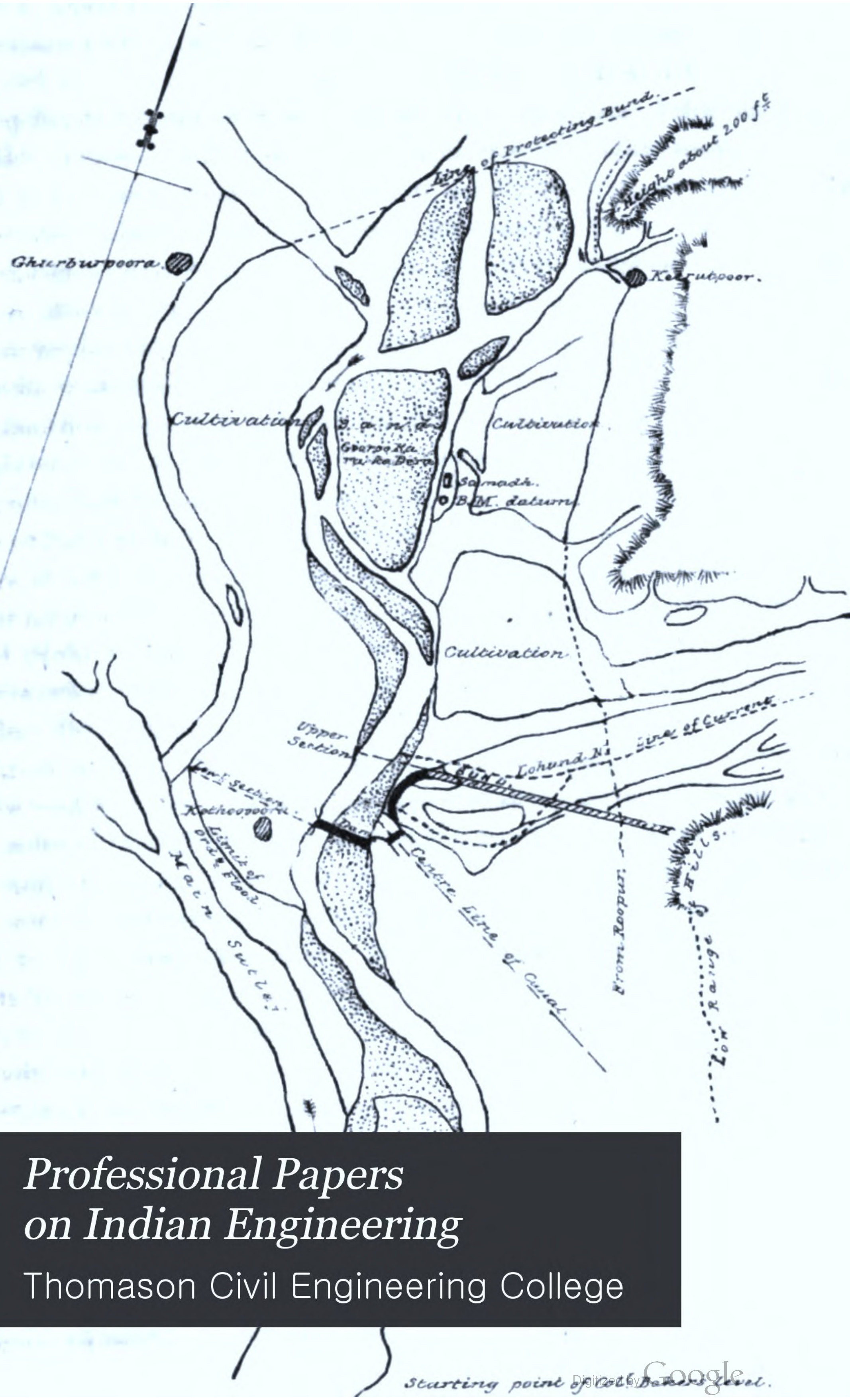

Professional Papers on Indian Engineering

Thomason Civil Engineering College

PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING.

VOL. II.—1865.

EDITED BY

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PREFACE TO VOL. II.

I HAVE to congratulate the Subscribers to these Papers on the successful completion of the Second Volume, and to thank the Contributors who have so willingly and gratuitously aided me. Without being over sanguine, there is I think a fair promise of the series being creditably carried on, at least for the present. Any suggestions for improvement from Subscribers will be gladly welcomed.

The number of original contributions received has been quite as many as I could reasonably expect. The other Papers have been chiefly abridged or adapted from Government Reports, or from books not generally accessible; and I have been guided by my own judgment of their probable utility and interest to the majority of Subscribers. To the P. W. Secretariats of India, the N. W. Provinces and the Punjab, I am indebted for assistance in this matter. From the Madras, Bombay, and Calcutta offices, I regret to say I have as yet received nothing, though many works of great interest are in active progress under those Governments. It is, however, to individual Officers, Civil and Military, of the P. W. Department, and other members of the Profession, especially the Railway Engineers, that I look for aid; and judging from the past two years, I am sure I shall not look in vain.

Several enquiries having been made for particular Papers, an extra number of copies will in future be printed, so that any Paper can be had separately (price 8 As.), and the more interesting of those already issued will be re-printed. Each Contributor will in future be supplied with six copies of his own paper *gratis*, and can have more if desired.

No. X. being the first Quarterly Number of Vol. III., will be issued on 1st February next.

The price for Vol. III. for 1866, will be as before, Rs. 14, if paid by 1st January next; *after* that date, Rs. 16, or Rs. 4 for each Quarterly Number.

Orders and Subscriptions received by the Editor at Roorkee; by Messrs. Thacker and Co., Calcutta or Bombay; or Messrs. Gantz, Brothers, Madras.

English Subscribers will receive their copies through Messrs. Smith, Elder & Co., for 32*s*. the Volume, including postage.

J. G. M.

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there perfectly steady; while by means of the registers, he marked exactly the places of the two extremities of the chain. The chain was then taken forward, and the near end being adjusted to the scale which had before marked the fore end, a new chain's length was laid off, and so on till the base was finished. Thermometers were placed in the coffers to determine the temperature of the chain; and the rate of expansion being previously determined by experiment, the necessary corrections were made for the varying temperature of the measurement. The quantity of this correction had been found by Colonels Williams and Mudge, to be on 100 feet, ·0075 inch for every 1° of Fahrenheit; but Captain Lambton, by some experiments performed with the chain itself, in October 1800, found ·00725, which quantity he applied as the correction of his measurement.

Besides the original chain a second was obtained from England, exactly similar. Its length had been fixed in the temperature of 50°. This chain was preserved as the standard, and to its indications were reduced all the measurements made with the other. The length of this standard chain was afterwards corrected for a trifling discrepancy detected by Captain Kater, when comparing standards at home, previously to establishing a uniform system of weights and measures.

In May, 1804, a base of verification of 39793·7 feet was measured by Lieutenant Warren, Captain Lambton's Assistant, near Bangalore; and though the distance was 160 miles nearly, the computed and measured lengths of this base, differed only 3·7 inches, or about half an inch in a mile: a proof of the great care and accuracy with which the work had been conducted. This base was adopted for the origin of the great Indian Arc series. It is hardly necessary to say that the steel chain is now entirely superseded by Colonel Colby's apparatus of Compensation Bars.

From this base a series of triangles was carried across the peninsula to the opposite coast, and a meridional series also commenced on a meridian about 35 miles west of Madras, which was subsequently abandoned for the meridian of Dodagontah further to the west, and on which the Great Indian Arc series was gradually established from Cape Comorin up to latitude 29½° N.; being the largest Arc yet measured on the earth's surface.

In his early operations Colonel Lambton was assisted by Lieutenant

Warren, of the 33rd, and Captain Kater, of the 12th, Foot. The first named officer belonged to the ancient noblesse of France, to which country he returned after the peace. His stay with Colonel Lambton was of short duration, as he was, at a very early period of the work, appointed to the charge of the Madras Observatory. Captain Kater's health having failed, obliged him to quit the department. This officer afterwards acquired an European reputation as a scientific man, having become a member of almost every academy in Europe, been employed on every business of national research, appointed a member of the Board of Longitude, and finally elected vice-president of the Royal Society. Thus it appears that, during the greater portion of his career, Colonel Lambton worked nearly single handed in the extensive and arduous operations which he carried on, amidst the formidable trials and obstacles that the baneful nature of the climate and the want of resources in the country everywhere presented.

It must also be borne in mind, that for a long period these operations were frequently interrupted by the disturbed political condition of the country, which was often the scene of warlike operations; for it was not until the Marquis of Hastings destroyed the Pindaree confederacies in 1818, that the Peninsula and Dekhan settled down into repose. The mysterious character of the instruments and operations, as well as the planting of flags and signals, have always more or less awakened the apprehensions or excited the jealousy of the native princes; it requires, therefore, no ordinary tact, firmness, and patience, on the part of the head of the department to conciliate good will.

Shortly after the commencement of his labors, Colonel Lambton was called on to demonstrate the utility of his work. It was asserted that surveys on an Astronomical basis would be equally accurate, and more economical than Geodetical operations. The futility of these views was ably exposed by the Colonel, and being supported by the Astronomer Royal of the day, (the Rev. N. Maskelyne,) all open opposition was withdrawn, and Major Rennell, who was the chief advocate of the astronomical basis, afterwards concurred in the trigonometrical system.* As this view of the subject has been confirmed by the prac-

* Colonel Lambton's operations detected an error of no less a quantity than 40 miles in the breadth of the Peninsula, as previously laid down astronomically in the way Major Rennell proposed. All the principal places on the old maps, which had been fixed astronomically, were found

tical testimony of every nation in Europe, and the importance of trigonometrical operations is now universally admitted by all practical scientific men as the only trustworthy basis for extensive national surveys, it is unnecessary to discuss the first principles any further in this place, and they are only adverted to in illustration of the formidable prejudices the trigonometrical survey in India has all along had to contend with. The Hon'ble the Court of Directors, however, when once convinced of the important practical utility of the work, have ever since continued its firm and powerful supporters, and in the words of the "Edinburgh Review," "their liberal and enlarged views cannot be too highly commended."

Colonel Lambton remained at his post till his death, which occurred on the 20th January 1823, at the age of 70, at Hingun ghât, about 50 miles from the city of Nagpore, in the Dekhan.

The professional account of Colonel Lambton's labors is given in the first five volumes of the General Report, which are deposited at the India House in manuscript. Condensed accounts of the more scientific part of his operations have been from time to time published. (*See* Vols. VII., VIII., X., XII., and XIII., *Asiatic Researches.*)

Colonel Lambton, between the years 1802 and 1815, covered the whole country as high as 18° latitude with a net work of triangles, whereby the Peninsula was completed from Goa on the west to Masulipatam on the east, with all the interior country from Cape Comorin to the southern boundaries of the Nizam's and Mahratta territories. Subsequent to this achievement, the great Arc triangulation was extended nearly to Takal Khera, in latitude 21° 6′. The greater part of the Nizam's eastern territories were triangulated by meridional series between the Kistnah and Godavery, and considerable progress was made in the longitudinal series from the Beder base towards Bombay. All these operations are described in minute detail in the volumes of the General Report, at the India House.

The area comprised by the whole of the operations prosecuted during the time Colonel Lambton was superintendent, aggregates 165,342 square miles. The expense incurred amounted to 8,35,377 Rs. Consequently, the rate at which the triangulations have been executed

considerably out of position. For example, Arcot was out 10 miles, and Hydrabad no less than 11′ in latitude and 32′ in longtitude.

averages Rs. 5-0-10, or less than 10*s*. per square mile; which cannot but be considered remarkably cheap.

From the circumstance of Colonel Lambton's operations having commenced in Southern India arises the great superiority of the maps of the Madras Presidency; the atlas sheets whereof, published by order of the Hon'ble East India Company, are nearly complete. This part of India was surveyed in detail upon the basis of Colonel Lambton's operations, and on a scale of 1 mile per inch, by the officers and sub-assistants trained at the military surveying schools.

In October 1817, the Marquis of Hastings, impressed with a well-founded conviction of the important utility of the Trigonometrical Survey, resolved to transfer the control over its operations to the Supreme Government of India; and further, in consideration of Colonel Lambton's increasing age and infirmities, which were little fitted to encounter the laborious exertions, corporeal and mental, which such a task demands, selected Captain (now Colonel) Everest, as eminently fitted by mathematical attainments and practical skill to assist the superintendent, and eventually become his successor.

Captain Everest joined the Colonel as chief assistant in the latter end of 1818, and was employed, in the first instance, in the triangulation of the eastern parts of the Nizam's dominions; where in consequence of the extremely unhealthy character of the country, he twice fell a victim to jungle fever, and eventually was ordered to the Cape of Good Hope for the recovery of his health. While at the Cape, Captain Everest employed his leisure in investigating the circumstances appertaining to the Abbé de la Caillé's arc, which formed the subject of a valuable paper, published in the first volume of the Astronomical Society's Transactions.

On his return to duty Captain Everest was deputed on a longitudinal series of the great triangles emanating from the Beder Base line, and intended to connect Bombay. He was engaged on this important work at the time of Colonel Lambton's death, by which event he succeeded to the office of Superintendent, and immediately proceeded to concentrate the resources at his disposal on the extension of the Great Arc series, which after many difficulties was at length carried up to latitude 24°, where a Base line was measured at Seronj.

An account of these operations is given in detail in the fifth and sixth volumes of the General Report, deposited at the India House. All the scientific portion relating to the fifth section of the great Indian Arc was further published by order of the Hon'ble East India Company, in the year 1830.

After the termination of the Sironj base line, Captain Everest proceeded to England for the recovery of his health; and as there was no person in India competent to succeed him, the Supreme Government resolved to retain the situation of Superintendent open until his return.

During Captain Everest's absence the establishment was usefully employed under the principal sub-assistant, Mr. Joseph Olliver, in extending a longitudinal series from the Seronj base line to connect Calcutta, for which work written instructions were given by Captain Everest. This series traverses, throughout the greater part of its extent, a wild, desolate, and unhealthy tract of hill country, which presented formidable difficulties. Notwithstanding the frequent ravages of jungle fever, which has all along been the most baneful enemy of the trigonometrical survey, as well as one of the chief retarding causes, this party, composed entirely of East Indians, successfully overcame all obstacles, and the work was eventually brought to a close in the year 1832, at the Calcutta base line, having occupied a period of six years in accomplishing a direct distance of 671 miles. The progress, therefore, was at the rate of 112 miles per annum, including branching series of secondary triangles. On account of the defective state of the instrumental equipments, the professional value of the work is only of a secondary or tertiary order. The area comprised in these operations is 33,442 square miles.

Colonel Everest returned to India in 1830, liberally provided by the munificence of the Hon'ble Court of Directors with geodetical instruments and apparatus of every description, in the construction of which the most skilful artists of the day, Messrs. Troughton and Simms, exhausted every resource of modern invention. The equipments consisted of a complete Base line apparatus, the invention of Colonel Colby, precisely similar to that employed on the Ordnance survey; a great Theodolite, 36 inches in diameter, designed by Troughton, which even at the present day is supposed to stand unrivalled by any other instrument of the kind in the whole world, and which most probably will never be surpassed; two 18-inch Theodolites, and a variety of smaller instruments from 12 inches diameter downwards, all by the same celebrated maker. The signals, all of the most efficient kind, and recently invented, consisted of Heliotropes, reverberatory Lamps, and Drummond's Lights, of which the two former have been exclusively used; and here it may be remarked, that the substitution of luminous signals for opaque ones has contributed vastly to the improvement of the observations. These modern inventions together with the extreme precision of Troughton's graduation, as well as the high optical power employed, and the rigorous system of changing zero, introduced by Colonel Everest, has brought the terrestrial operations to a refinement of accuracy which may almost be pronounced unsurpassable.

During his absence from India, Colonel Everest had made himself acquainted with the English Ordnance Survey system, and with every modern improvement in geodetical matters that had taken place in Europe. The apparatus supplied by order of his Hon'ble masters was superior to any in the world, and London artist, Mr. Henry Barrow, was sent out to maintain the apparatus in order. Thus splendidly equipped, Colonel Everest returned to India in the prime of life, the full vigour of his faculties, and with an undaunted determination of character that never quailed before any difficulties, nor yielded to any opposition. The task before him required indeed the full display of all the vigour he possessed. In addition to the duties of Superintendent of the Trigonometrical Survey, he had now to perform those of Surveyor-general of India, to which office he had recently been appointed by the Hon'ble Court of Directors. This union of offices, though it served to facilitate arrangements, nevertheless vastly increased his labors at the outset; for the apparatus being new to India, and the establishment untrained, the whole task of teaching devolved on him unaided. In 1833, moreover, the offices of Deputy Surveyor-general at Madras and Bombay were abolished, which further increased the duties of the Surveyor-general of India, so that Colonel Everest had, in fact, to perform the work which had hitherto occupied the undivided attention of four officers. In the sequel these reductions have been found to operate conveniently enough, and so far have justified the expectations of the Hon'ble Court by whom they were ordered, but the additional labor thrown on the Suryeyor-general at the time that the Trigonometrical survey was about to recommence on a new organization, made his task a very arduous one.

He was detained by all these arrangements, by official delays, and by the measurement of the Calcutta Base line, until the end of 1832, from which time the Great Arc may be considered to have actually recommenced, after a cessation of seven years. The work was carried on unremittingly till December 1841, when the whole Indian arc, from Cape Comorin to the Himalaya mountains, forming the main axis of Indian geography, was finally completed.

These operations are fully detailed in Colonel Everest's book, published in 1847, by order of the Hon'ble East India Company. The area comprised by the Great Arc operations, principal and secondary, aggregates 56,997 square miles, including the revision of the section from Beder to Kalianpur, and the measurement of three base lines, each from 7½ to 8 miles in length, viz., those of Beder in lat, 18°: Seronj, near Kalianpur station in lat. 24° and the Dehra base about 70 miles N. of Kaliana station in lat. 29·30, where the Great Arc actually terminates, this distance being observed on account of the proximity of the Himalayas.

On comparing the actual measurement of the Dehra Doon base (by Colby's apparatus) with that calculated from the Seronj base measured in 1824 (by the chain), a difference of nearly 8½ feet was found. In former times this would have been considered a very satisfactory agreement, seeing that the length of the base is 7½ miles, and its distance from the new base upwards of 400 miles in a straight line; but Colonel Everest justly considered the difference as indicating a much larger error than ought to exist, regard being had to the precision of the new methods; and, in order to set the question at rest, he resolved to re-measure the old base with the more accurate apparatus he now had at his command. This operation was completed in January 1838, when it appeared that the length given by the chain measurement of 1824 was too short by nearly three feet, as compared with the new result.

The Plate represents the termination of the Measurement of the Calcutta Base in 1832, by Colby's apparatus. The six sets of bars are resting upon their tripods, levelled and in the act of adjustment, longitudinally, by means of the directing or boning telescope, to the left hand. The boning telescope ought to have been considerably more distant from the bars, but it would then necessarily have been excluded from the drawing. A moveable covering of tent-frame work protects the bars from the influence of the morning sun; at their left extremity is seen a cast-iron tripod, firmly imbedded in the ground, bearing a brass vertical cylinder and plate, upon the surface of which is the minute dot which marks the termination of the last, and acts as the starting point of the present measurement, by the adjustment of the cross wires of the end microscope in the true vertical line bisecting the dot. These apparatus are represented on a larger scale in the foreground; as also one of the wooden boxes containing the compound bar, showing the two projecting tubes, within which lie the cross levers of the compound bars, upon which are engraved the dots, or marks to be read off by the double microscopes interposed between each box, as will be comprehended by reference to the drawing. The right extremity of the line is seen to enter the door of the tower, where it terminated in a coincidence with the original dot, engraved upon a metallic disc attached to a sunken stone pier.

The great accuracy and value of this apparatus may be judged of by the measurements of the three bases of the Great Arc. The Dehra Doon base is nearly 7½ miles in length. The ground is undulating and by no means favorable; the line is twice intersected by the stream of the Asan; and the height above the sea level of one end of it is 186 feet greater than that of the other. The base was measured twice, first from west to east, and then in the opposite direction. After all reductions the two results were as follows:—Length in feet at the level of the sea—by the measurement, 39183·97329; by the remeasurement, 39183·77357; difference, 0·19972, corresponding to two inches and (nearly) four-tenths of an inch. Another test was applied with an equally satisfactory result. The entire line was divided into three sections, and the two end sections deduced from the middle one by triangulation. The discrepancies between the measured and computed distances were + 0·333 of an inch in the one case, and — 0·078 of an inch in the other; so that the whole base, deduced in terms of the middle section, differed from the length actually measured by scarcely more than a quarter of an inch.

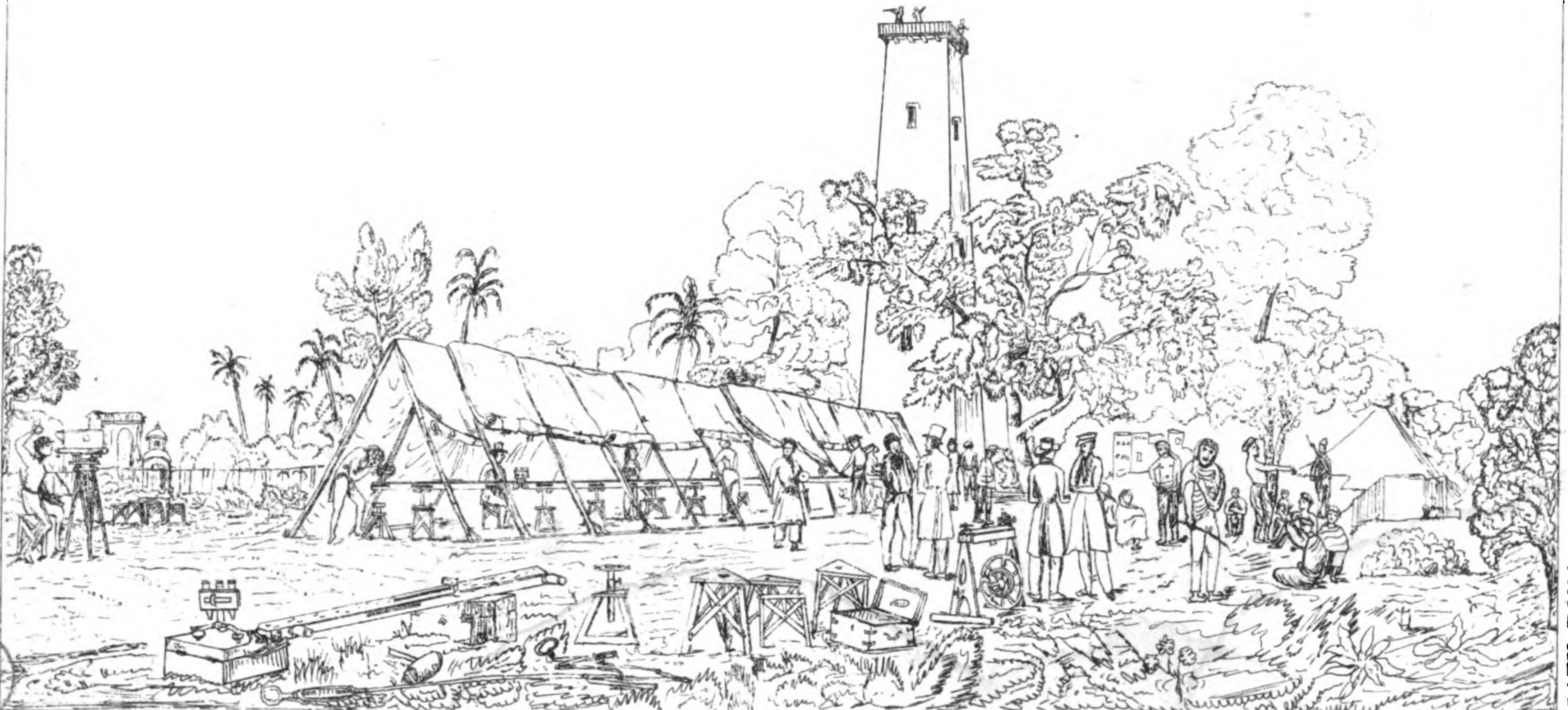
TERMINATION

OF THE

MEASUREMENT OF THE BARRACKPOOR BASE.

January 1832,

(From a Sketch in the Asiatic Society's Journal.)



LITHO: T. G. PRESS

The other two bases, at Seronj and Beder, were measured exactly in the same manner as that in the Dehra Doon. In the case of the Beder base (nearly 8 miles) the measurement was tested by dividing the whole length into three sections, and computing the two end sections from the middle one by a triangulation. The difference was found to amount only to an inch in the one case, and about two-thirds of an inch in the other; the computed length exceeding the measured length in both cases.

The superb Theodolite above mentioned had an azimuth circle of 34 inches in diameter, and by means of five miscroscopic micrometers the divisions could be read to one or two-tenths of a second. It carried a telescope of 39·4 inches focal length; the attached vertical circle was 18 inches in diameter; and every contrivance had been applied to provide for accuracy and facility of adjustment, which the genius of the artist could devise.

In order to eliminate instrumental errors and obtain results of uniform precision, the angles were measured from eight different zeros on the circle, the established rule being "to observe three times at each zero with the face left and as many with the face right, then to change the zero three times by 9° each time, and at each position go through a like operation, whereby it is evident that every ninth degree will in turn fall under one or other of the microscopes."

Great importance was attached to the construction of the Stations. Throughout the Doab it was necessary to erect artificial structures of sufficient height to overtop the trees, and of sufficient solidity to afford a firm support to the theodolite. These were of a very substantial kind—square towers of solid masonry, about fifty feet in height, with walls five feet in thickness at the foundation, and two at the top. A stone slab, supported on two transverse stone beams, formed the floor on which the instrument stood: and the stage for the observers was entirely disconnected in order to avoid vibration while the observations were going on. The centre of the station was carefully defined on a plate of metal let into a stone, and sunk in the ground for further security, and the theodolite and signals were in all cases acccurately adjusted over the centre. The sites of stations were also carefully selected with a view to *well-conditioned* triangles. It was a general rule, steadily adhered to, that no angle of any triangle should be less than 30°. The sides of the triangles may be stated to be from ten to twenty-five miles. In a very few instances only are they found so much as thirty miles.

The Heliotrope was used for day observations; it affords an exquisite object for bisection, but as it must be adjusted by signals from the observer, it was only available for short distances. Reverberatory Lamps, with argand burners, and enclosed in air-tight cases, were generally used by night; and when these were found to be too feeble, recourse was had to blue lights, burned at regulated intervals. Means were provided to prevent any rays from the luminous object reaching the observer at the telescope, excepting those which passed over the centre of the station. With the heliotrope and blue lights it was found to be scarcely possible to arrange for the observation of more than one signal at the same time; and hence the usual mode of proceeding was to take the angles between a mark of reference set up at some convenient distance from the station where the instrument was placed, and the signals displayed from each of the surrounding stations successively and independently.

For computing the sides of the Triangles, the theorem of Legendre was used. Of the sufficiency of the methods, and the great precision of the whole of the geodetical operations, the most satisfactory proof is found in the agreement, almost absolute, in the lengths of the two bases at the extremities of the arc, as found by actual measurement and by computation through the series of triangles from the one near the middle. The results are as follows:—the length of the Dehra Doon base, brought out by computation from the Seronj base, was found to be 39183·273 feet, and by the actual measurement, 39183·873 feet, the difference being 0·600, or six-tenths of a foot; that is to say, a little more than seven inches, the distance between the two bases being about 430 miles. Again, the Beder base brought out by computation from the Seronj base was found to be 41578·178 feet, and the length given by the measurement was 41578·536, the difference in this case being only 0·358 parts of a foot, or a little more than four inches, the distance between the two bases being about 426 miles, and the calculation made through 85 principal triangles. The agreement is certainly remarkable.

The relative Heights of the stations were determined by means of observations of their vertical angles, as seen from each other, made with 18-inch altitude and azimuth circles. The observations were reciprocal, that is to say an observer was placed at each of two stations whose difference of altitude was to be found, with a heliotrope or lamp by the side of his instrument, and each observed the angle between the zenith and the signal of the other at the same instant of time, according to preconcerted signals. This method is perhaps the only one which can be depended on in any country, but especially in India, where the effects of terrestrial refraction are so great and irregular.

For deducing the amplitude of the northern section (Kalianpur, (Seronj) to Kaliana) thirty-six stars were selected, half of them to the south and the other half to the north of the zeniths of both stations, but none of them having a zenith distance exceeding 5° from the nearest vertical. The observations were not, as was intended, strictly simultaneous, Captain Waugh having commenced his observations at Kalianpur a few nights before the time agreed on, and Colonel Everest and Captain Renny, who observed at Kaliana, having met with some interruption from unfavorable weather. For the southern section thirty-two stars were observed at Kalianpur and Damargida (Beder), and in this case the observations, with scarcely an exception, were literally simultaneous. Precise rules were laid down with respect to the mode of observing, reading the microscopes and levels, changing the zero points, &c.; and every necessary precaution appears to have been taken to obtain results free from instrumental errors.

Further details will be given in a subsequent paper of the methods of observing and computing employed in the Indian Trigonometrical Survey.

In the year 1829, a trigonometrical survey in the Bombay Presidency was commenced by Lieut. Shortrede, on an independent base and point of departure. These desultory principles were objected to by General Hodgson, at that time Surveyor-general of India, who recommended that the work should emanate from the Great Arc, and proceed to Bombay precisely according to Colonel Lambton's original design. This injunction, however, remained unheeded; and notwithstanding the respect due to Colonel Lambton's judgment, and General Hodgson's authority, the survey proceeded in an unsystematic manner until it was brought under Colonel Everest's control in 1831. Finding that no use could be made of this confused net of triangulation, the Colonel directed that the longitudinal series should be taken up where he left off in 1823, at the time of Colonel Lambton's death. Lieut. Shortrede resigned in 1836, and was succeeded by Lieut. Jacob, of the Bombay Engineers, by whom the Bombay longitudinal series was brought to a conclusion in the year 1841, and the whole work now rests on his observations alone. This officer united to considerable mathematical attainments, great practical skill as an observer and mechanic; and although the instrument employed, a 15-inch theodolite, by Dollond, was small for such extended operations, no man could have turned it to better account, and the work accordingly bears a superior character for accuracy. The series extends 315 miles in length, and having occupied 12 years, progressed at an apparent rate of only 26 miles per season; but in fact the only efficient part of the work, viz., that executed by Lieut. Jacob, was performed in three seasons.

Immediately after the measurement of the Calcutta base, Colonel Everest fitted out a party under Lieutenant James Western, of the Engineers, for the purpose of carrying a triangulation along the meridian of Parisnath, dependent on one of the sides of the Calcutta longitudinal series. This work commenced in February 1832, Lieutenant Western continuing in charge till September 1834, when he was relieved by Lieut. Bridgman, of the Artillery, who shortly afterwards was compelled to relinquish the duty from ill health, induced by exposure and fatigue, which obliged him to proceed to Europe on medical certificate, and soon after this promising young officer died on the voyage. No final work that could be made use of was executed up to this period, and the cost incurred, Rs. 35,224 was in fact fruitless. Lieut. (now Lieut.-Col.) A. H. E. Boileau assumed charge in 1835-36, and commenced the work *de novo*. Excepting an absence of six months on medical certificate, he continued to conduct the triangulation till December 1838, when he resigned his appointment in the Great Trigonometrical Survey for one of superior emolument and less exposure; the small portion remaining to connect the series with Lieut. Buxton's triangulation in Cuttack, was executed by Mr. Sub-assistant Kallonas. On account of defective instrumental power, this work is only of a second-rate order.

Colonel Everest at the end of 1832 fitted out another party, under Lieutenant Roderick Macdonald, of the Bengal Native Infantry, to carry on the Budhun meridional series, dependent on a side of the Calcutta longitudinal series. Lieutenant Macdonald broke ground on the 2nd February 1833, and was obliged to relinquish the work in September 1835, on account of ill health produced by exposure. Consequent on the departure of Lieutenant Macdonald, Lieutenant Ommanney, of Engineers, was placed in charge, and he remained in that post till April 1837, when he resigned his appointment, and was succeeded by Mr. Olliver. In the early part of 1838 operations were suspended on account of Mr. Olliver's services being required with Lieutenant Waugh on the Great Arc. Up to this time the progress of the Budhun series had been satisfactory as far as the hilly country extended, and ceased to be so as soon as the operations entered the flat lands in the valley of the Ganges. Until November 1839, no officer or sub-assistant of experience being available, the work remained suspended, but on the conclusion of the Amua series, the party under command of Lieutenant Renny (now Captain Renny Tailyour) was transferred to this series, and placed under Mr. Sub-assistant Murphy. After the termination of the Great Arc, on which Captain Tailyour had been employed, he proceeded to take personal charge of the Budhun series, and the work was at length brought to a successful conclusion by that able and energetic officer in one season, having occupied in all no less than eleven years from the commencement. The reasons for this slow progress may be inferred from this narrative. The area covered amounts to 12,468 square miles.

In 1832, Captains Waugh and Renny (Tailyour) joined the Survey Department, and were employed in exploring the wild and jungly country between Chunar and the sources of the Soane and Nerbudda rivers, and up to the city of Jubbulpore. This extensive survey was completed in the season 1832 and 1833, and formed the subject of a topographical and geological report, submitted in 1834. After closing the work at Jubbulpore in March 1833, they proceeded to join the approximate operations of the Great Arc series in the Gwalior country, with which they remained till August of the same year, when they were ordered to organize two parties, one for the Ranghir meridional series under Captain Waugh, the other for the Amua meridional series under

Captain Tailyour, both series being dependent on sides of the Calcutta longitudinal series. In December 1834, Captain Waugh joined the Great Arc as astronomical assistant, in which capacity he remained until he was selected to succeed Colonel Everest, on that officer's retirement from the service in December 1843.

The Ranghir series was completed in 1841, having occupied nine years. The meridional distance comprised is about 400 miles, showing an average progress of 44 miles per annum. The area covered amounts to 16,088 square miles.

The Amua series was brought to conclusion by Captain Tailyour, in June 1839. The instrument used was a good 18-inch theodolite, by Troughton and Simms, and the work possesses superior merit. The area comprised is 5,565 square miles.

Lieutenant W. Jones, of Engineers, was appointed to the trigonometrical survey in the year 1835, and remained till 1838 attached to the Great Arc. After the measurement of the base near Seronj, in which operation he took a part, Lieutenant Jones was deputed to conduct a series on the meridian of Karara, dependent on a side of the Calcutta longitudinal series. The work was commenced, but towards the close of 1838 the whole party was attacked by jungle fever, from the effects of which one sub-assistant, Mr. Scully, died, and Lieutenant Jones himself was obliged to seek for restoration to health in the hills. In consequence of this disaster, a fatal stop was put to the progress of the work. The establishment was broken up, and the work remained in abeyance till 1845, when it was completed by Mr. Armstrong, who had previously been employed in the Ranghir series. The instruments employed were of an inferior order, and this series cannot, therefore, be considered a first-class performance. It embraces an area of 5,819 square miles.

(To be continued).

No. XCII.

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

(2ND ARTICLE.)

Compiled from a Return to an order of the House of Commons. BY LIEUT.-COLONEL A. S. WAUGH, R.E., *Surveyor General (*1850*)*.

BREVET Captain Du Vernet, of the Madras Army, who had previously been employed on the Hyderabad Topographical Survey, was appointed to the Trigonometrical Survey in the year 1840, and in the year 1841 proceeded to prosecute the triangulation of the Himalaya Longitudinal Series, extending from the Great Arc along the southern face of the sub-Himalayan range, so as to connect the nothern limits of all the meridional series. This work, together with the Pilibit series, conducted by Captain Waugh, forms a portion only of the "North Longitudinal Series," under which head it will be discussed.

Previous to Colonel Everest's departure, Captain Du Vernet was ordered to continue the North Longitudinal Series, between the meridians of Amua and Karara, which he successfully accomplished in one season. During the year 1844-45 he was employed in prosecuting the triangulation from the north along the meridian of Karara, to form a junction with Captain Shortrede, who was working from the south, as already explained.

On the termination of this duty, Captain Du Vernet was directed to take up the Gurwani Meridional Series, depending on a side of the Calcutta longitudinal series. This work commenced in 1845-46, and was accomplished in two years. The area embraced is 6,298 square miles. In this series was employed for the first time a 24-inch Theodolite, made up by the Surveyor General from various materials belonging to Government, and lying useless in store, the fundamental part being a 24-inch circle hand, divided by Mr. Simms, formerly appertaining to the astronomical circles. It was fitted up with five micrometers, and the results showed that it was capable, in good hands of measuring angles to half a second of the truth.

On the completion of the Gurwani meridional series, Captain Du Vernet with his establishment was transferred to the North-West Himalaya series, proceeding from the Great Arc to Peshawur. This work was intended to form the foundation of the triangulation of the newly conquered Province of the Punjab, and its progress will be detailed further on.

On the termination of the Great Arc, the two parties which had been engaged on that work were reduced, and placed respectively under the charge of Mr. George Logan, a Surveyor of experience and ability, and of Mr. James, principal Sub-assistant. These parties were deputed by Colonel Everest before his departure, to take up the Chendwar meridional series, and the Gora meridional series, dependent on sides of the Longitudinal series, both of which were completed by 1846.

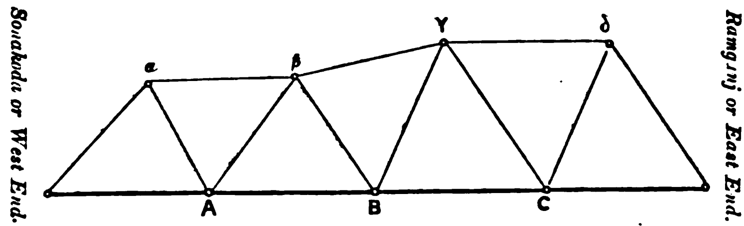
On the conclusion of the Budhon series, Captain Renny Tailyour was ordered to take up the Maluncha meridional series, dependent on a side of the longitudinal series, which was completed by Lieut. Reginald Walker of Engineers in 1846.

The Calcutta Meridional series was commenced at the base line in 1844, by Mr. Sub-assistant Lane, in 1848. The series in its whole extent traverses the alluvial plains of the Ganges, in which great difficulties had to be surmounted. The instrument employed was an 18-inch theodolite, by Troughton and Simms. On closing at Sonakoda base the linear error amounted to 0·64 feet in seven miles, from which is inferred an average error of 0·09 foot per mile; which considering the size of this engine-divided instrument, and the extent of triangulation, 260 miles, entirely in a flat marshy country, may be considered creditable. The area comprised amounts to 4,136 square miles.

In the year 1845, Captain Thorold Hill, of the Madras army, who had formerly been employed in the Madras Topographical Survey, was nominated by Government to succeed Captain Shortrede. He was deputed to the charge of the Coast series, intended to extend from the the Calcutta base line to the Madras Observatory, according to Colonel Lambton's original design. For this work Capt. Hill was supplied with a new 24-inch theodolite, of which four had lately been made by Mr. Simms for the Indian Survey, and graduated by his new self-acting apparatus. Colonel Lambton, in his project for this series, contemplated that great difficulty would be experienced in carrying it over the flat lands between Balasore and Calcutta, and the obstacles proved as great as that officer anticipated. The low lands are covered with water, and very unhealthy till December. During the cold season fogs are prevalent, and at the vernal equinox, as well as during the hot season, tornados, or circular hurricanes, are of frequent occurrence, producing the most devasting effects. During one season the whole tent equipage of the party was utterly destroyed. The country is not only flat and covered with groves, but intersected with creeks and marshes, which renders triangulation both slow and expensive. On the other hand, the unhealthiness of the climate was such that every season the party was driven away by sickness, and Capt. Hill's health suffered so much that he was compelled to proceed to sea for two years. From all these causes combined, progress was very slow.

The North Longitudinal Series extends from the Dehra Doon base to the Sonakoda base, a distance of 690 miles along the frontier. This work has been executed by various parties at different times. The first part from the Great Arc series to the Ranghir series, was executed by Captain Du Vernet, as already stated. The next portion, between the Ranghir and Amua series, was completed by Capt. Waugh, prior to his succeeding to Colonel Everest. The part between Amua and Karara was executed by Captain Du Vernet, but on account of some defect in the instrument was not considered satisfactory, and was revised by Mr. Logan, who completed the whole extent as far as the Chendwar series, under great difficulties as regards climate and forest, from which his party suffered greatly. The whole of this portion is excellent, having been executed with Barrow's great Theodolite, by Mr. Logan himself. From Chendwar to Muluncha series the work rests on Messrs. Peyton's and Nicolson's observations, with a 24-inch Theodolite by Barrow. The remaining portion from Maluncha series to Sonakoda base depends on Lieutenant Walker and Mr. Lane's observations, with Troughton's great Theodolite.

In the year 1847-48 the Sonakoda Base line, was measured for the verification of the North Longitudinal and the Calcutta Meridional series, as well as to furnish a new basis for the extension of operations into Assam, and up to the extreme frontier of British India on the east. This base line was very satisfactorily measured with Colby's compensation apparatus, and being proved by minor triangulations, in four sections, exhibited the following results.



Scale—2 Miles to an Inch.

Each Section of the Base compared with the whole Base.

	West end to A.	A to B.	B to C.	C to east end.
Measured length, inches, ...	109625·15	110381·17	116428·94	103794·45
Computed from the whole base, do,	109625·00	110381·17	116429·03	103794·51
Error, inches, ...	+ 0·15	0·00	− 0·09	− 0·06

Each Section compared with the other Sections.

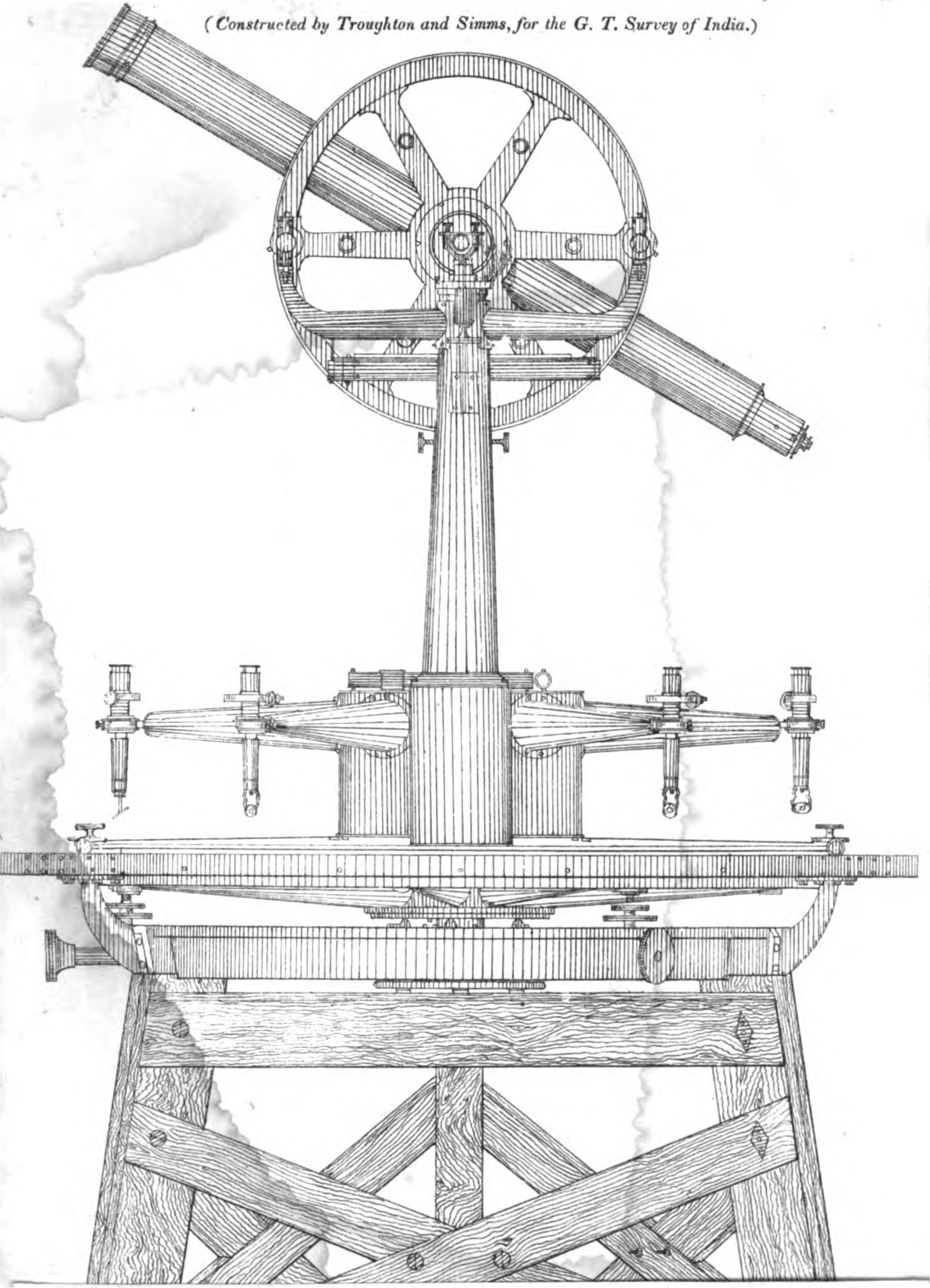
Measured length, inches, ...	109625·15	110381·17	116428·94	103794·45
Computed from 1st section, „	...	110381·32	116429·20	103794·65
„ 2nd „ „	...	...	116429·03	103794·51
„ 3rd „ „	...	...	...	103794·43

The area comprehended by the North Longitudinal Series amounts to

Plate.

THE GREAT THREE-FEET THEODOLITE,

(Constructed by Troughton and Simms, for the G. T. Survey of India.)



15,826 square miles, exclusive of the mountain operations in Sikim and along the frontier, which cover a further area of 73,920 square miles, giving a total of 89,746 square miles.

Captain Renny Tailyour, while in England, made himself acquainted with the progress of the Ordnance survey, and returning to India in 1847, gave his assistance at the Base line, after which he was deputed to proceed to Sironj with Troughton's great theodolite, for the purpose of extending the great Longitudinal series from the Sironj Base to Karachi in Sind. Some account of this important series will be given below.

After the conclusion of the Bombay Longitudinal series, Captain Jacob proceeded to England on sick certificate, and was succeeded by Lieut. Harry Rivers, of the Bombay Engineers, by whom the Trigonometrical operations in that presidency were conducted for some time. These consisted of the South Konkan series, dependent on a side of the Bombay longitudinal series. This work was completed between the years 1842 and 1844. After its conclusion Lieut. Rivers took up the North Konkan series, in the prosecution of which the health of his party suffered so much that it became necessary to withdraw from it when it had attained the parallel of 21° 54′. He next took up the Khanpisura series on the meridian of 75°, which he continued up to Ajmere. The area comprised in these several operations conducted by Lieutenant Rivers, amounted to 45,854 square miles.

[The following observations by Colonel Waugh, on the general state of the work up to 1850, have been abridged from his report for that year, and will be found interesting to read before proceeding with the subsequent history of the Survey].

The accuracy attained by the modern operations may be thus briefly stated. In the large triangulation, where of course the greatest refinement and most scrupulous care is observed, an error of one inch per mile, or $\frac{1}{63360}$ part, amounts to 500 inches or 42 feet, or nearly half a second in arc of latitude or longitude in 500 miles, which distance is even exceeded between some of the bases. The work is reckoned liable to half this error when executed with the great Theodolite on the principle of double series; the results attained by the new 24-inch theodolites are but little inferior to this degree of accuracy. When the series are single, the liability to error is reckoned to approach nearer to one inch per mile; when performed with good 18-inch theodolites, the error will exceed one inch per mile, according to the character of the graduation. With inferior instruments, or a less careful system, the accumulation of error would approach a foot per mile, which is equal to a ratio of $\frac{1}{5280}$ in linear dimension, or $\frac{1}{2640}$ in area, or $\frac{1}{26}$ per cent., or six seconds of arc in the above distance.

In reviewing the whole progress of the Trigonometrical Survey of India from its commencement by Colonel Lambton to the year 1848, it appears that the grand total of area triangulated amounted to 477,044 square miles, and the grand total of cost to Rs. 34,12,787, or say £312,389, showing an average cost of Rs. 7-2-5 per square mile, or about 13*s*. 1*d*., which cannot be but considered remarkably moderate, especially when the nature of the country and climate, as well as the absence of all the usual resources to be found in Europe, are taken into account. The hardships and exposure of surveyors working in the field for the greater part of the year, in such a climate as India, are either little known or little appreciated. They have on several occasions kept the field throughout the year. The duties of the trigonometrical survey likewise are often unremitting day and night, because the best observations are obtained during the nocturnal hours, when the dust raised by hot winds subsides, and the atmosphere becomes clear and calm.

The total area of British India as it stood in 1850, including Sind, Punjab, the and Tenasserim, was carefully estimated at 800,758 square miles,* and the native states at 508,442 square miles, making a grand total of 1,309,200 square miles as the area of survey. A complete delineation of this vast superficial extent, amounting to 1¼ million of square miles, confined within an external boundary of 11,260 miles in length, including every variety of configuration and climate, is an undertaking of unprecedented magnitude, demanding considerable time to accomplish with any pretensions to mathematical accuracy. The exertions hitherto made have been unremitting, and it is but justice to say that the progress has been, generally speaking, as honorable to the officers employed as the results have been useful to the country.

* Since then, the great Provinces of Oudh, Pegu, and Nagpore, have been added.—[ED.]

The programme of future operations, as laid down by Col. Waugh in 1850, was as follows:—According to Colonel Everest's design, an ellipsoidal space is included between the great arc on the west, the Calcutta meridional series on the east, the great longitudinal series on the south, and the north longitudinal series along the frontier; which are verified by four base lines at their origin and termination; all measured with Colby's apparatus. This immense ellipsoidal area is filled up by subordinate meridional series nearly one degree of longitude apart, which series depend on the Great Longitudinal series for origin, and on the North Longitudinal for verification. This has been denominated the gridiron system, and obviously possesses superior facilities for rapidity and accuracy. This design of Colonel Everest's has been completed and the country to the west of the Great Arc is intended to be triangulated on precisely the same principles—1st, The North-West Himalaya series will extend from the Dehra Doon base line to Peshawur, where it will be verified by a measured base; 2ndly, the Great Longitudinal series will be extended from the Sironj base to Karachi, where a base will be also measured;* 3rdly, between the Attock and Karachi bases extends a great meridional series,† between which and those before described is included an immense ellipsoidal area, averaging 9° of latitude by 10° of longitude. As all the bounding series will be executed with superior instruments and duly verified by base lines, whereby limits are placed to the intrusion of error, those series will be fit to verify the subordinate meridional series by means of which the intermediate space is intended to be rapidly filled up at every degree of longitude apart, according to Colonel Everest's system.

To the east of the Calcutta meridian it is proposed to extend the North Longitudinal series, from Sonakoda base into Assam. From this series will depend other meridional triangulations at one degree apart, upon which the accurate geographical delineation of eastern Bengal will be based.

The Bombay party will complete the remaining triangulation of that presidency in a few years. There only remains, therefore, to be considered the vacant space to the south of the Calcutta longitudinal

* Since completed.—[ED.] † The Indus series, since completed.—[ED.]

series, in which is embraced the hill country of Gondwana and tributary mahals, between the sources of the Son and Narbada, the Godaveri river, and the sea. This region, inhabited by aboriginal tribes, is unhealthy in the extreme, and of no value; but from its rugged configuration, any survey not based on triangulation would accumulate vast errors. It is proposed to triangulate this region by meridional series at every two degrees apart, filling up the interstices with secondary triangulation. In this way that space can be most rapidly surveyed.

The instrumental equipments are admirably adapted for the work in hand, and in 1850, consisted of the following apparatus :—

1 Colby 's compensation apparatus for measuring base lines.

2 Great theodolites, 36 inches diameter, by Troughton and Simms, and Barrow, respectively.

4 24-inch theodolites, by Simms and Barrow.

2 18-inch theodolites, by Troughton and Simms.

6 14-inch Vernier theodolites, by Simms.

6 12-inch theodolites, by Troughton and Simms.

20 7-inch theodolites, by Troughton and Simms.

2 Astronomical circles of 3-feet diameter, by Troughton and Simms.

5 Astronomical clocks.

14 Chronometers.

The signals consist of Argand lamps and Heliotropes.

With regard to the rate of progress, much depends on the efficiency of the officers, and on the accidents of climate to which the parties are so much exposed. In a hilly country, the average advance made per season by each party is about 120 miles in length by 30 in breadth, or say 3,600 square miles. In a flat country the average is 80 miles in length by 12 in breadth, or about 1,000 square miles. The average for both kinds of ground may be taken at the mean, or 2,300 square miles.

As to the land surveys by which the interior is filled up. The greater part of the Madras peninsula has been taken up on the basis of the great triangulation, by means of minor triangles and military plane table surveys, executed on a scale of one inch per mile. This style of work is remarkably cheap, the cost per square mile not exceeding Rs. 6, or less than 12*s.*; and in favorable localities, free from jungle fever, which is the dire enemy of all survey operations in India, the expense becomes much lower. This kind of survey being based on triangulation cannot accumulate error, and gives an admirable representation of the land, but it requires good draughtsmen, who are difficult to be obtained in India. The system is peculiarly adapted to mountainous countries, where the value of the land being small, an expensive system is inapplicable. It has already been extensively carried out in the native states, and it is proposed to extend the same principles to the remainder.*

The Revenue Survey of Bengal commenced in the year 1822, and consists of the measurement of the boundaries of estates, which are executed by theodolite and chain, upon the traverse system. Up to the year 1830, the rate of progress at which the operations proceeded was extremely limited, only 3,020 square miles or little more than half a square degree had then been performed in seven years, with ten officers employed in the department, the annual rate of progress of each surveyor ranging from 50 square miles to 338 as a maximum. The officers employed in those days, however, had little or no assistance, and the duties performed then by the revenue surveyor himself, are now entrusted to competent Assistants and Sub-assistants, with large native establishments under them, whilst the Surveyor acts as a superintendent over the whole; the result of which has been, that since 1830, the whole of the North Western Province districts, all Behar and Orissa, and a considerable portion of Bengal proper, have been completed.*

As respects the accuracy attainable by the measurement of the Revenue Survey, it may be stated generally that the maximum error allowed in linear dimension, according to the test it is submitted to by traverse proof, is 10 links in 100 chains, equal to 5·28 feet per mile; but in the actual prosecution of the extensive surveys of the season 1847-48, covering an area of about 16,000 square miles, the average ratio of correction employed for the closing of the traverses is found to be only two feet per mile, or rather more than one-third of the allowed correction: $\frac{1}{10}$ per cent., therefore, for the pergunnah or main circuit measurement is fully within practicabillity; $\frac{1}{10}$ per cent. also may be allowed for the area of the district; $\frac{1}{2}$ per cent. for the village survey area, and 1 per cent. for the interior detail measurement of cultivation and waste. But the most severe test to which a Revenue

* Col. Waugh's Report of 1850.

survey can be subjected is, the comparison of its results with those of the Trigonometrical survey; and that this comparison may be performed as readily as possible, a due and proper connexion between the two surveys is essential, and is now scrupulously maintained.

The azimuth of any side of the large triangles likewise proves a check on the deduced azimuth of the revenue survey, as conveyed from one main circuit to another, and this comparison is carefully carried out when opportunity is afforded for so doing.*

It will be apparent, from the foregoing statements, that the Revenue surveys supply the interior filling up of the triangles in the British revenue districts, which are chiefly flat lands, to which that system is most applicable. In native states and wild hilly countries, the Topographical surveys before described are admirably adapted to the object in view, which is a complete and inexpensive first survey of all India. Considered in this point of view, the work may challenge comparison with any in the world. The Triangulation supplies a permanent and accurate basis for the present, as well as for future internal surveys; for it must be borne in mind that, as the resources of this country become developed under the fostering protection of British rule, the topographical aspect of many districts must, in a moderate number of years, be completely changed. Tracts now covered with jungle will be reclaimed, canals will be dug, marshes drained, and roads established. New towns and villages will arise, fresh groves be planted, and rivers will change their course. That these views are not chimerical may be attested by experience, for places where the tiger, the bear, and the boar, were formerly hunted are now covered with fields, yielding a plentiful harvest to the cultivator. The greatest difference is also perceptible in the extension of towns and villages, showing the increase of productive wealth which is taking place on all sides. These alterations cannot but produce, in the course of time, considerable changes in the topographical features of the country, for which reason revised surveys will be required, and these, like the present ones, will be based on the operations of the Great Trigonometrical Survey of India, which are intended to form a lasting monument for future generations, and an imperishable record of the landmarks of the present time.*

(To be continued.)

* Col. Waugh's Report of 1850.