SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2301.*)

"Preliminary Survey in New Countries, as Exemplified in the Survey of Windward Hawaii."

By THEODORE GRAHAM GRIBBLE, Assoc. M. Inst. C.E.

IN January, 1887, the Author was requested to make a survey of the windward side of the Island of Hawaii, Sandwich Islands, and report upon the feasibility of a narrow gauge railway, 70 miles long, to carry the sugar and other produce to the port of Hilo. The country is entirely volcanic, sloping down from three extinct, and one active crater to the sea. The engineering difficulties were mainly those presented by the gorges, or "gulches," so graphically described by Miss Bird in her "Six Months in the Sandwich Islands."

The exports of the districts of Hilo and Hamakua have now reached 45,000 tons of sugar alone. The fruit trade is increasing; and coffee of very fine quality has been produced above the sugar belt, in small quantities only; but the new Government are portioning out homesteads for coffee-cultivation, which are being freely taken up by the Portuguese settlers with their large families. At its present price, coffee will pay better for cultivation than sugar. The present outlets for the commerce consist of timber landings with cranes, built out on promontories underneath precipices. Here the sugar is received from the rope-way in a tram, or cage, and conveyed to schooners or coasting steamers upon boats or punts, when the weather permits. Sometimes the plantation has to suffer a month's detention, at others the loss of a boat-load of sugar.

The advantages of a railway in such a situation were undoubted; but it was a question whether a line could be constructed at a cost which would yield a profit to the stockholders. The gorges above referred to are about a hundred in number, running down from the volcanoes to the sea, intercepting in every case the line of route. The methods adopted on the survey were mainly those in vogue in America; and the object of this Paper is to describe them for the assistance of young English engineers who may use them in the Colonies. The survey occupied five months of field work, and one month of office work. The cost averaged £20 per mile.

The original intention was to run in and out of the gorges by means of forty back shunts. These were all dispensed with by means of curves of not less than 143 feet radius. The curve limits were combined with gradients as follows: a radius of 150 feet with a gradient not exceeding 1 in 50; a radius of 300 feet with a gradient not exceeding 1 in 40; and a radius of 450 feet with a gradient not exceeding 1 in 33. Within these limits, one engine will haul all the load required by the traffic. The estimate was for a 3-foot gauge line, with a maximum engine weight of 25 tons. Two types of engines, four wheels coupled and six wheels coupled, were used for ascertaining the maxima moments of flexure on bridges; and from these an equivalent uniformly distributed load was determined for each separate span. Plate girders, on the deck system, were adopted up to 50 feet span, and beyond that truss bridges. The estimated cost was somewhat under the limit prescribed by the promoters for assurance of financial success. The demonstration of the practicability of the line was largely due, in the Author's opinion, to the methods of telemetry adopted. A list of the instruments used, and particulars about them will be found in Appendix I.

A route survey, or reconnaissance, was rendered unnecessary by the existence of excellent maps of the district, prepared by the Surveyor General, Professor Alexander, and his assistant, Mr. Curtis Lyons; these maps show the coast-line, Government road, the outline of the gulches, and most of the earlier mill buildings. The geodetic survey, on the same lines as those of Great Britain and the United States, is plotted to 500 feet per inch, and referred to rectangular co-ordinates of latitude and longitude, which proved of great service in checking the azimuths. The route was determined by the situation of the mills, all of them close to the sea.

It was brought out very clearly upon this survey that neither triangulation of the gorges, nor chainwork in the more even country, could afford the same degree of accuracy as the stadia work; and in respect of despatch, they were not to be compared with it. The problems presented by the gulches were of great variety, from huge gaps, a quarter of a mile wide and 400 feet deep, necessitating a two-mile detour, down to openings which could be cheaply spanned. The gulchwork was all done by optical measurement; chaining was out of the question. The sides of the gorges sloped 35° on an average, but often reached 60°, with bluffs here and there of crumbling lava rock, giving a bare foothold to the men, and no place for an instrument. In addition to this, the vegetation was extremely dense, having grown undisturbed for centuries on the richest soil in the world. The Hau, or yellow hibiscus, is the greatest foe to the climber; its roots run several hundred feet above and below ground, and its branches mat into a web, pliable yet hard; it resists alike axe, hatchet, or cane-knife, and to cut a trail through it would take days. The system of optical measurement only requires the clearing of a small spot here and there to catch a sight of the staff, yet this often took from an hour to two hours and a half. The location between the larger gulches, including a considerable number of small ravines, was done with the chain, transit, and level, by Mr. Lincoln Cabot of Boston and a field-party. The whole of the traverse was plotted to astronomical azimuths, corrected every now and then by observations. The compass was quite unreliable, as the magnetic attraction of the hills frequently caused a deviation of several degrees within a few hundred feet. The azimuths were all determined by solar observations.

The following four methods are recommended, of which only the two latter were used—

(1) Observation of Polaris at its greatest elongation.[1]

(2) Observation of a pair of circumpolar stars when in the same vertical.[2]

(3) Equal altitudes of the sun.

(4) A single observation of the sun out of the meridian.

The two first require an illuminated axis in the transit. The observer must, in either case, sit up to catch his stars, and chance their being clouded. Methods 3 and 4, being diurnal observations, are more convenient; but the calculation is more lengthy. A close approximation to No. 3 is obtained, without calculation, by taking the equal altitudes about two hours from the meridian, and taking the mean bearing to be the meridian. This method has the disadvantage of bringing back the observer to the same point of observation to take his second altitude. The last is by far the most useful method, both as being diurnal, and, as consisting of only one observation. The calculation needs an ordinary

[1] This method is most common. See Trautwine's pocket-book, 'Hints to Travellers,' 'Raper's Navigation,' &c.

[2] This method is described by Professor Stockwell, of Cleveland, U.S., in the Journal of the Association of Engineering Societies, and may be used without a transit.

table of logarithmic sines and cosines, and a Whitaker's almanac. The importance of the observation for azimuth can scarcely be overstated; any error, either in the field or in the plot, is thereby at once detected. Even a good surveyor will rarely run a line for several miles in rough country without making some error; but a frequent check of azimuth will enable him so to distribute minute instrumental errors as to render them unscaleable quantities.

The modus operandi of the optical work at the gulches varied somewhat according to the nature of the obstacles; but the following course was adopted where the difficulties were greatest. The transit was fixed on one side of a gulch, and foothold dug out; the observer gave his entries to a calculator, who booked them, and worked up the position of each sight there and then. On the other side of the gulch, the leader of the staff-gang held the levelling-staff, the head chainman carried only a sight-stake, the tail chainman carried the compass clinometer, only the tape being used; and short distances of from thirty to fifty, and occasionally a hundred feet, were run. The tail chainman booked distances, bearings, and vertical angles. One of the axemen took the slopes of the hill at right angles to the line. Thus the line was run through the bush until a spot was reached suitable for a clearing. All hands then went to work with axes, hatchets, and cane-knives, and cleared a sight of the levelling-staff for the observer at the transit-station. This observation determined: (1) the actual distance of the staff from the transit, by observing the stadia hairs; (2) the true azimuth of the same by observing the horizontal limb; (3) the elevation above sea-level of the same, by observing the vertical lines. These points were termed primary points, and were laid off first upon the plot, from the transit-station. The compass-traverse, made by the staff-gang, was then plotted on tracing-paper, and superimposed upon the plot of the primary points; the intermediate points were then pricked through, the traverse completed, and the contours filled in. When one side of the gulch was finished, the two parties changed sides, and repeated the same operation. By this means, a net-work of triangulation was obtained, serving as an independent check to the stadia work. The use of the compass was thus limited to short stretches between points accurately determined in elevation and azimuth. The survey was plotted on a scale of 100 feet to the inch on account of the steepness of the side hill, a difference of 10 feet in height showing very little, even on this scale, when the slope is 60°. The contours were drawn at every 5 feet of height in the open country, and every 10 feet in the gulches. The alignment was laid on from the contours; after which the profile was plotted on ruled profile paper, to a scale of 400 feet per inch horizontal, and 40 feet per inch vertical.

Telemeter station (T. S.), and staff station (S. S.), mean respectively the positions occupied, at the time of observation, by the instrument and the staff. When the instrument is shifted, say from A to B, a backsight is first taken from B to A. The elevation of the staff station B is now re-booked as the elevation of the telemeter station B, and *vice versâ* with A (Appendix II). The plotting of the survey is simply the reproduction, on paper, of points obtained by radial distances from the telemeter station, the angles being the actual astronomical azimuths of the radial lines. The detail of buildings was filled in upon the same principle, but with the plane-table; this instrument, of the simplest construction, was placed over one of the points previously fixed by the theodolite, and carried a field tracing of the spot showing the skeleton traverse. It was generally arranged to fix the plane-table within 100 feet distance of the corners of the buildings, so that the subsidiary radial lines could be taped at once. By this means, the labour was divided and time saved.

The term elevation is the elevation of the point above mean sea-level. The term optical axis means the intersection of the vertical axis of the pivot with the axis of the telescope, and the abbreviation for its elevation is O. A. The vertical component (V. C.) is the product of the direct distance measured along the line of sight by the sine of the vertical angle. The horizontal component (H. C.) is the product of the said distance by the cosine of the said angle. The backsight or foresight is the reading on the staff of the axial hair. It is a backsight (B. S.) when used to determine the elevation of the optical axis from the known elevation of a staff station, which is only done to commence work and in shifting the instrument. It is a foresight, or intermediate (F. S.), when the reverse operation is performed. The working out of the vertical component is sometimes done by the slide-rule; but it is better to use a table of sines to four places. The horizontal component is obtained from the graduations on the inner side of the vertical limb of the instrument, "ratio of hypotenuse to base." The multiplications of the sines by the direct distance are done very rapidly by two office hands, the one with the sine-table, the other with Dr. Crelle's calculating tables.

In the example of field-book chosen (Appendix II), the direct distances given are all just equal to the difference of the upper and lower stadia readings, multiplied by 100. The divergences actually existing at each 100 feet are usually booked on the fly-leaf of the field-book, so that, without any further tables, the direct distance can be corrected and entered at once from the sight. The lower hair was, whenever possible, directed on the first joint of the staff, so that a simultaneous reading of upper and lower hairs could be obtained. The central or axial hair was always a mean reading between the other two. It was not read except at a change of telemeter station as a check, but it was left to the recorder to work out.

Rule 1.—To obtain the elevation of the optical axis (O. A.) from a backsight on a bench mark or other datum point, the known elevation of which is booked as elevation of staff station (S. S.):

(*a*) When the vertical angle is *plus*, O. A. = S. S. + B. S. − V. C., where B. S. is the backsight and V. C. the vertical component.

(*b*) When the vertical angle is *minus*, O. A. = S. S. + B. S. + V. C.

Rule 2. From the elevation of the optical axis, ascertained as above, to obtain the elevation of any staff station (S. S.):

(*a*) When the vertical angle is *plus*, S. S. = O. A. + V. C. − F. S., where F. S. is the foresight or intermediate.

(*b*) When the vertical angle is *minus*, S.S. = O. A. − (V. C. + F. S.).

When the instrument is shifted, the new elevation of the optical axis is obtained, as at first, by a backsight upon the known station just left; but an independent check is obtained by actual measurement of the height of the optical axis above the new telemeter station. This may be done by an ordinary tape; but in the Author's instrument, the plummet-chain terminates in a hook exactly 2 feet below the optical axis; a steel tape is hooked on, and measures the height more quickly and correctly. Even with the utmost care, there will generally be a slight error discovered here, sometimes arising from fault of adjustment, sometimes from incorrect reading of the stadia. If the discrepancy is divided equally between the two stations, the error will be removed if it arises from the first-mentioned cause; if from the second cause, it is impossible to locate it, and if it amounts to anything serious, the sights should be repeated. The Author has levelled 100 feet in one shot with only a divergence of $\frac{1}{100}$ foot between backsight and foresight; the vertical angle was about 15°, so the direct distance was nearly 400 feet. Generally the discrepancy in such cases averaged from 3 to 6 inches.

In conclusion, it is suggested that for rapid and effectual preliminary survey—

(1) A telescope should be used which will discern Jupiter's satellites, mounted either on the Y, or transit plane of the theodolite.

(2) The micrometer and stadia systems should be combined in the one instrument.

(3) The staff should be provided with sights and bubbles, to dispense with double calculations by insuring a position of the staff at right-angles to the line of collimation.

(4) An independent check of the levels should be made with each change of telemeter station, by means of the measurement of the height of instrument with the steel tape.

(5) The bearings should be all taken from the north point, ascertained and frequently checked by astronomical observation.

(6) The plane-table should be used, both as a sketching-board and also on its tripod; but only as an auxiliary, and without any of the expensive attempts at making it a universal instrument.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

List and Description of Instruments.

1. One 6-inch transit theodolite, with a telescope of 14″ focal length eccentrically fixed and counterbalanced in place of the ordinary one. Stadia hairs were added, reading 1 foot per 100, correct at 500 feet, the intermediate values being determined by a measured base in the usual way. The short telescopes usually fitted with stadia hairs would not have sighted across the ravines.

2. One micrometer telescope, 2 feet focus, by Elliott, as supplied to the army. It measures distances approximately from the height of infantry or cavalry. It was modified to suit with observations upon a pair of disks 10 feet apart. A tripod was added, fitted with tangent-screw; the same tripod carried a plane-table of cheap construction, as the two instruments were not used simultaneously.

3. One 14-inch dumpy-level.

4. One box-sextant, by Troughton and Simms.

5. One $5\frac{1}{2}$-inch aneroid, in sling-case, by Steward, reading with vernier to single feet. This instrument is very distinct in its graduation. The differential scale of elevations, and uniform scale of pressures, are transposed by means of a "snail," so that the pressure-scale becomes differential, and the scale of elevations uniform, thus permitting the introduction of the vernier. The scale of elevations was specially worked out from Guyot's formulas, and found to be somewhat at variance with those usually adopted by instrument makers. The instrument was verified at Kew Observatory, and the errors at different pressures registered. The climate of the Sandwich Islands is very equable, causing less fluctuations in the barometer than in most countries; but a lighter, cheaper, and more compact aneroid is recommended, as the gain through precision of graduation will be often annulled by atmospheric changes. A 3-inch Sopwith aneroid would be much handier.

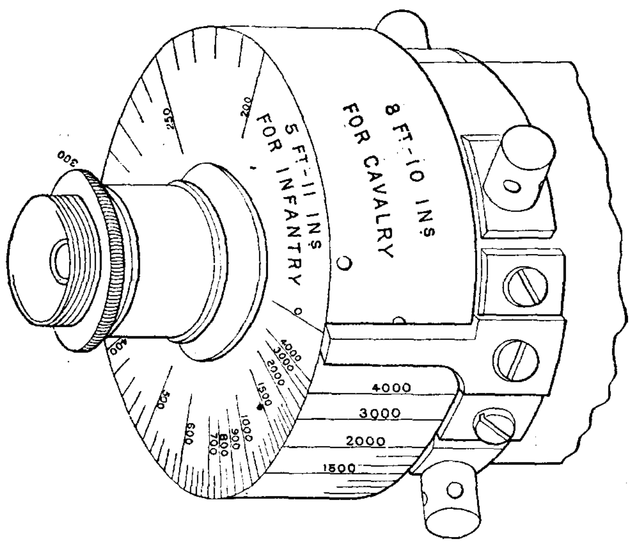
6. Two Abney levels.

7. One compass-clinometer, Colonel O'Grady Haley's patent, by Elliott. The prismatic compass is all that could be desired; but the clinometer, being of the plummet type, is too slow in its action. Messrs. Elliott now make a combined prismatic compass and Abney level, of the Author's design, which will be found quite as accurate and more rapid than the O'Grady-Haley instrument. The same makers also construct the Author's telemeter-theodolite. It is a 7-inch Y theodolite, surmounted by an 18-inch telescope of twenty power, which may be also carried in a sling-case for reconnaissance. Another telescope of forty power is provided in the same box for astronomical purposes, and long-range stadia measurements. The telemeter-theodolite is a combination of the micrometer-telescope and the stadia-theodolite (Fig. 1). Though heavier than the ordinary theodolite, it can be carried by one man, and is much less bulky than two instruments, each with its own tripod. When used upon its tripod for the actual survey, the ordinary Sopwith staff is used, being read by the horizontal stadia-hairs. Two small levels are attached to the staff, and a sight-vane for placing it always at right-angles to the line of sight; also a pair of sliding disks are fixed to the staff when, by a signal from the leader, the assistant knows that an extra or check-

sight is required, by means of the movable micrometer hairs. The stadia readings are used up to the limits of such observation; and the micrometer readings are taken occasionally as a check. Beyond these limits the micrometer only can be used. The stadia hairs are fixed at 1 per cent., as is customary,[1] subtending 1 foot on the staff for every 100 feet of actual distance. The instrumental constant is obtained, and the values of readings registered, by actual observation at every 100 feet, and the intermediate by interpolation.

The Author's experience does not go to prove the extraordinary accuracy claimed by the various inventors for the instruments of this type. If the registration just referred to be perfectly made, it is clear that the limit of accuracy with the stadia measurements will be in the same ratio as the power of the instrument. An ordinary 5-inch theodolite will only read the hundredths on

FIG. 1.



MICROMETER HEAD TO THEODOLITE.

the staff at about 300 feet. The Author's two telescopes will read them at 600 and 1000 feet respectively. Therefore the limit of accuracy is 1 foot up to these distances, and beyond them depends upon the experience with which the trained eye can estimate the portion intercepted upon the tenths by the stadia hairs. Beyond that limit, the accuracy is reduced to estimation between the feet-marks on the staff. If the telescope were of sufficient power to observe with the micrometer hairs the precise extremities of the disks, the accuracy would be as great at a mile as at 100 yards, but this is impracticable; and the one method is about as accurate as the other. The stadia hairs are needed for the shorter distances, as being very much more conveniently reduced in the field-book; the micrometer cannot be dispensed with for the longer distances. The combination of the two in one instrument has been a long-felt want of surveyors.

[1] Minutes of Proceedings Inst. C.E., vol. xci. p. 285.

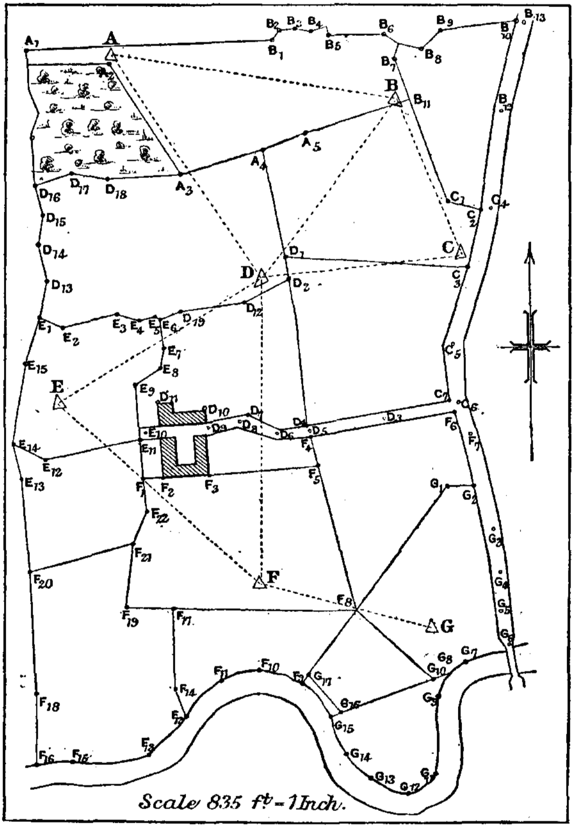
APPENDIX II.—

Telemeter Station.	Staff Station.	Horizontal Limb.	Vertical Limb.	Stadia Hairs.	Direct Distance.	Horizontal Component.	Vertical Component.
A	BM		+ 2° 05′	500 780	280	280	10·16
	A_1	273° 05′		500 870	370	..	..
	A_2	205° 18′		500 535	35	..	..
	A_3	149° 28′		500 1,115	615	..	..
	A_4	122° 30′		500 1,260	760	..	..
	A_5	111° 40′		500 1,390	890	..	..
	B	98° 48′	— 3° 14′	200 1,430	1,230	1,228	69·26
B				..	..	..	..
	A	278° 48′	+ 3° 35′	300 1,530	1,230	..	76·87
	B_1	295° 35′		500 1,075	575	..	..
	B_2	300° 05′		500 1,085	585	..	..
	B_3	303° 03′		500 1,050	550	..	..
	B_4	307° 38′		500 980	480	..	..
	B_5	314° 07′		500 900	400	..	..
	B_6	351° 29′		500 790	290	..	..
	B_7	359° 42′		500 665	165	..	..
	B_8	26° 20′		500 745	245	..	..
	B_9	31° 40′		500 850	350	..	..
	B_{10}	54° 35′		500 1,130	630	..	..
	B_{11}	104° 27′		500 553	53	..	..
	B_{12}	104° 27′	— 1° 25′	500 976	476	..	11·75
	B_{13}	56° 05′	+ 0° 06′	500 1,148	648	..	1·09
	C	157° 18′	— 1° 20′	500 1,250	750	..	17·47
C	..	..	..	..	..	..	..

—Field-Book.

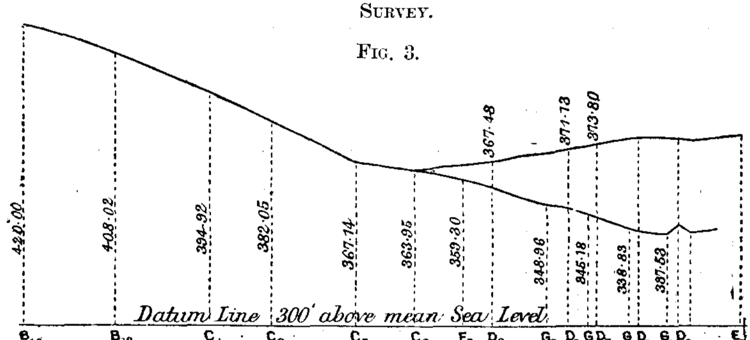
Elevation of Tele-meter Station.	Height of Instru-ment.	Backsight.	Foresight or Inter-mediate.	Elevation of Staff Station.	Elevation of Optical Axis.	Remarks.
494·91	4·75	6·40	..	503·42	**499·66**	
..	..	..	..	..	..	N. corner of hedge.
..	..	..	..	..	..	Hedge.
..	..	..	..	..	..	Junction of hedge.
..	..	..	..	..	..	,, ,,
..	..	..	..	..	..	Hedge.
..	..	..	8·15	422·25	..	
422·25	4·90	..	..	..	**427·15**	
..	..	9·15	..	494·87	..	
..	..	..	..	..	..	Hedge.
..	..	..	..	..	..	,,
..	..	..	..	..	..	,,
..	..	..	..	..	..	,,
..	..	..	..	..	..	,,
..	..	..	..	..	..	,,
..	..	..	..	..	..	,,
..	..	..	..	..	..	,,
..	..	..	..	..	..	,,
..	..	..	..	..	..	,, at corner.
..	..	..	..	..	..	,, ,,
..	..	..	7·38	408·02	..	Centre of road.
..	..	..	8·24	420·00		
..	..	..	8·75	400·93		
400·93	5·11					

FIG. 2.



SURVEY.

FIG. 3.



Horizontal Scale 835 ft = 1 Inch *Vertical Scale 75 ft = 1 Inch*

SECTION OF PUBLIC ROAD AT OCCUPATION ROAD.

APPENDIX III.

General Principles of Telemetry and Telemeters.

The term telemeter, which was introduced by surveyors, has been appropriated to so great an extent by electricians, that it is likely to be abandoned by the former for the term tacheometer. The simplest form of telemeter is the plane-table;[1] it is a graphic triangulation to attain the same end as the optical telemeters. The optical telemeter triangulates for distance upon the same principle, but with the additional precision of the telescope.

1. One class of telemeters is that in which the measured base forms part of the instrument itself. Such are Adie's 18-inch and 3-foot telemeters, described in Heather's "Instruments," in Weale's Series, Piazzi Smyth's 5-foot telemeter, Colonel Clerke's 6-foot telemeter, and Otto Struve's 7½-inch telemeter. The disadvantage of this class is the error produced by expansion and contraction. They are not much used now.

2. The second class is that where the measured base is at the point observed, generally consisting either of a graduated staff, or a pair of disks connected by a rod. In this class there are two subdivisions.

(*a*) Those which have a fixed base and a varying angle, as the Rochon micrometer telescope, furnished with a reflector by which the images of the disks are made to coincide, as in a sextant, and the angle is then measured in terms of distance. Elliott's army telescope, in which the fixed base is the height of infantry or cavalry, where two wires fixed in the diaphragm are caused to approach to or recede from one another by a micrometer screw; the wires are actuated so as to exactly include the object observed, and the distance is read off either on the infantry or cavalry side of the screw, as the case may be. Binoculars are made upon the same principle. The advantage of this method is that it may be used approximately, by observing a man on foot or on horseback when impossible to send out a man with a target; but it may be also used with precision in cases where the rod-man can hold up a target with a pair of disks whose extremities are equal to 5 feet 11 inches, or 8 feet 10 inches.

Eckhold's omnimeter is a combination of the first class and subdivision (*a*) of the second class just alluded to. The instrument is a transit to begin with; it is furnished with a graduated distance-plate on the horizontal limb, worked by a micrometer screw, and read by a very powerful microscope at right-angles to the telescope. At one operation, by observing top and bottom of a 10-foot staff, the distance and elevation are obtained by means of calculation. The instrument has given much satisfaction both in India and the Colonies; it is, however, more complicated than the stadia principle, takes longer to adjust and to work, and is not more accurate.

(*b*) Telemeters which have a variable base and a fixed angle. This is the stadia principle, described by Mr. B. H. Brough in his Paper on "Tacheometry, or Rapid Surveying."[2]

3. The third class of telemeters is that in which the base is measured on the ground, at the point of observation. The Hadley sextant, though not, strictly

---

[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 187.

[2] *Ibid.*, vol. xci. p. 282.

speaking, a telemeter, is used as such when a distant vessel is observed simultaneously from the deck and maintop. The Dudge-Steward omnitelemeter,[1] the "Bates" range-finder, and many others of this class, are more suitable for military than civil engineering. The measurement of a base upon the ground at the point of observation, unavoidable with military engineers, has not yet been successfully accomplished with that combination of celerity and accuracy which is reached by the stadia and micrometric measurements.

[1] *Engineering*, August 20th, 1886.