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Bar-Subtense Survey

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shutter by electric current: he could watch the moment when the camera reached the desired point by artificial horizon.

A series of photographs taken in this way would complete the survey of the city, and might be transferred direct to the printing press. The balloon would of course require to be shifted for photographing each section of the city. Such photographs taken with a rectilinear lens could be fitted together, section to section, with perfect accuracy, and a single photograph afterwards taken from the combined portions, which would form a complete and minutely accurate survey of the city. This plan, without touch of pen or graver, may, as I said, be transferred to a metal plate or to a lithographic stone for printing on the printing press.

*Bar-Subtense Survey.**

By Colonel H. C. B. TANNER, Indian Staff Corps.

THE system of survey which I am now about to explain was introduced by me some years back, when called upon to execute a 4 inch = 1 mile ($\frac{1}{15840}$) survey of the Kangra district, situated partly amidst the snowy regions and partly in the broken hills at the foot of the Himalayan Mountains.

2. In Kangra, and elsewhere in highly mountainous tracts in India, traverse surveys had already been carried out by means of chain measurements before my party was organised. The resulting surveys, which were mainly undertaken for purposes in connection with the fiscal operations of the country, were not free from large errors resulting from the impossibility of obtaining accurate horizontal measurements across slopes intersected by fissures, broken by cliffs, and covered for the most part either by forest or scrub. In such localities a chain line might be run after immense labour, but with a resulting error of such magnitude that only the exigencies of the case rendered it admissible.

3. Several delicate and expensive instruments were already to hand, with micrometer eye-pieces attached, by which, when used in conjunction with bars of known length, a horizontal distance could be measured more or less near the truth; but such instruments were too complicated and delicate in their parts to bear the rough treatment they might receive at the hands of the native establishment to whom I had mostly to look when conducting the Himalayan survey. Besides this drawback, I had not found micrometer instruments capable of yielding results sufficiently accurate for the purpose of obtaining traverse distances within the prescribed error admissible for work on the large scale of 56·7 inches = 1 mile ($\frac{1}{1117}$) which was laid down for the more open tracts that would come under my measurements. The weak point

* Read at the Geographical Section of the British Association, Cardiff, Aug. 21st.

of micrometer eye-pieces for measuring distances lies in the fact that the wires are in different planes, i.e. they are not all exactly in focus at the same time, and this parallax renders them inadequate for the measurement of small angles with the exactness claimed for them by their makers. Micrometers attached to the eye-pieces of small theodolites have three wires, and to enable them to pass each other freely when working the screws so much space has to be allowed that, so far as I am aware, they are fit only for measuring small arcs approximately. Fullest trials under favourable conditions were given these instruments, and after repeating over and over again observations to well-defined signals, the resulting angles were found to be so widely discrepant that I had to give them up; and so long as the error of parallax spoken of above shall remain, so long will this objection to the use of such micrometers be a bar to their use for reliable work of the class now under notice.

4. The Bar-Subtense method which I then introduced has none of the drawbacks attending the use of the chain or of micrometer instruments; it is more accurate than either, and is effected by means of an ordinary theodolite, together with bars of varying lengths, according to the nature of the work to be performed.

5. The system is readily acquired by native surveyors after a week's instruction, and in their hands, over the roughest possible mountain tracts, is capable of furnishing horizontal measurements up to a maximum of some two miles with an error of about 0.5 per mile, or say three feet per mile, and up to a distance of three miles with a somewhat greater error; and an adaptation of the process is capable of yielding reconnaissance traverses and approximate trigonometrical work far more accurately and expeditiously than can be looked for by any other means, unless a regular trigonometrical survey be resorted to.

6. The theodolite used should be six-inch or larger; it should be simple in construction, and furnished with one vertical and one horizontal wire. The bars may be of varying lengths. In the Himalayas the 20-foot bar was in general use, but ten and two-foot bars were found convenient for some purposes. A 20-foot bar with 12-inch circular discs is capable of furnishing, under favourable conditions of light and atmosphere and by a skilled observer, a 3-mile distance with an error of six feet. A ten-foot bar with eight-inch discs will give good results up to a mile and a half, and a two-foot Gunter's scale blackened at the ends with two-inch paper discs pasted on two feet apart, and properly mounted, will give distances up to 20 chains. The latter bar, as used in the Himalayas, I hoped to have been able to exhibit.

7. I may here remark that portable folding 20 and 10-foot bars have not yet been constructed. The former might be designed to fold into seven and the latter into three and a half feet, and still have sufficient rigidity when in use to give good results.

8. The *modus operandi* of a traverse surveyor must now be explained in detail.

9. The forward signalman sets up the horizontal bar over the station mark, and then, by means of the folding sight-vane, directs the bar at right angles to the observer, who then intersects and records the reading of the back signal. Then, leaving the lower clamp fast, he releases the upper plate and intersects the right-hand disc of bar, the reading of which he records.

Now release lower clamp (leaving upper clamp fast) and intersect left-hand disc. Again release upper plate and intersect right-hand disc, and for a second time the left-hand disc with lower plate, and so on, continuing the repetition until, say, ten times, and then read and record the right-hand disc. In this operation the graduated limb of the theodolite will have moved over an arc ten times greater than that subtended by the bar. Now repeat again, ten or twenty times, and record readings of right-hand disc, and then, having taken a vertical angle to bar, and leaving lower plate fast, intersect, and record the reading of back signal with upper tangent screw, and such a record as I here show will have been obtained :—

Signals observed.		Reading of A vernier.	Differ- ences.	Subtended angles.		Error of 20 ft. bar — 0·2 of an inch.
Back station	A	126 14 20	0 ' "	' "		
Right-hand disc ..	B	206 26 30				
" "	B ₂	209 48 30	3 22 0	d	20 12	
" "	B ₃	213 10 15	3 21 45	d ₂	20 10·5	
" "	B ₄	216 32 5	3 21 50	d ₃	20 11	
Back station	A ₂	136 19 55	M 20 11 2 = x.			
(30 repetitions) ..		10 5 35	From Table, Chains 51 60*			
		10 5 35	Correction † — 4			
Subtended angle ..	x	20 11·2	Corrected distance 51 56			

$$\begin{array}{rcl} \text{Traverse angle:—B - A (= B}_4\text{ - A}_2\text{)} & 0 & 12 & 10 \\ & \frac{x}{2} & - & 10 & 5 \end{array}$$

$$\begin{array}{rcl} \text{Angle at station 1, between back station} & & \\ \text{and centre of bar at No. 2 .. } \} & 80 & 2 & 5 \end{array}$$

* For actual use the distances have been tabulated between 2 and 180 chains.

$$\begin{array}{lcl} \dagger \text{ Bar = 20 ft. = 30·3 lks. log. } & 1·48144 & \\ & 20' 11·9'' & \text{cosec. } 2·23122 \end{array}$$

$$51·60 \text{ log. } 3·71266$$

10. A 10-foot bar with an error of 0·2 of an inch would give—

Chains	..	..	..	25·80
Correction	..	..	—	·08
				<hr/>
Corrected distance, ch. 25·72				

11. A 2-foot bar with an error of 0·02 of an inch would give—

Chains	..	..	..	5·16
Correction	..	..	—	1
				<hr/>
Corrected distance, ch. 5·15				

12. I wish to draw attention to the complete system of checks on the observations furnished by the above record. In the first place there are two values of the azimuthal or traverse angle $B - A$ and $B_4 - A_2$, both of which should nearly correspond, and show only trifling differences.

13. The subtended angle, or x , which is D divided by the number of repetitions, should correspond very closely with d_1 , d_2 , d_3 , and, as a check on the arithmetic, it should agree exactly with the mean of d_1 , d_2 , d_3 . These values are taken out during the progress of the observations, and should one of them show even a small discrepancy, the work must be condemned and done *de novo*. Again, $A_2 - A_1$ and $B_4 - B$ must agree very closely. The checks are such that, by examining his record, the observer can make certain before proceeding to his next station that he has obtained the correct distance. Up to a mile he can detect any error made by the signalman in placing the bar at right angles, for it is only when exactly set that the black lozenge at the end of the sight-vane of the bar appears to him in the middle of the white patch on the bar itself.

14. The signalman soon learns to place the bar sufficiently near the horizontal for practical purposes. An error of 2° of dislevelment, which would seldom occur in practice, would only produce an error of about three inches in a mile.

15. Such is the mode of procedure to be followed in running an ordinary traverse, and I will now endeavour to show how an adaptation of the method may be made applicable to other classes of survey, such as reconnaissance of an unknown country, and an approximate triangulation.

16. There are two positions in which an explorer or surveyor may be placed: 1st, he may find it possible, before commencing operations, to send signals on a-head into the region he proposes to visit; and 2nd, as when accompanying an army in the field, he may not be able to determine, when at his initial station, the exact direction in which his operations will lie, and the country in his front will be closed to his signalmen.

17. In the former of these cases, having selected some suitable eminence, he will proceed to lay down thereon and measure, by the Bar-Subtense method, two or more short bases, in length according as the configuration of the ground may admit, say of 10 or 20 chains, and after taking a round of angles to surrounding signals and including the signals at the ends of his short bases in the circuit, he will advance to the next station of his series and observe to the signals of A station, treating them in pairs as if they were discs of a bar, and recording them exactly as described for a traverse. (See para. 9.)

18. The configuration of the ground at A station is not likely to have been such that the bases could be laid down at right angles to B, but they would have been placed as near a right angle as possible, when the following computation would be necessary, in order to determine the distance required :—

Left hand base. By Bar-Subtense. Chains 12·91. Log. 1·11091.

Names of Stations.	Obsd. angles.	Angles for comp.	Log. sines.	Log. sides.	Chains.
Left Base Stn.	Supplementary	94 13 34	9·99882		
A Station ..	85 10 0	85 9 10	..		
B Station ..	0 37 16	0 37 16	2·96496	3·07469	1187·65

Right hand base. By Bar-Subtense. Chains 19·06. Log. 1·28012.

A Station ..	57 53 0	57 53 0	..		
Right Base Stn.	Supplementary	121 19 52	9·93155	3·07460	1187·41
B Station ...	0 47 8·2	0 47 8·2	2·86293		

Error per mile = 3 feet.

The two triangles give the common side A to B, with a discrepancy of a little under 3 feet per mile, and this *mean* value would probably furnish a reliable base for a trigonometrical survey of limited extent.

19. In the second of the two contingencies under which a surveyor might probably have to work, namely, when B station could *not*, from want of a mark thereat, be observed from A, it would be necessary to determine at A the true azimuthal directions of the short bases at that station, and then, arriving at B, he would take the angles as on para.

17, and in addition observe the azimuth of A from B, and in order to compute the triangles shown in para. 18, he will have to *deduce* the angles from the azimuths in the following manner :—First, make on some convenient scale a rough plot of the work so far as it has gone, and enter thereon all the data so far forthcoming. Then, in order to deduce the angles of the triangles on para. 18, he will assume, as near as he can, by estimation or otherwise, the difference of longitude between A and B in miles, and on this difference of longitude compute the convergency of the meridians of the two points, and enter the same with its proper sign on the rough plot. Then, by applying the reversed azimuth of A from B, $\pm$ convergency, he will obtain the approximate azimuth of B from A ; and now, having all the azimuths at A, he can for a first approximation compute the triangles. This will determine the difference of longitude far more nearly than the surveyor could look for by estimation, and in the case of the distance here instanced—about 15 miles—he should have been able to estimate it within, say, five miles, that is, he guessed B to be nine miles west of A, then, the convergency on that diff. long. in lat. 29° would be $-4' 20''$.

20. In the following table may be seen the observed and the deduced data :—

At A Station.					At B Station.				
Azimuths (from south.)					Azimuths.				

Second (final) Approximation Convergency (*computed*) — 7' 6"

Base, chains, 12·91				Log.	1·11091.		
Left Base Stn.				94 15 48	9·99879	3·07466	1187·57
A Station ..	85	6	56				
B Station ..	0	37	16		2·96496		
	85	44	12				

Base, chains, 19·06				Log.	1·28012.		
A Station ..	57	56	50				
Right Base Stn.		..		121 16 2	9·93184	3·07489	1188·20
B Station ..	0	47	8·2		2·86293		
	58	43	55				

Showing a difference between the common sides of 63 links = 41 feet, or less than three feet a mile.

21. The simplest way of determining the azimuths required in this process would be by observations to the sun, or to the Pole star during daylight. This star may readily be found by means of a simple star-finder, used by myself for the past twenty years, and is visible with a 12-inch theodolite throughout the day. For two hours after sunrise, and before sunset, it may be seen with a seven-inch, and half an hour before and after with a six-inch theodolite.

22. Though this application of the Bar-Subtense method to a more extended class of operation has never been used in actual survey, yet it has been carried out by myself experimentally, to a sufficient extent to prove its trustworthiness as a basis for topographical survey and for geographical explorations of fairly extensive limits. In the Himalayan districts of Kulu and Kangra I was able to repeat the triangulation of the Grand Trigonometrical Survey, with an error quite inappreciable, on the scale of one mile = one inch. By fixing two "short bases" on the conspicuous Asapuri range in Kangra, I had a ready means of fixing my position, with a close approximation to the truth, within an area of many hundred square miles to the north and south of that range, and up to a limit of some 20 or 25 miles could obtain a base for further extension, with an expedition quite impossible by any other means I am acquainted with, and with an accuracy only surpassable by a regular trigonometrical survey extended from an elaborately measured base.

23. With respect to the Bar-Subtense regular traverse system, I may say that hundreds of such traverses, based on trigonometrical points in the Himalayas, have been tested, showing the error of the same to be

within three feet per mile. That is to say, a country which from its physical difficulties would ordinarily be closed to any kind of chain measurements, may be freely measured by this process with an accuracy only obtainable on level ground by a careful and well trained squad. By properly mounting the humble two-foot Gunter's scale, you may obtain "short bases" capable of yielding trigonometrical work that will not be far from the truth, and which, for moderately large areas will be quite sufficiently rigorous to form a basis for ordinary topographical purposes.

24. In conclusion, I would beg of any surveyor who has been brought up in the belief that triangles should nearly approach the equiangular, to pause ere he condemns this, my process, which I and others have tried, in which the triangles, when plotted on paper, appear from the shortness of their bases as straight lines; when, instead of finding the angles to be within a few degrees of 60° he finds one of them to slightly exceed four minutes.

25. I regret that I have been unable to obtain the requisite instruments by which I might have given a practical illustration, but failing this, I shall be happy to explain my system to any one who may wish to be further enlightened on it. For railway surveys in mountainous tracts, and for coast and riverain surveys, it is invaluable, and has only to be once fairly tried to become a favourite method with the intelligent surveyor; but, except in India, it is not known, and I shall therefore be glad if the short description given of it here may cause it to be taken up in other parts of the globe—in such localities where the physical obstacles are such as to preclude any other simple and accurate method.

GEOGRAPHICAL NOTES.

Exploration in the Karakorum.—In the course of last session the Council, after examining the proposals of Mr. W. M. Conway for a journey of exploration among the high peaks and glaciers of the Karakorum range, to be undertaken by a party trained in Alpine mountaineering, and competent to undertake survey work and make scientific observations, agreed to offer Mr. Conway, under certain conditions, a grant in aid of such an expedition. During the past summer the projected plan has taken further shape, and the basis of the party has been constituted by the association as a leader with Mr. Conway of the Hon. C. G. Bruce, of the 5th Goorkhas, a son of our former President, Lord Aberdare. Mr. Bruce's large experience of Himalayan travel should be of great service, and he is also a practical mountaineer. Mr. Conway himself is well known both in the literary world and in the Alps as a writer and a climber, and has in his Pennine