimating is superior to both the foregoing, dispensing as it does alike, with the objectionable necessity of changing pivots in the one process, and the angular measurement whereby errors of graduation become involved in the second method. Also, the adjustment being performed at solar focus, and that focus being the one ordinarily employed in Principal operations, this very desirable condition is secured, viz. that the Instrument is collimated at a Focus, which requires no change in actual observation. Whence in collimating large Theodolites by *changing Face,* it is essential that the object observed should be fully ten miles away, otherwise the focus must be altered to suit the cases which occur in real work, and the line of collimation be thereby deranged. The reason for the latter derangement is as follows. The sliding and fixed Tubes of the Telescopes cannot be fitted to each other so accurately, that the line joining their centers shall remain constant when focus is changed. But the first carries the wires and the second the object glass, wherefore the line joining the former with the optical centre of the latter (*i. e.* line of collimation) becomes variable if focus be altered. The adjustment performed by Gaus's method requires two auxiliary Telescopes fitted with wires, and it will be found that the Telescopes of the small Theodolites are most suitable for this purpose:

Gaus's method of collimating.



Let W_1 W_2 be the wires and O_1 O_2 the respective object glasses of the two auxiliary Telescopes T_1 and T_2, which set up about 15 feet apart on firm stands. Place the Instrument to be collimated (or T_3) halfway between the auxiliaries and in the line joining then. That is to say, when T_1 and T_2 are mutually directed on each other, the line joining the centres of their object glasses, should pass through the Telescope T_3. Having ascertained a place for T_3 corresponding to the above condition, remove that Instrument for the present. Now set the two auxiliary Telescopes to solar focus as indicated in para. 37. Next turn them to look into each other, and intersect the wires of T_2 (which will appear as if painted on O_2) with T_1, and *vice versa*, until the two Telescopes stand mutually intersecting one another and firmly clamped. It is essential that these mutual intersections should remain unaltered during the after process. Now T_1 and T_2 being both set to solar focus, while their lines of collimation have been placed in the same straight line, it follows that the rays of light emanating from W_1, after being refracted through O_1, are parallel to each other and to the other rays emanating similarly from W_2 and refracted through O_2, while both these sets of rays appertain to the common optical axis W_1 W_2. Whence place T_3, set it likewise to solar focus; intersect W_1 azimuthally and clamp fairly. Now turn T_3 180° in altitude, and if in adjustment it will intersect W_2, otherwise half the apparent is the real error, which correct by the collimating screws. Repeat the process until the error is eliminated. Finally remove T_3, and satisfy yourself that T_1 and T_2 continue mutually to intersect each other.

Making the Vertical and Horizontal wires, respectively Vertical & Horizontal.

55. Adjustment 9. The angular relation of the Horizontal to the Perpendicular wire is always defined on the Diaphragm, and as they are made to cut each other thereon at right angles, to adjust one wire is to adjust both. For this purpose both the Vertical and Transit axes (see adjustment 10.) must be throughly levelled. Now adjust by (say) the vertical wire, thus, intersect any small well defined object, and see if it continues bisected along the wire, when the Telescope is moved in the vertical plane. If otherwise, make the Diaphragm revolve until this condition be secured. Similarly, an object bisected by the Horizontal wire should continue bisected when the instrument is turned azimuthally. Another method is to suspend a heavy plummet by some fine cord, immersing the former in water to steady it. Now having levelled the vertical and transit axes as before, intersect the cord with the Vertical Wire and see if the wire and cord run parallel to each other. If necessary make the diaphragm revolve through a suitable arc. This last method is not applicable to large Theodolites, because it requires that the focus should be altered to the near object presented by the cord.

56. As already remarked adjustment 10 can be performed only in those Theodolites which are fitted with the means of raising or lowering one of their *Ys*. We will therefore assume, that in this instance, the instrument under manipulation is a 12 or 14 inch. And of smaller theodolites it may be noticed, that their pivots are levelled once for all in their original construction.

Prefatory.

57. A theodolite fitted as above, will also be found provided with a riding or striding level, so called from its being made to ride a stride on the pivots when in use. This level has a smaller level attached to it at right angles, or other contrivance provided, whereby it is "cross levelled" *i. e.* placed constantly in the same position, with reference to the Co-ordinate which runs at right angles to the transit axis.

The same.

58. To perform adjustment 10, Level the theodolite exactly on its azimuthal axis. Place the riding level on the pivots, and by tapping it gently side-ways, being the bubble of the cross level into the centre of its run, and when the Bubble of the striding level has ceased to move, read and register at what numbers of the level scale this bubble stands. It will be simpler to take only one end of the Bubble into account, viz: that end towards the cross level, and let it be supposed, that when the foregoing reading was registered, the cross level stood over that pivot nearest to the Face of the Instrument. Also for the sake of distinction, call the other pivot, the plain pivot. Now reverse the level end for end, this is to say, place the cross level end over the plain pivot. Cross level as before, read and register. If the transit axis be level, then will the cross level end of the Bubble read the same number of divisions on the second occasion as it did on the first. But if otherwise, then half the apparent is the real error to be corrected by the moveable *Y*. For instance, if the reading on the first occasion was a_1 divisions and that on the second a_2 divisions, then $a_1 - a_2$ should $= o$ divisions; or $\frac{a_1 - a_2}{2}$ = correction by moveable *Y*. It will be noticed that during the foregoing process, the instrument must not be moved azimuthally and that both the vertical and Horizontal clamps should be left free (1.)

How to level the Transit Axis.

NOTE (1.) The "Axis Lamp" or Lamp for illuminating the wires always heats and (more or less) raises that Pivot on which it shines. Wherefore, for celestial night observations, the transit axis should be examined after the Lamp has begun to exercise its full influence.

59. We have now completed a consideration of all the adjustments enumerated, and of which adjustments it may be remarked, that if a classification be desired, the following represents the required combinations.

Classification of adjustments.

General adjustments	1,2,5,6,9 and 10
Telescopic adjustments	3 and 4
Of the Diaphragm	7 and 8

On the calculation of correction due to imperfect adjustments.

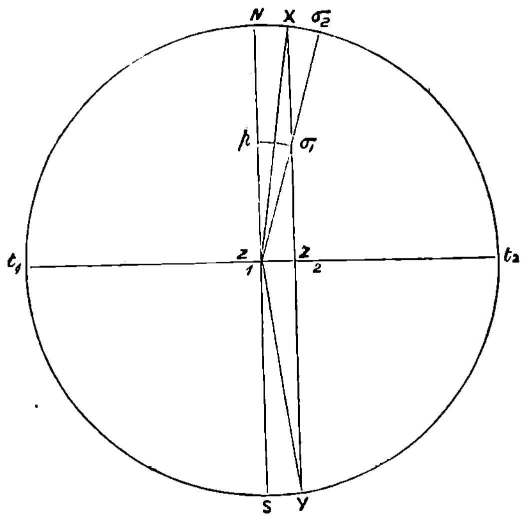
60. Practically and mathematically speaking, there is no adjustment which can be so accurately performed, or which is of so invariable a nature, that the errors due to it should be constantly in a condition of elimination. And it is also to be remembered, that frequent movement of the adjusting screws, is a sort of remedy which is worse than the original disease. For so that the existing errors be constant in magnitude during the intervals between relative observations, the corrections due thereto may be readily and accurately calculated. But when once the adjusting screws are worked loose in their sockets, and the error has become of a fluctuating nature,, it defies alike cancellment by any system of observation, or elimination by calculated corrections. Wherefore, the adjustments being once fairly and firmly performed, they should not be disturbed unless their errors run high. As respects collimation an error of 5″ at the Horizon may be readily not exceeded, and 5 divisions of dislevelment in the transit axis is better left unadjusted. It will be remembered that the foregoing limits represent apparent errors of 10″ in collimation, and 10 divisions of dislevelment in the transit axis. But even supposing these limits to be exceeded, the corrections due may be readily computed as follows.

How to calculate the corrections due to collimation error.

61. And firstly of the computation of corrections due to collimation error.

62. (See Fig 1.) Let t_1 t_2 represent the transit axis, while N S denotes the meridian to the given point as also the plane generated by the revolution of the line of collimation when that line cuts t_1 t_2 at right angles. Now disturb the adjustment, so that the telescope will intersect a point X in the Horizon instead of N, and when made to revolve in altitude it will describe the small circle XY. Then NX = observed collimation error at Horizon $= P\sigma_1 = Z_1Z_2 = c$.

Fig. 1.



Z_1 is the true, and Z_2 the false zenith, and of any elevated object σ_1 its *alt* $= \sigma_1\sigma_2 = A$, and its zenith distance$=$ $Z_1\sigma_1 = Z\ D$. Now the true vertical plane appertaining to the given station of observation and to σ_1 would refer the latter point on the Horizon to σ_2, whereas in the assumed state of the adjustments, σ_1 will be referred to X. But X is erroneous by NX, therefore $NX + X\sigma_2 = e + X\sigma_2 = pZ_1\sigma_1 = c$, or correction to reading of the object σ. Therefore in the spherical Triangle $p\sigma_1 Z_1$ right angled at p, we have,

$$\left.\begin{array}{r} Z_1\,\sigma_1 = ZD \\ \text{and} \quad p\ \sigma_1 = e \end{array}\right\} \text{ to find } pZ_1\,\sigma_1$$

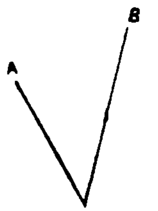
$$\text{whence sin. } pZ_1\sigma_1 = \text{ sin. } p\sigma_1 . \frac{1}{\text{sin. } Z_1\sigma_1}$$

$$\text{or sin. } c = \text{ sin. } e \frac{1}{\text{sin. } ZD} = \text{ sin. } e \text{ Sec. } A$$

but as c and e are both minute angles

$$c'' = e'' \text{ Sec. A.}$$

Wherein if $A = o^\circ$, then $c'' = e''$. Whence the effect of collimation error is at a minimum, when the point observed is situated in the Horizon; also, if the altitude be constant for any two fixed points between which it is desired to measure the Horizontal angles, then will the collimation error become eliminated, in taking the difference of the two horizontal readings. Further if the two altitudes be unequal then will the two angles, one on face left and the other on face right, disagree from each other, by twice the difference of effect of collimation error due to their respective altitudes. Wherefore by finding the mean angle from both faces, the effect of collimation error will become cancelled. Finally the sign of the *correction* due to any given *reading* from this cause may be determined by the following considerations. When the reading to any fixed object is greater at Face Left than at Face Right, then will the sign of correction to all readings at face left be —. But, the foregoing conditions still holding, the observed ∠ at face left between A and B will be greater than the same observed ∠ at Face Right only so long as altitude of B > altitude of A; because, as already shown, the amount of the correction or error varies as the altitude. Also if the distant object observed be not situated in the horizon (see fig. 1) then it is evident that.

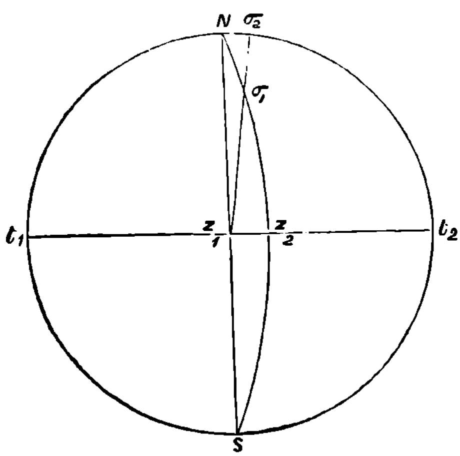


$$NX'' = p\sigma_1'' = pZ_1\sigma_1''. \, Cos \, A.$$

How to calculate the corrections due to dislevelment of Transit axis.

63. And secondly of the computation of corrections for dislevelment of Transit axis.

64. It as already been shown, that the difference of the readings obtained from the Striding Level before and after changing it end for end on the Pivots, measures, in Divisions of the level scale, twice the angle $Z_1 Z_2$. Whence $Z_1 Z_2 = \epsilon$ may be found in seconds, since the arc value of 1 division of the level scale is supposed to be known. Now t_1 t_2 represents the transit axis as before, and N S the plane generated by the line of collimation when the pivots are level. But if t_1 be high, then may that plane become $N Z_1 S$, so that any elevated point σ_1 will be referred to the Horizon at N, instead of at σ_2. Wherefore in the spherical triangle $\sigma_1 Z_1 Z_2$, right angled at Z_2, we have



$$\left.\begin{array}{l} Z_1 Z_2 = \epsilon \\ Z_1 \sigma_1 = Z D \end{array}\right\} \text{ to find } \left(\frac{\pi}{2} - \sigma_1 Z_1 Z_2\right) = c$$

$$\text{whence } \cos \sigma_1 Z_1 Z_2 = \tan Z_1 Z_2 \cot Z_1 \sigma_1$$

$$\text{or } \sin. c = \tan \epsilon. \tan A$$

and since c and ϵ are minute angles

$$c'' = \epsilon''. \tan A$$

wherein A = Altitude of σ_1. Whence if $A = o°$ then $c'' = o''$; whereby it is proved that the effect of error from dislevelment of the transit axis varies as the altitude, becoming evanescent for a point situated in the Horizon. Also, as in the case of collimation error, the results of the error under comment become eliminated in the following cases.

1. When the observed angle at any one face between fixed objects A and B, is such that altitude A = alt: B.

2. And in the mean of the observed angles on both faces, between fixed objects A and B tho', alt of A $>$ or $<$ alt B.

Further the sign of the correction may be determined by the following considerations. When that pivot nearest to the face of the instrument is high the readings of all elevations at face left referred to the Horizon will be too low, while depressions similarly referred, will produce readings higher than those truly due.

Wherefore if A and B be both Depressions or both Elevations.	Then the observed ∠ will be effected by the *difference* of the corrections due to each reading.
But if A be a Depression, and B an Elevation.	Then the observed ∠ will be effected by the *sum* of the corrections due to each reading.

And the sign of such corrections to observed *angles*, must be determined by considerations anologous to those set forth in discussing the corrections for error in collimation.

The Everest and old fashioned Theodolites briefly contrasted.

65. The reader having considered the foregoing remarks, will probably now be better able to appreciate a brief comparison between Everest's and the old fashioned Theodolites.* The former instrument is peculiary superior in its stability and general simplicity. Thus, the old Theodolite has a smaller base, while its centre of gravity stands at a greater height. Now stability varies directly as base, and $\frac{1}{\text{height of centre of gravity}}$, whence the advantage in this respect is evidently in favor of Everest's instrument. Again in the first case we have four foot screws, while in the latter there are only three. But in the same circle the base of support offered by the former, is to the same presented by the latter, as 2 sin. 45°: $r +$ cos 60° or as 1 : 1·06. Also three points define

* A sketch of one of the old fashioned Theodolites will be found at page 107 of "Manual of Surveying for India."

but one plane, while through four points not in the same plane, no less than five planes may be made to pass. Whence in the old fashioned Theodolite, and especially if the foot screws work unsatisfactorily, there is some difficulty in placing the four points of support, which its foot screws offer, all in the same plane. The Everest Theodolite is also superior in its facilities for changing face, and in the circumstance of a level being directly attached to its verniers, whereby, in observing vertical angles, the surveyor is rendered independent of the azimuthal axis except for the purposes of cross levelling. In its clamp and Tangent screws, in its single plate instead of a double one, in the attachment of its lenses, as well as of its telescope, the Everest Theodolite is as superior in theoretical principles, as modern mechanical improvements make it practically superior in elegance and construction. It is *the* pattern of Theodolite which from the 5 to the 14 inch instrument is exclusively employed in the great Trigonometrical survey of India, and it is also widely adopted in most other surveys.

Vernier Theodolites and celestial observations.

66. Vernier Theodolites in the Great Trigonometrical survey of India are not usually employed for celestial observations unless for the purpose of finding time, by equal altitudes or otherwise; or yet, on other occasions, when extreme accuracy is not required. But the reason why vernier theodolites are not so employed, is, that the department being provided with far superior reading-microscope instruments, these latter are rightly used in preference to the former. Practically however occasional opportunities occur, when vernier Theodolites *are* used for celestial observations. For instance, at the closing of any extensive secondary operations which may happen necessarily to terminate at a distance from the principal series of triangles. Here the vernier Theodolite may be called upon to verify both Azimuth and Latitude, the former by observations on a circumpolar star when about its Elongations, and the latter by circum-meridional altitudes.

Of Azimuth obtained from observations to a circumpolar star.

67. The problem of observing an Azimuth briefly resolves itself into measuring the Horizontal angle between any terrestrial mark and the star selected, when the latter is at either its Eastern or Western Elongation. At this instant of time, the ∠ between the star and pole is a quantity which may be readily computed (see manual of surveying *p* 682), and hence too may be obtained, the azimuth or ∠ between the south pole and Terrestrial mark adopted. The foregoing process however furnishes only one measure of the required angle at each Elongation, but for Vernier Instruments that one value is pro-

bably all that need be observed. When a more rigorous determination of Azimuth is required, the process adopted should be in accordance with that detailed at p. 687 in the Manual of Surveying for India. Whereby all errors from imperfect adjustments of the Instrument, in the place of the star, or the Latitude of the station of observation become eliminated. But though the effects of those errors exist in a single measure of an Azimuth observed at only one Elongation, they need never be sensible in amount to a Vernier Theodolite, unless the Instrument is seriously out of adjustment.

Of observed Latitude.

68. A Latitude may be observed either by a single observation on the Meridian, or by circum-meridional collimated observations precisely as in the case of ordinary vertical angles. The latter process however requires that the time should be accurately known, and for the former the Collimation or Index error, as well as the Meridian, must be determined.

General.

69. In fact the Alt-Azimuth might fitly be named the Universal Instrument, since it may be made to produce any angular measure required, either by direct observation, or indirectly from computation of the same. As such, every surveyor should be thoroughly acquainted with its use, adjustments and individual peculiarities; remembering that truthful measurements depend alike on his skill in observing as on the attention bestowed on his Theodolite, and that accuracy is unattainable if patience and a rigorous sense of appreciation be not ever present. To this end too must the Surveyor guard against lateral Refraction in his Horizontal angles. A Movement as insidious as it is dangerous, and one which may pass undetected without warning, until exposed by the discordancies in the resulting angles. Lateral Refraction is understood to signify a slow oscillation of the object observed ; such, that if intersected and watched for some few minutes, it will be observed to move to one side of the wire, then to return to the bisection, and next to perform a similar excursion in the opposite direction. If the wire be so placed that these excursions shall be equal, then it is evident, that that position will represent an intersection. Guard too against hurry and confusion from any cause, bearing in mind that celerity is the result of knowledge, practice, calmness and aptitude combined. Bad angles are worse than none, since the first are absolutely untruthful, while time and patience will always overcome the deficiency. So also discourage self sufficiency. It is a conceit which rarely comes too late, and there is no more truthful sentiment than that which says," a little learning is a dangerous thing." Geodetical operations in all their details have long since

been brought to a high state of perfection, so that notwithstanding the commendation due to a spirit of research and discovery, see that you do not adopt fictitious ideas on this point, and waste your time and energies in attempting alterations, which, if escaping untruthfulness, are at the best, probably speaking, but innovations. Follow the broad beaten track, until divested of timidity on the one hand, and of self sufficiency on the other, you are at least qualified to discriminate between improvement and innovation. Nor have you but a little to learn. As men, though similary constructed, are yet characterized by special vices and virtues, so Theodolites alike in principle and execution have each some peculiar conditions under which they will be found to work more truthfully or otherwise. It is essential that the Surveyor should discover these conditions. That he should guard the Instrument from Sun and Rain, from the influence of strong currents of wind blowing on it during observation. That he should pack and unpack it carefully *himself*, and not by proxy, as is frequently done from laziness and indifference. That he should keep the axis glib, the glasses clean, and the Instrument generally in thorough order; and lastly, while in Transit from one place to another, the Theodolite should be carried by men, with as little concussion and as much care as can be ensured. Observing these precautions, and recording without bias whatever his Instrument may indicate, the surveyor *must* arrive at truthful results. Bearing in recollection, that when men's minds are engrossed with microscopic quantities, they are apt to neglect grosser magnitudes; and that to estimate the fractional parts of seconds correctly, while the degrees and minutes are erroneously recorded, is not the way to observe truthful angles. Mistakes in observation occur just as frequently from reading, as from registering, wrongly; and when these two duties are performed by different persons, it is essential that the recorder should repeat distinctly after the observer, the numbers which the latter calls out for registry.

Survey Operations in which Vernier Theodolites are usually employed.

70. Finally the 5 and 7 Inch Theodolites are chiefly employed in route Surveys and Secondary Triangulation of an inferior order. Where the Secondary operations are of an extensive nature, or other necessity for greater accuracy exists, the Theodolite suitable to use is a 12 or 14 Inch. The signals in all these instances are generally speaking flags, but the 12 or 14 Inch is quite capable of appreciating the additional refinement which the employment of luminous signals introduces. Indeed the Vertical angles observed with the 14 Inch Alt-Azimuth, appear to be equally accurate as those determined by the 24 or 36 Inch. So much so, that these two classes of Instru-

ments are sometimes conjointly employed, when it becomes desirable to observe Vertical angles simultaneously.

71. In conclusion, it may be some recommendation to the surveyor if he remembers, that the Instrument herein commented on, is one of the principal means we possess, of becoming acquainted with the dimensions and figure of our Planet, as well as with our possessions thereon. Through its agency countries and cities are Geographically found, Rivers traced, and Mountains sketched. It precedes our Roads and our Railways, and conduces to the construction of our Canals, bringing prosperity and happiness where poverty and barrenness before prevailed. In short it is to the Theodolite mainly that we owe our accurate knowledge of the British possessions. It was chiefly with this Instrument that the late Lieut. Colonel Lambton, discovered the breadth of the Peninsula, in the Parallel of Madras, to have been exaggerated by some Miles, and finally it was with the Theodolite, that the surveyor, looking from a distance of 133 miles at the summit of Mont Everest, proved its height above the Level of the Sea to be nearly Six English Miles.

In conclusion.

J. B. N. HENNESSEY,

August, 1859.

1*st. Assistant Great Trigonometrical Survey of India.*

MEMORANDUM ON THE USE OF THE PLANE TABLE, FOR TOPOGRAPHICAL PURPOSES, DRAWN UP BY ORDER OF LIEUT. COLONEL A. SCOTT. WAUGH, ENGINEERS, SURVEYOR GENERAL OF INDIA, BY CAPT. D. G. ROBINSON, ENGINEERS, 1ST ASSIST., SURVEYOR GENERAL'S DEPARTMENT, IN CHARGE TOPOGRAPHICAL SURVEY, BENGAL ESTABLISHMENT NO. 1.

1. It will be seen from the following description of the Plane Table, and of the mode of using it, that the same species of results are obtained from it, as regards the plotting of horizontal angles, as are obtained from the Theodolite in the measurement of them, *i. e.*, in both cases the true Azimuthal angle is taken; consequently it is a true triangulating instrument, and a fit adjunct *for filling in the details*, of a Trigonometrical Survey, but as in building up triangle on triangle by simple plotting, a large error rapidly accumulates, it should never be used for purposes of extension, or any external work, where great accuracy is required.

2. On a plane table the Surveyor plots off direct from nature, the angles subtended at his eye, by the various objects he may desire to lay down, or work from, and as his ruler is of full length, his plotting is as accurate, as it well can be. He therefore saves much time and avoids all the errors and mistakes to which he would be liable, if he observed his angles with a suitable instrument first and then plotted them with a protractor.

3. The plane table and apparatus generally used in the Indian Topographical Surveys, are fully described in Appendix (*D*) the table (30 inches by 24 inches) is as large as can be conveniently used, strong and very firm. It answers admirably for accurate survey purposes, but is too heavy for the rough, and rapid work of a military re-connoisance. For the latter, a table made of Papier Maché or any suitable light material $15'' \times 12''$, and attached by a ball and socket joint, to a light folding tripod stand would answer better.

4. The ruler is usually about (30) thirty inches long, two (2) inches wide and (⅓) one-third of an inch thick. The sights are usually about 5 inches long. The slit of the object sight should not be less than half an inch in width and three or four fine holes should be drilled at intervals on the fine cut of the eye sight. The ends of the ruler should be capped with thin sheet copper, to save the ruler from splitting, and to allow the sights to

be screwed on (either temporarily or permanently) more securely and firmly, than can be done to the mere wood. Five inches of sight, to a thirty inch ruler gives sufficient command of elevation or depression for general use. When the elevation or depression is more than can be embraced by the sights, the intersection must be made with the assistance of a plummet, suspended in the exact ray either before the object, or behind the eye sight as may be required.

The sights of the ruler may be graduated into scales of tangents (to radius length of ruler) or into divisions of so many feet, to enable the Surveyor to determine, by the subtended angle, the height of a building or other object, whose distance he knows, (either by means of Plane Table or otherwise) or conversely for judging the distance if he knows the height of the object. This may be useful on a re-connoisance, but being only approximate is of little use to a Topographical Surveyor.

Let us suppose the surveyor in possession of such an apparatus, as that described in Appendix *D*. First he must see that the upper surface of the table is a true plane, and also free from cracks and holes, that the fiducial edges of his ruler are perfectly straight and that the fine cut (slit) of the eye sight, and the wire of the far sight are in the same plane, and that plane perpendicular to the lower plane, or base of the ruler. This can be tested thus. Point the ruler on some small and well defined object, at the distance of 200 or 300 yards or more. Intersect the object with the upper or lower portion of the sights, and moving the eye up and down, see if the slit, the wire, and the object still remain in the same line, if they do not, the wire or even the sight must be altered until they do. The perpendicularity, may be tested by comparing the sights with a plumb line suspended in front of the board which must be truely level. Next examine the compass. It should play freely, be strongly magnetized, be very sensitive and yet settle quickly.

Having seen that the apparatus is in good order, proceed to mount the board, thus. With a wet sponge thoroughly damp the reverse side of a sheet of good drawing paper, laid flat on a clean table, then roll it up and put it aside until wanted, then thoroughly wash a piece of long cloth, sheeting or some similar material, to get the dirt and starch out of it (the cloth should be large enough to overlap the board by two or three inches every way) let it remain in the water, then spunge the upper surface of the board, and lay on it whilst wet the thinnest paste, then stretch the cloth on the board, as tight as possible, securing the overlap with stiff paste, or glue, to the edge and under surface of the table. Rub the cloth well down on to the board, this will cause it to adhere slightly, and a certain quantity of the thin paste to ooze up through the interstices of the cloth. Then take the paper which by this time will be thoroughly damp, lay it smoothly on the cloth, press it out from the centre with a dry clean towel and paste the edges down to the cloth with stiff paste. The thin paste which has oozed through, will cause the paper to adhere firmly to the cloth, sufficiently to prevent the paper rising, but not so much as to prevent its being easily separated when the the paper is removed from the board. Great care must be taken not to rub the upper surface of the paper, as by so doing, its texture is liable to be spoilt and the sizing removed. This may be restored by glazing it with isinglass and alum in the manner recommended in the Manual, Chapter XXX, page 462. The paper should be watched when drying and if the centre appear to be drying quicker than the edges damp it with a sponge.

When the paper and table are thoroughly dry, which will not be for two or three days* the surveyor may proceed to project the Trigonometrical points, the positions of which have been previously determined by careful triangulation with a theodolite. He should first examine the chart of triangulation and see what points he can get on his table. This is easily done by cutting out a piece of paper to represent the table on the scale of the chart *i. e.* if his plane table be 30 inches by 24 inches, the scale of the required survey one mile = one inch, and the chart on the quarter inch scale, he will prepare a rectangular piece of paper a trifle less than $7\frac{1}{2} \times 6$ inches. This section will contain fifteen minutes of Latitude × fifteen of Longitude and his chart will be divided into fifteen minute sections. He lays his piece of paper over the section he is to take up and shifts it about so as to embrace the whole section and as many Trigonometrical sections, and other valuable points as possible, (taking care that the section falls well within it,) and draws a line all round the edge of the paper. The area enclosed by this line, represents on the chart the area proposed to be projected on the plane table.

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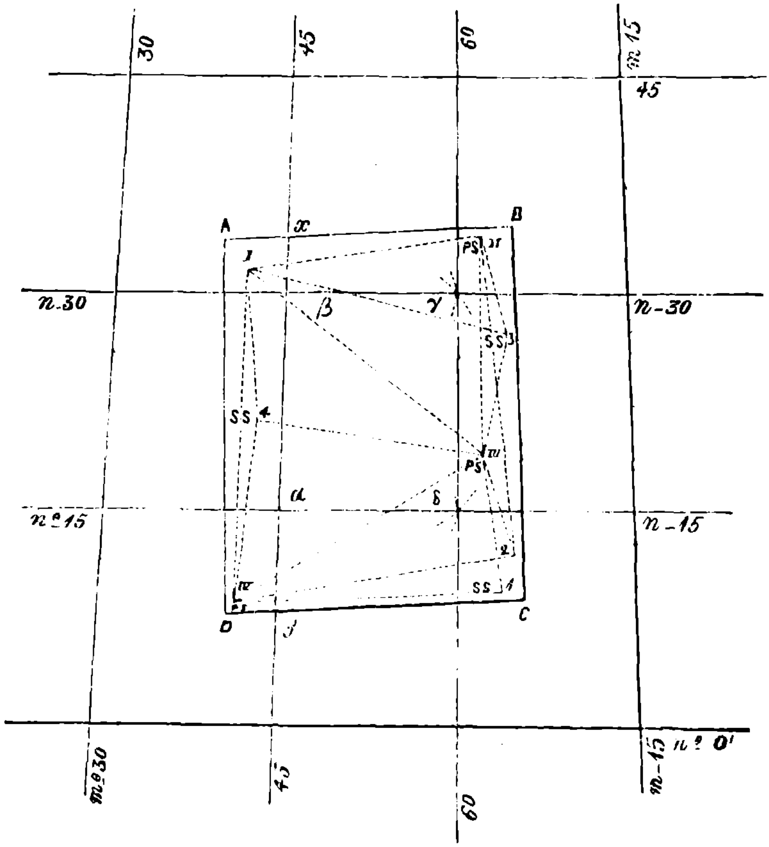
* (Unless the wood be close grained and very well seasoned, the table will always expand and contract considerably according to the dryness, and temperature of the air, and in one direction more than in another. In mounting the table the wood becomes saturated with moisture which is not expelled for some time after. I therefore prefer keeping the tables mounted several days before the points are projected, and to project them in warm dry weather. Hygrometric expansion or contraction is the bane of a plane table Surveyor. By painting, varnishing or by giving some other similar coating to the wood, or by the introduction of some other material in lieu of wood, this evil might probable be ameliorated or eradicated. Oak, teak and Toon appear to be the the best woods for plane tables, Deal and other soft woods imbibe moisture quickly and expand across the grain.)

Thus in the accompanying sketch on a scale of four inches to one inch *ABCD* which includes the required section say between the Latitudes $(n^\circ - 15')$ and $(n^\circ - 30')$ and Longitude $(m^\circ - 45')$ and $(m^\circ - 60')$ represents the area to be projected on the plane table on a scale of one inch to one mile. The paper has been shifted so as to include the Trigonometrical Stations *I, II, III,* and *IV,* and the secondary points 1,2,3,4. Lay off with a pair of compasses on your plane table from the corner corresponding to *D,* four times the distance *Dy* along the edge corresponding



to *DC.* Similarly lay off from corner corresponding to *A,* four times *Ax.*—draw the line *xy.* This line represents on the plane table the meridian $(m^\circ - 45')$ lay off with compasses four times the distance *yα*, and four times *xβ.* Then *α* and *β* will represent, approximately the two western corners of the section. Next with a beam compass take off, from a Gunter's scale the number of inches corresponding to 15 minutes, difference of latitude betw en parallels of $(n^\circ - 15')$ and $(n^\circ - 30')$, and lay off that distance, so that the points of the beam compass should be nearly equidistant from the positions

(α) and (β) found approximately. These new points define the true position of (α) and (β). Similarly take off with the beam compasses 15 minutes of difference of Longitude at Latitude ($n^\circ - 30'$) and with centre (β), and this radius, draw an arc (γ) also with a distance equal to 15 minutes of difference of Longitude at Latitude ($n^\circ - 15'$), and from centre (α), draw an arc (δ), then with the length of the diagonal for a 15 minute section situated between the same parallels of Latitude, from (α) and (β) as centres, draw other arcs cutting those already drawn in (γ) and (δ) * respectively, (γ) and (δ) are the eastern corners of the section. Test them by seeing if $\gamma\delta = \alpha\beta$ and prolong the sides ($\alpha\delta$), ($\delta\gamma$), ($\alpha\beta$), ($\gamma\beta$) both ways to the edges of the board. The quadrilateral drawn is a fifteen minute section; subdivide it into (5) five minute sections, and construct diagonal scales for Latitude and Longitude in convenient positions an shewn in Appendix *G*, Colonel Waugh's Topographical Instructions. By means of these scales lay down the different Trigonometrical stations. Next test the positions of the Trigonometrical points † by trying with a beam compass, if the distance between them on the plane table corresponds with the Geodetic distance from the triangle computations. The Trigonometrical Station having been found correct, lay down the secondary points. If their Latitudes and Longitudes have been computed, project their positions in precisely the same manner as before, but if not, by their distances, striking the arcs of intersection with a beam compass. In the latter case every point should have at least three distances. The table is now projected and the Surveyor is ready for the field.

On arriving in the field, the Surveyor proceeds to some centrical Principal Station, and having first seen that the screws of his table and stand, are firm, he puts up his table unclamped, as level as possible, and nearly over the centre of the station. He lays whichever fiducial edge he finds most

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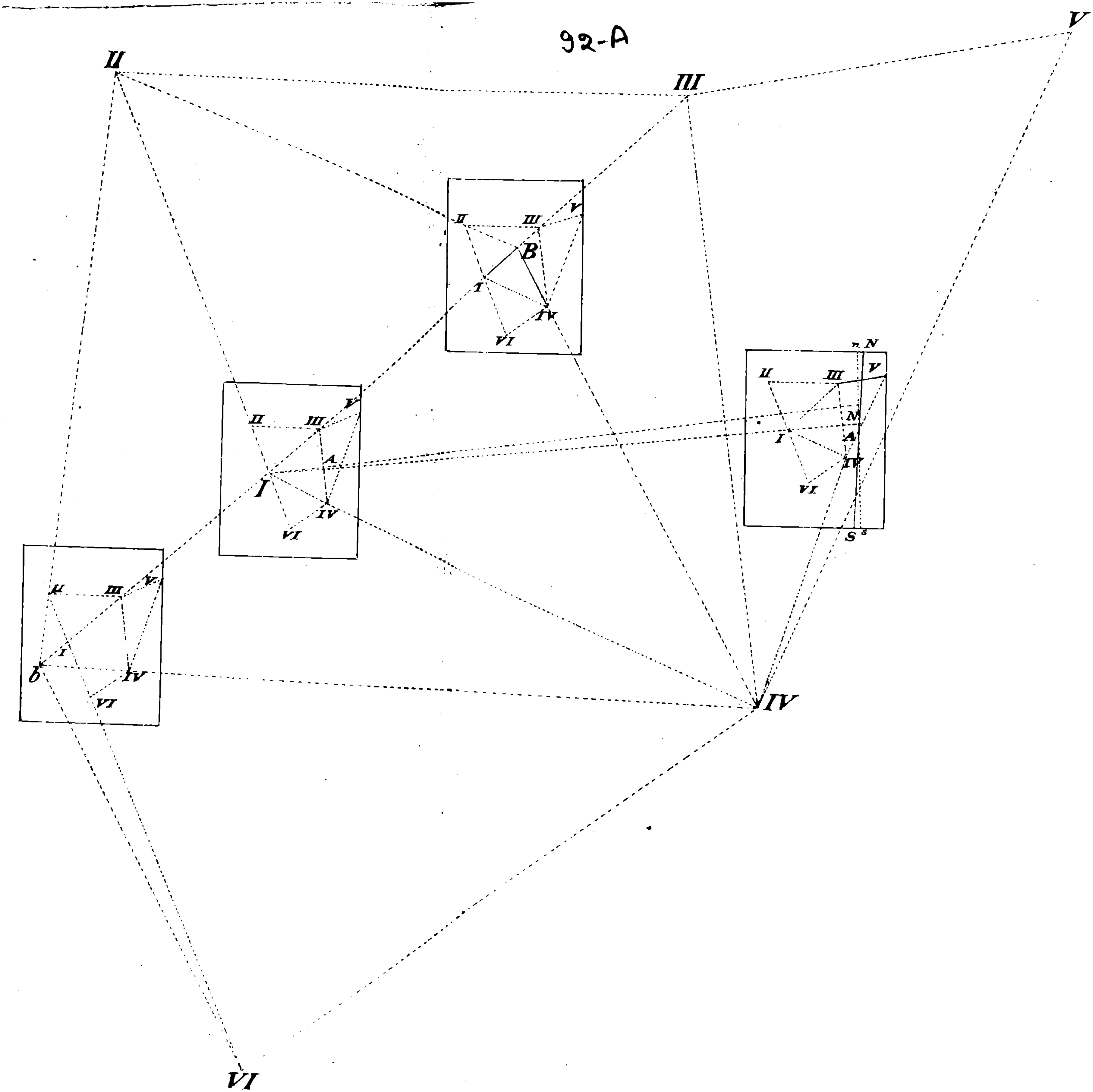
* (1). The length of the several degrees and half degrees of Latitude and Longitude, and the diagonals of the section corresponding to them for various scales are tabulated under the letters *m*, *n*, *p*, *q*, in which (*m*) represents the length of Meridional lines, or difference of latitude (*n*) the lower, and (*p*) the upper latitude lines, and (*q*) the diagonal $= m\sqrt{1 + \frac{np}{m^2}}$ *vide* Manual of Surveying for India and Geodetic tables for use of Great Trigonometrical. Survey of India.

†(2) When considering what arrangement of the plane table will be best, after the Trigonometrical Stations, preference should be given to those objects which being, visible at a great distance are likely to be most useful, (or as will be seen hereafter, a distant well defined object is of immense use to the surveyor as a point of check, when he requires to find his position by interpolation To include such valuable points, a small amount of slue may be given, but on no account should the section to be plane tabled, be brought so near the edge of the board, as to leave a margin too narrow to include the external points required for the survey of that portion of the work.


II
III
V
B
I
IV
VI
A
N
n
S
s
b
IV
VI

handy (he should make a practice of always using the same edge) so that a line drawn along this edge shall pass exactly through Station *I,* and *II,* on the plane table, Station *I,* being the station he is at, and *(II,)* any other distant, but clearly visible Trigonometrical Station. Holding his ruler firm in this position, he moves his table round (in Azimuth) until the eye cut and object hair intersect the real station *II,* then the straight line connecting Stations *I,* and *II,* of the plane table is part of the actual straight line between the real stations *I,* and *II.* * He then tightly clamps the table, and examines the intersection and position of the ruler. Finding them correct he next tests his points. This is done by laying the same fiducial edge so as to intersect Plane table Station *I,* and each other Plane table point in succession, and seeing if the sights in each instance point exactly to those real points. Or better, reversing the process, he keeps the edges of his ruler close to his plane table position, and intersects the real points with the sight, and sees if the fiducial edge passes through or is exactly parallel to the straight lines connecting his station with the corresponding points on the plane table. † Having satisfied himself that his points are all right, and the table still correctly set he must proceed to adjust his compass. ‡ If the Surveyor has the long box compass, he takes it out of its travelling case, and lays one of its long sides coincident with the meridian line nearest his station and notices its variation. If there be no local attraction, this variation will be pretty constant for all parts of his work provided he lays the same side of the box on the meridian nearest the point at which he is working. If the compass has no graduated arc but simply a zero mark, he places the compass either firmly secured in its box, or as before, on any convenient spot on the margin of the table, moves it about until the needle points to zero,

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* This is not exactly the case, unless station *I,* on the plane table is exactly over the dot of the station. Practically it is however correct, as the angular error at station *II,* subtended by the station *I,* and the position of the plane table when the distance between them is only 4 or 5 feet is so small as to be far beyond the limits of plotting on a scale of one mile to one inch and is therefore in appreciable.

† This is usually done by using as a pivot a finger of one hand or a pencil held vertically with its uncut end resting on the paper at a tangent to the station ; and with the other hand making the ruler revolve round it so as to intersect each station in succession, in such wise that the fiducial edge of the ruler shall coincide with, or be parallel to the line joining the station he is at (the eye station) and the plane table station corresponding to the actual station (object station) intersected.

‡ Any kind of a magnetic compass will answer but the best and most convenient are long box compasses furnished with graduated arcs of about 20 degrees similar to those furnished to Everest's Vernier Theodolite.

Setting a table correctly, is simply to clamp it in that position, that any given line on the table passing through your place of observation, shall prolonged pass through or be parallel to a corresponding line of the country, so that if you can at once set your meridian line to pass true and south, your table is at once correctly set. The compass is a very valuable assistant in obtaining this object and if the needle points truly, the Surveyor at once fixes himself from two known points and checks himself by a third point.

and then with a pencil draw lines clearly all round the case, or compass box, so as to be able to replace his compass at pleasure precisely in the identical position which it now occupies.

The Surveyor is now in a position to commence filling in, but before entering upon this subject, we will consider the various conditions under which he may have to determine his exact position upon his table.

Let it be supposed that having left station *I*, he has put up his table at *(A)* see diagram No. 2.

Now the proper proceeding is that when his table was fixed at station *I.* he should before proceeding to *(A)* have drawn the ray *(IA)* prolonging it, at both ends to the edge of his table * so that when he comes to station *(A)* he has merely to place his ruler, so that the fiducial edge shall coincide with the line *(IA)*, with the eye sight to the *(A)* end, and to turn the table so that the sights intersect station *I*, and clamp it, then he evidently has fixed his table correctly in Azimuth. If now he places his pivot at plane table station *(II,)* and directing his ruler to real station *II*, he draws the ray *(IIA)* its intersection with the line *(IA)* is the correct position of *(A)* upon the table. The correctness of which he tests by drawing rays from *IV, III*, or any other fixed station each of which should pass through the same point *A*. In the diagram No. 2, Stations *III*, and *IV*, are more suitable than *II*, because the rays from them cut the line *(Ia)* more nearly at right angles, than the ray from station *II* does.

It follows from the above that if the positions of *II, III, IV*, and *V*, are not known, but the distance from *(I,)* to *(A)* be known, that if you lay off from your scale the distance *IA* and fix your table in Azimuth by the back ray, you can by drawing rays from *A* to *II, III, IV*, and *V*, fix the positions of those stations, provided the rays to them from Station *I*, have previously been drawn. †

It was before observed that the essential point in setting the plane table is that, the meridian line nearest to the plane table point, at which the surveyor is working, should be parallel to the actual meridian of that point in other words that the meridian line of his place should point true north and south, consequently if the distance from station *(I)* to *(A)* be compara-

* To give a long time to set by.

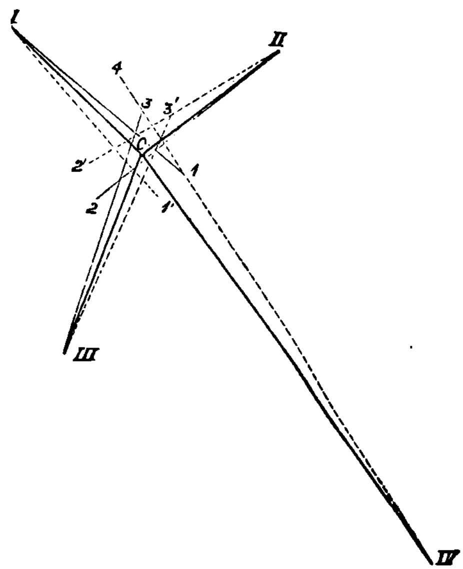
† Consequently if you have a base you can build up triangulation by means of a plane table; but however useful this may be for a reconnaisance it is quite inapplicable to a Survey owing to the rapid accumulation of error.

tively short, great care must be taken to set the table *exactly* on the ray *(IA)* and to ensure this, a flag should be sent on from station *I* to station *(A)* for the forward ray, and a flag left behind at station *I* for the back ray. Suppose in the diagram No. 2 that from want of a flag or other mark, the table is set up by mistake at (*a*) off the *(IA)* instead of at *(A)*, then the meridian line of the plane table will take the position *sn* instead of *SN*, and the angular error is the angle Nan = angle AIa. Now as $\frac{Aa}{a\ I}$ may be taken as the measure of this angle it follows, that in proportion as *A* is nearer to *I* so much the more careful must the surveyor be to place his table carefully on the forward ray. There is no necessity for the plane table being placed exactly over the position occupied by the forward flag all that is necessary is that, it be on the ray *i. e.* that when the table is set by the back ray, on the back flag, the sights of the ruler point to both flags.

The method just mentioned of fixing the plane table by back ward and forward rays, has all the advantages of regular triangulation, there is no accumulation of error, and the plotting is as accurate as it possibly can be. This system has also the advantage of requiring fewer points to work with, than any other, and it matters not how those points are situated with reference to each other, provided the angles of intersection are not less than 60′ (the nearer to right angles the better) ; but unfortunately it often so happens that the surveyor on arriving at *A* finds that it is not suitable for his purpose. It may be that *A* is in the centre of a plateau or in some such position that the view of the ground he wishes to sketch is obstructed: or in passing from *(I)* to *(A)* he comes to a more desirable position, to which no forward ray has been taken, and from which he would like to sketch. He then fixes himself by interpolation. The method of interpolation described in Appendix *A.* of Colonel Waugh's Topographical Instructions, is theoretically correct, but is evidently bad in practice. Indeed, under almost all circumstances fixing by interpolation is objectionable and the evils of the system vary according as the position of the stations fall under the following cases.

No. I.—The best of all cases is when your position falls exactly in the same straight line with two fixed stations as at *B* or *b* in diagram (see fig: 2), the first between, the second outside, of the stations *I* and *III*; in this case, move your table until the sights intersect *I* or *III*, if it intersects one it will intersect both—clamp, draw rays from *II* and *IV* and *VI* (the best points for intersection) those rays will cut the straight line *I* and *III* or its prolongation, in the same point, (and check each other) *B* in the first case, or *b* in the second is evidently your position on the table.

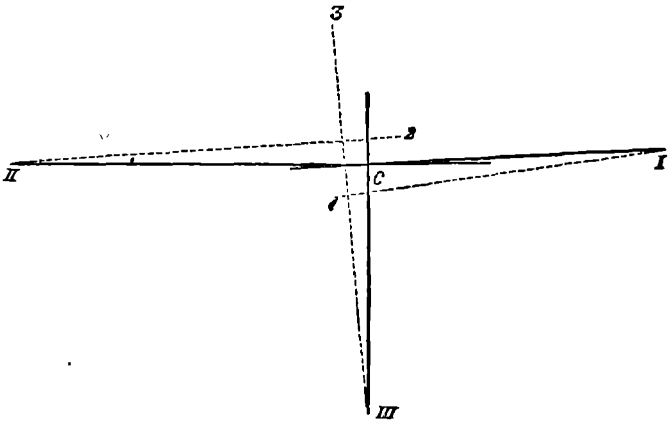
The next best condition is when points on all sides are visible from your position *A*, see former diagram. Put up your table, place the side of your compass to correspond with the nearest meridional line to your position, or if a place has been drawn for it on the table, into that place and turn the table round until the compass stands precisely at the same variation as it did at your starting station *I.*—Clamp—your table is now fixed approximatly in Azimuth, put your pivot on any near Trigonometrical point of your table such as *III.* Point the ruler to *III* and draw the ray, do the same through *VI* and *V* and if your please through *I.* If your compass be a good one, your table will in all probability be at once set correctly in azimuth, and the rays will then pass through one point, if they do, check by seeing if the ray from the farthest visible point will do so also, if it does you have determined your correct position on the table; but if not, then your table has been set slightly wrong in azimuth, and the angular error must be eliminated. If in the accompanying sketch we suppose the table in the first instance to be set correctly—*i. e.* with the meridian nearest to *C* pointing due north then will all the rays from station *I, II, III, IV* pass through *C* but if incor ectly set then will the rays fall as 1_1 2_2 &c. oras 1_1 2_2 3_3 &c. according as the error in Azimuth is east or west. Now it is evident that the angles formed at the station *I, II, III,* and *IV,* by the correct, with the incorrect rays are for the same position of the table always equal, also that when your stations are around you the figure formed by either set of incorrect rays inclose the true position and consequently we obtain the following rule. *When the points by which you are fixing are around you. Your position is within the figure formed by the intersections of the rays and distant from each ray exactly in proportion to the distance of the stations appertaining to that ray from your position.** Estimate *C* to be that point lay the edge of your ruler



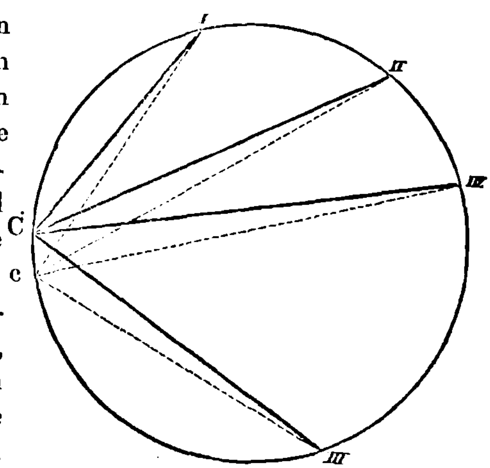
* As the error in Azimuth is the same for all rays the error in position depends upon the length of the rays. *Ergo*, a Surveyor should always fix himself by near points as giving the least errors of position and check himself by far, as shewing most strongly the amount of error to be eliminated.

coincident with your longest ray (*IV*) *c* shift the table so as to intersect station *IV*, clamp and draw fresh rays from *I*, *II* and *III*. These rays should intersect each other in one point which is then your correct position If they do not, repeat the operation until they do. Each approximation will of course come nearer and nearer to the truth.

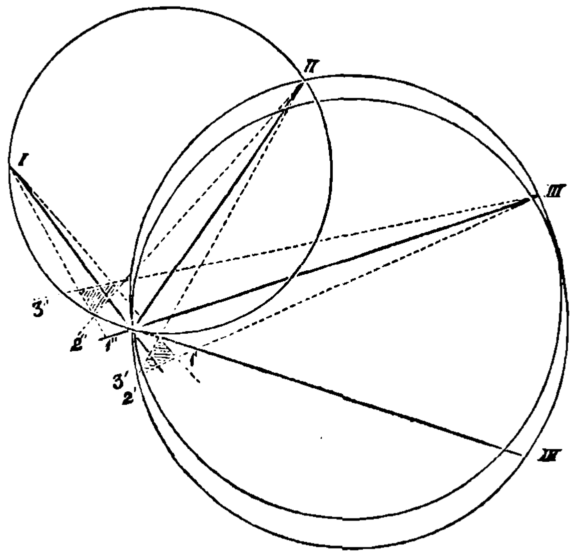
Again—If, as in the Fig. station *I* and *II* be nearly opposite each other and *C* be the correct position of the surveyor it is evident that the erroneous rays due to the same error in Azimuth from *I* and *II* fall on opposite sides of *C*. Consequently if you have only the erroneous rays drawn, you know that the true position of *C* is between I_1, and II_2, and on the same side of III_3 (looking from the station *III*,) as it is if the other rays looking from *I* and *II* respectively. In the figure, it falls to the right of I_1 and II_2 therefore it is to the right of III_3. Its distance from those rays will be also, as the distance of the stations from it. Estimate accordingly, and having assumed your new position, set your table by it and the furthest station distinctly visible, and proceed as before.



The fourth, and worst case is when the stations all fall on the same side of the position. It may so happen that the stations *I*, *II*, *III*, even more stations, and the point *C* are in the circumference of the same circle or very nearly so. When this happens, let the surveyor's Azimuthal angular error be ever so great, the rays from those stations must intersect in one point, and consequently he cannot detect his error, should there be one. His eye can tell sufficiently nearly if a circle described through *I*, *II*, *III*, would



pass through or nearly through *C*, and should such be the case he should on no account whatever attempt to fix himself by those points. Under the best of circumstances his rays must fall if wrong something similar to $I_1\, II_2\, III_3$ forming a figure on one side of *C*, and there is nothing in that figure to assist him in judging on which side of it *C* should fall. He may obtain his position by judging how a circle passing through *I* and *II*, and the intersection of the rays from those two stations would intersect another circle passing through *II* and *III* or *III* and *IV* and the intersection of their respective rays. (The point of intersection is manifestly the same for all the circles.) He may assume this point as an approximate position for *C*. Let him then set his table by this approximate *C* and his furthest station, and try to fix himself by the near stations, and continue repeating the process until all the rays intersect exactly in one point.*



This last case is manifestly so unsatisfactory that it should never be resorted to except under the greatest necessity. In no case should the Surveyor attempt to fix himself by distant points, and he should only sketch such ground from positions so determined as he can get at in no other way.

The following are instances in which case No. 4 are likely to occur and the following hints may be useful to enable the Surveyor, to make the best of the difficulty.

The most ordinary case is when the Surveyor has to descend the side of a hill, in order to see into some hollow, or to sketch some ground not visible from the top. In this case unless the ground permits of his taking

* As he approximates nearer to his true position, the figure formed by the intersection of the rays will decrease. And should he pass to the further side of *C*, the figure formed by the intersection of his rays will be inverted,

a forward ray he is without remedy. At another time he will find his view so obstructed by trees covering the whole top of the hill, that his angle of view is very limited at every position he may take up. In this instance starting from any point near the centre he should set table by the compass, and take rays to all the points that are visible, then shift a few feet and set his table by the longest of the rays just taken, draw rays to new points that are visible then shift again, and so on until he is properly fixed remembering always to fix by long rays, and never to shift from his original starting point, more than is utterly inappreciable on the scale of his Survey.

Again he may be working along the edge of a forest or in a plane below a range of hills, where he cannot see any or perhaps only one station in the plain besides the stations on the hills, or may be no plain stations at all. In this case he should regularly traverse by backward and forward rays, with flags, starting from one station and closing on another, fixing himself by rays from stations on his flank, when visible, or when none are visible, by measuring his distance from flag to flag, by chain or perambulator, and laying off those distances with a pair of compasses from a scale on to his table.

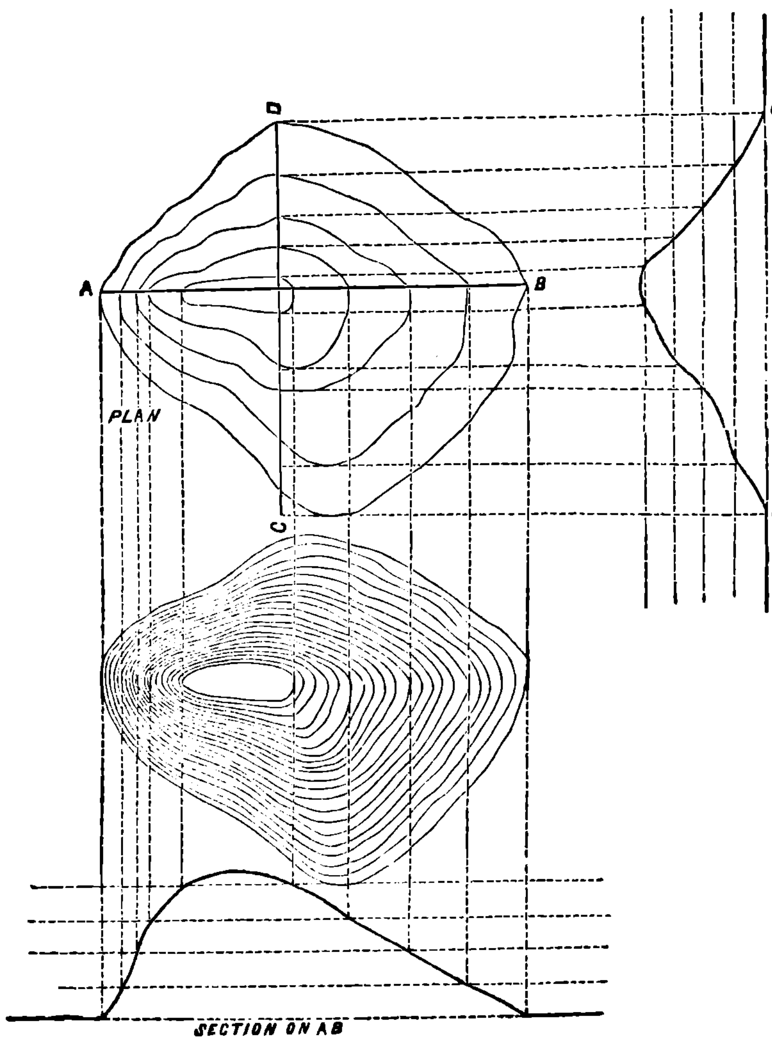
He should close his traverse on a Trigonometrical point, and avail himself of every opportunity of check. He should traverse as straight as possible and by long lines so as to reduce to a minimum the accumulation of angular and linear error. If he has a choice, and in the plains he often will have, he should start from a Trigonometrical Station and move in a continuous straight line, until he arrives at a good point of check then he may run off on a different line, his measurements will then all be from origin, and his linear and angular error will be at a minimum.

These same triangulating principles which we have described, as guiding the Surveyor in determining his own, and in laying down the position of other fixed points, also hold good in filling in the ground. Let us consider this filling in.

The first great rule in sketching ground is to give a proportionate amount of shade for a corresponding steepness of slope. Some writers give a regular scale of shade which is very well in theory, but which if strictly adhered to in practice would make the drawing of a map, hard, unsightly and illegible. A good Surveyor will make this rule his guide, but influenced by a good taste he will always give to his higher mountains a darker shade, than is simply due to the slope, in order to make them appear to stand out from the paper. His high level grounds in the same way will be lighter, and the summit of his high mountains bright white, whilst he will put a flat shade over his low valleys and plains, and suppress all lower features and this he will so judiciously, that whilst the general tone of his map is enhanced, he will in no instance destroy its truthfulness. This judicious application of light and shade may be termed the artistic portion of a Surveyor's work, and is far easier learnt from a few field lessons than from the clearest written lecture.

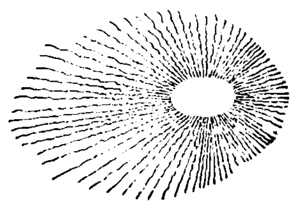
Mountainous features may be drawn; *first*; by contours; *secondly*; by eye contours, a modification of the first; *thirdly*; by vertical hatching; *fourthly* by shading with the brush in Indian ink, or some other suitable tint.

In contouring, regular horizontal lines at fixed Vertical intervals are traced

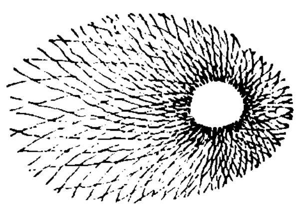


over the country, and plotted on to the maps. It is a tedious and expensive process, and in the richest country, in the highest state of civilization is not worth the expense. The accompanying diagram will give some idea of this mode of delineating ground. The contours are supposed to be drawn at certain equal vertical distances, and it will be evident from inspection of the sections that where the hill is steepest the contour lines are closest. These contours at long intervals on a large scale are difficult to read, but if between the lines you interpolate 10, 20, or 15 other lines, you will get a closer and closer approach to regular shading, and it is evident that in proportion as the hill is steep so will this shading be dark or light. Eye contours sometimes called the horizontal system of sketching, is an eye modification of contouring. The style is easy, light, effective, and affords great opportunity for artistic skill. All that is necessary is that the Surveyor when sketching an eye contour should consider, if a person walked horizontally, what lines he would move on, or what routes would he pursue and his eye contours should approximate the plans of those imaginary lines.

The Vertical system, or hatching, starts by considering the course a volume of water, equally disseminated from the top of a hill would naturally pursue, in running down its sides (*Vide* sketch). In this system also it is evident that the steepest sides will have the shorter bases, and the streams will then flow closer to each other than in the more gentle slopes, and thus the different slopes are shaded darker or lighter according as they are steep or gentle. In shading with a brush the same principles still guide us.



For effect: The hill sides are usually shaded off, from darkest at the top, to lightest at bottom, which also generally corresponds with nature, as most mountains are steeper at the summit and ease off near their bases. The great objection to simple shading is the difficulty of shewing all the minor features, clearly and effectively, without overcrowding, and making the whole confused. This is not the case with the simple pen lining. Every line with the pen expresses a feature, and every feature that will shew on the scale, can be accurately and easily drawn. But unless the pen work be highly finished and minutely worked up, it is ineffective, and difficult to read. I



have therefore introduced into the surveys of which I have had charge a combination of the pen and brush, which includes the advantages, and excludes the disadvantages of each system. The ink lining is penned in over the pencil lines executed in the field. The paper is then cleaned, and the relief is obtained by judicious shades of Indian ink or any neutral colour. This is an expeditious, and very effective mode of deliniating ground.

It is usual to consider the light to come into the map from the upper left hand or North West corner and consequently to shew all parts of buildings, steep banks, and such like objects, (which shew no base) with a thick line on the obverse *i. e. South East* and *North East* sides of them.

This arbitrary arrangement gives great effect to the parts of a map to which it is applicable, but is sometimes inconvenient; a river may have both steep or both low banks, or one steep and one high. According to custom if the bank lies on the North West side of the water-course it ought to be drawn with a thick black line, but if it lies on the South East side, it ought to have a fine line, *i. e.* it ought to be drawn in precisely the same way if the bank be low or high, or if there be no bank at all, which is manifestly wrong and inconvenient.

The symbols used to represent Churches, Temples, various Bridges, and other remarkable objects are given in most works on Surveying or Reconnoisance. A very useful table of them adapted to India is given in the "Manual of Surveying for India." Chapter XXV. page 480.

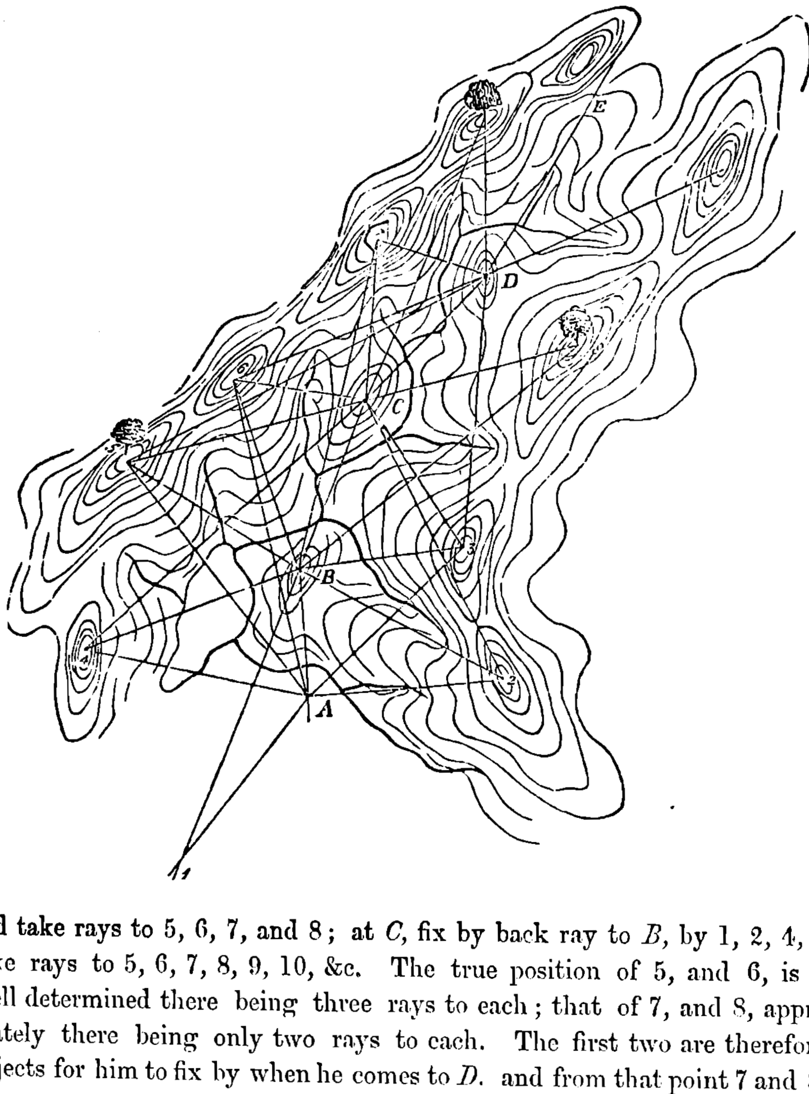
The following hints on sketching and filling in the ground will be found useful. As soon as the Surveyor has set his table at Station *I* and tested his points he is ready to commence sketching. With this object he draws rays from his station to all the remarkable points, such as peaks, houses, trees, &c., around him, and within a reasonable distance (5 or 6 miles); and estimating the distance assigns an approximate position to them on his plane table; he also draws rays to the junctions and turns of the different water-courses, and of spurs, knolls, &c. in his immediate vicinity, and sketches in (lightly) the ground by eye contours. This completed he should move off to some distant commanding point (2 miles at least from his first station) set up his table and fix himself (as previously directed). He should then draw rays to all the remarkable objects to which he drew rays from his first station. The intersections of the new and old rays fix the position of all the objects thus laid down, more or less correctly, according as the angles of intersection are good or bad. The positions given by the intersections if not less than 60° may be assumed to be correct, but when the intersections are sharper, only as approximate. These points now be come of great assistance, they cover a good area and enable the Surveyor to judge pretty correctly the positions of all objects, that fall with in them or near them. He next draws rays to the spurs, water-courses, and other physical features in his immediate vicinity, and sketches these features lightly in pencil. He then works back towards station *I*, putting up his table at intervals of from 200 yards to half a mile according as the ground is more or less intricate or difficult to see. From each station he draws rays as before and fixes the position of the junctions of the water-courses, ends of spurs, knolls, &c. to which he previously drew rays, and he then sketches that part of the ground. In this way he works back past station *I*, always taking rays to remarkable objects and keeping approximate work in advance of his final work. He should never consider any position determined until it has been tested by at least three rays intersecting at not less then a right angle. When a Surveyor gets into a position where he cannot fix himself for want of Trigonometrical data, he may use any point which has been laid down by not less than three rays from Trigonometrical points, provided these intersections be at not less than a right angle, or his position does not fall outside the pencil of rays of intersection. To secure a number of such subsidiary points, the Surveyor should always work along the ridges before descending into the lower ground. He will also find it much easier to sketch with the sun in his front, for if the sun be behind him, no shadows are thrown on the features he is looking at, all look like one continuous mass; but if he have the sun in front of him, objects stand out in strong light and shade, every ravine and turn of a ravine may be detected at once, and it is far easier to pick out or recognise the prominent points.

He will also find it a great advantage to traverse by zigzag (like triangulation) in circuits through the Country when the physical formation permits of it. The blank areas thus circumscribed are always filled in much easier, and the zigzag process affords better intersections than can be obtained by working on straight lines.

The amount of detail to be shewn will depend upon the scale. On a small scale villages are shewn by circles, on an inch scale they may be laid down by tangents to their edges, the tangents being drawn from so long a distance as to give nearly the correct area of the village, but on the six inch scale the streets and houses should be shewn. On the one inch scale, it is also usual to shew, all the different areas, such as cultivation, various kinds of jungle, swamps, &c. The different minor features and the lay of the strata can generally also be shewn, but on the half inch and quarter inch scales it will be generally sufficient to shew all ridges and spurs, without reference to their respective slopes. It is a great mistake to attempt to shew too much as it only tends to confusion. Further more many objects such as precipices, roads, wells, temples and such like small objects, which would if drawn to scale be represented by almost invisible fine lines or points must be exaggerated on the map, in order that they may draw sufficient attention and receive their true value. Much more might be written to meet the various contingencies of ground, and position a Surveyor may meet with, but without a few lessons and a little practice in the field, it is almost hopeless to attempt to make a good Topographer, and when once the Surveyor has acquired a little practical knowledge, his own wits will always suggest to him the means of overcoming a difficulty.

The foregoing observations appertain to the rigorous filling in of the details of a survey. It often however happens that the Officer in charge deputes an assistant to make a rough reconnoisance of the country in advance. This reconnoisance becomes a most valuable aid to him in laying out his triangulation, in placing and afterwards in finding the position of any poles he may put up to mark peaks, and other remarkable points likely to be useful to the Surveyors employed on the filling in. The plane table is very useful for this kind of work. The assistant can advance by a regular series of triangles through the country, laying down the position of all the remarkable objects, with quite sufficient accuracy for the purpose required, and if one chain of triangles passing through the table be measured with a theodolite, computed out and projected as the assistant travels on, a limit of error is fixed, and a really good reconnoisance is made. When the Surveyor comes to observe his final angles he puts up his plane table near his instrument, and sets it in the usual manner; he then notes what points he has to observe and by laying his ruler on each ray in turn, discovers their position. Any Surveyor who looking down from the top of a hill into raviny or flat ground has had to hunt for poles, or other opaque objects, whose exact position he has not exactly known, will acknowledge the immense comfort of having a good reconnoisance mounted on a plane table by his side to guide him in his search.

A very fair reconnoisance may be made by a traveller in a hilly country by keeping himself supplied with points for fixture as he journeys on. Thus from *A*, fix by 1, 2, 3, 4,* and take rays to 5 and 6; at *B*, fix by *A*, 1, 2, 3, 4,



and take rays to 5, 6, 7, and 8; at *C*, fix by back ray to *B*, by 1, 2, 4, and take rays to 5, 6, 7, 8, 9, 10, &c. The true position of 5, and 6, is now well determined there being three rays to each; that of 7, and 8, approximately there being only two rays to each. The first two are therefore fit objects for him to fix by when he comes to *D*. and from that point 7 and 8 are also permanently laid down. Thus the Surveyor can proceed from station to station always supplied with points for data and keeping approximate work in advance which in turn affords fresh data. Should a theodolite he used very fair results should be obtained, but with a prismatic compass or plane table much error is sure to creep in, and it is evident that such a system of reconnoitering is only suitable for a rough preliminary survey, or for military

* Given points which must have been correctly laid down in the first instance.

expeditions through a mountainous country where the Surveyors cannot leave the line of march.

In conclusion I would observe that whereas, in reconnoitering, a surveyor should avail himself of every facility for making the most of the time and resources at his disposal, in a regular systematic survey he should never deviate from the strict laws of Triangulation on which extreme accuracy depends.

D. G. ROBINSON, *Capt. Engrs.*
In charge Bengal Topographical Survey, No. 1

Surveyor General's Field Office.
July 24th 1860.