London; and the municipal boroughs of Godalming (2505), Guildford (10,858), Kingston-upon-Thames (20,648), and Reigate (18,662). A considerable portion (22,472 acres, with a population in 1881 of 980,522) is within the metropolitan district of London, in addition to which there are the following urban sanitary districts—Aldershot (20,155), Croydon (78,953), Dorking (6328), East Moulsey (3289), Epsom (6916), Farnham (4488), Ham Common (1349), Hampton Wick (2164), New Malden (2538), Richmond (19,066), Surbiton (9406), Teddington (6599), and Wimbledon (15,950). The county has one court of quarter sessions, and is divided into twelve petty and special sessional divisions. The central criminal court has jurisdiction over certain parishes in this county. The borough of Guildford has a separate court of quarter sessions and commission of the peace; the boroughs of Reigate and Kingston-upon-Thames have commissions of the peace; the borough of Southwark is included in the petty sessional division of Newington; and the borough of Godalming, in which the mayor and ex-mayor are magistrates, forms part of the petty sessional division of Guildford, the county justices having concurrent jurisdiction. The county contains 152 civil parishes, with parts of two others. It is shared among the dioceses of Canterbury, Rochester, and Winchester. Until 1885 the county for parliamentary purposes was divided into East, Mid, and West Surrey; it is now rearranged in six divisions, viz., Kingston, Mid (Epsom), North-East (Wimbledon), North-West (Chertsey), South-East (Reigate), and South-West (Guildford). The portion of Surrey formerly included in the borough of Greenwich was in 1885 included in the borough of Deptford (Kent); the borough of Guildford was disfranchised; one member was given to Croydon; and instead of the two metropolitan boroughs of Lambeth and Southwark the following fifteen constituencies (each returning one member) were created:—Battersea and Clapham, constituting two divisions; Camberwell, embracing the divisions of North Camberwell, Dulwich, and Peckham; Lambeth, embracing the divisions of Brixton, Kennington, Lambeth North, and Norwood; Southwark, containing the divisions of Bermondsey, Rotherhithe, and Southwark West; Wandsworth; and Newington, with the divisions of Walworth and West Newington.

Since the beginning of the 19th century the population has increased nearly 600 per cent. From 268,233 in 1801 it had increased by 1821 to 399,417, by 1851 to 683,082, by 1871 to 1,091,635, and by 1881 to 1,436,899, of whom 683,228 were males and 753,671 females. The number of persons to an acre is 2·96 and of acres to a person 0·34. Within the last decade the increase has been 35·1 per cent.,—much greater than the increase in the general town population of England and Wales, which was 19·63 per cent., the increase in the whole population being only 14·34. Nearly two-thirds (980,522) of the population belong to the metropolitan district of London, but the suburbs of London extend practically throughout the greater part of the county, its increase in population being chiefly due to the building of residences for those who have business or professional interests in London.

History and Antiquities.—Notwithstanding its proximity to London, Surrey has been associated with few great events in English history. Roman remains have been discovered at Albury, Kingston, Titsey, Woodcote, and a few other places, but none are of much importance. On several of the hills there are remains of camps of either Roman or British origin. The Roman Stane Street from London to Chichester in Sussex passed by Kingston, Chessington, Leatherhead, Dorking (where its remains are specially well marked), Leith Hill, and Ockley. During the Saxon period Surrey was included in the dominions of the South Saxons and afterwards of Wessex. Its name Surrey or "south kingdom" has apparently reference to its position south of London or south of the Thames. Kingston in Surrey was in 838 the seat of a witanagemot convened by Egbert; and after the capture of Winchester by the Danes it was from 901 to 978 the place where the Anglo-Saxon kings were crowned. Surrey was an earldom of Godwine; and after the conquest was bestowed on William de Warren, who had married Gundrada, supposed to have been a daughter of the Conqueror. From the time that the great charter was on 15th June 1215 signed by King John at Runnymede near Egham the historical annals of the county are a blank, until the period of the Civil War, when a skirmish took place, 7th June 1648, at Kingston.

The only ecclesiastical ruins worthy of special mention are the picturesque walls of Newark Priory, founded for Augustinians in the time of Richard Cœur de Lion; and the Early English crypt and part of the refectory of Waverley Abbey, the earliest house of the Cistercians in England, founded in 1128 by William Gifford, bishop of Winchester. The *Annales Waverlienses*, published by Gale in his *Scriptores* and afterwards in the Record series of *Chronicles*, are supposed to have suggested to Sir Walter Scott the name of his first novel. The church architecture is of a very varied kind, and has no peculiarly special features. Among the more interesting churches are Albury, the tower of which is of Saxon or very early Norman date; Beddington, a fine example of the Perpendicular, and containing monuments of the Carew family; Chaldon, remarkable for its fresco wall-paintings of the 12th century, discovered during restoration in 1870; Compton, which, though mentioned in Domesday, possesses little of its original architecture, but is worthy of notice for its two-storied chancel, and its carved wooden balustrade surmounting the pointed Transition Norman arch which separates the nave from the chancel; St. Mary's, Guildford, containing examples of Norman, Early English, Decorated, and Perpendicular, but is of interest chiefly for the grotesque carving on the corbels of the aisles and the coloured medallions on the roof of the north chapel; Leigh, Perpendicular, possessing some very fine brasses of the 15th century; Lingfield, Perpendicular, containing ancient tombs and brasses of the Cobhams; Ockham, chiefly Decorated, with a lofty embattled tower, containing the mausoleum of Lord Chancellor King (d. 1734), with full-length statue of the chancellor by Rysbroeck; Reigate, chiefly Perpendicular, but with Transition Norman pillars in the nave; Stoke d'Abernon, Early English, with the earliest extant English brass, that of Sir John d'Abernon, 1277; and Woking, Decorated, with Early English chancel. Of old castles the only examples are Farnham, occupied as a palace by the bishops of Winchester, originally built by Henry of Blois, and restored by Henry III.; and Guildford, with a strong quadrangular Norman keep. Ancient domestic architecture is, however, well represented, the examples including Beddington Hall, now a female orphan asylum; the ancient mansion of the Carews, rebuilt in the reign of Queen Anne, but still retaining the hall of the Elizabethan building; Crowhurst Place, built in the time of Henry VII., the ancient seat of the Gaynesfords, and frequently visited by Henry VIII.; portions of Croydon Palace, an ancient seat of the archbishops of Canterbury; the gate tower of Esher Place, built by William of Waynflete, bishop of Winchester, and repaired by Cardinal Wolsey; Archbishop Abbot's hospital, Guildford, in the Tudor style; the fine old Elizabethan house of Losely near Guildford; Cowley House, Chertsey, originally of the time of James I., inhabited by the poet Cowley from the Restoration till his death; Smallfield Place, now a farmhouse, at one time the seat of Sir Edward Bysshe, garter king-at-arms; and Sutton Place, dating from the time of Henry VIII., possessing curious mouldings and ornaments in terra-cotta. Among the eminent persons specially connected with Surrey may be mentioned George Abbot, archbishop of Canterbury, the son of a cloth worker in Guildford; Arthur Onslow, born at Merrow in 1691, who became member for Guildford and speaker of the House of Commons; Sir William Temple, who had his residence at Moor Park, where he died in 1699; Sir Nicolas Carew, beheaded for conspiracy in 1539, and other members of the family, who had their ancestral seat at Beddington; John Evelyn, the diarist, who was born at Wotton in 1620; Malthus, the political economist, who was born at the Rooke, near the same place, in 1766; William Cobbett, who was born near Farnham in 1762; Horne Tooke, who was born at Westminster, wrote his well-known book at Purley, and died at Wimbledon in 1812; the historian Gibbon, who was born at Putney in 1737, which was also the birthplace of Cromwell, the minister of Henry VIII.

See Topley's *Geology of the Weald* and Whitaker's *Geology of London Basin*, forming part of the *Memoirs of Geological Survey of United Kingdom*; *Surrey Archæological Collections*; Aubrey, *Natural History and Antiquities of Surrey*, 5 vols., 1718-19; Manning and Bray, *Hist. and Antiq. of Surrey*, 1809-14; Brayley, *Topograph. Hist. of Surrey*, 5 vols., 1841-46; Lysons, *Environs of London*, 5 vols., 1800-11; Baxter, *Domesday Book of Surrey*, 1876. (T. F. H.)

SURREY, HENRY HOWARD, EARL OF (1516?-1547), one of the leaders in the poetic movement under Henry VIII. that heralded the great outburst of the Elizabethan period. Of his personal life outside his poetry only the barest outline is known, and till comparatively of late even that outline was not free from confusion. Three different men—the grandfather of the poet, his father, and the poet himself—bore the title within a period of ten or eleven years; and at one time the poet was confounded with his grandfather, and supposed to have been present at the battle of Flodden (1513). He was not born till at least two years after that event. It was his grandfather who distinguished himself at Flodden under the title of the earl of Surrey, and was created duke of Norfolk as a reward for his services, surrendering the title of Surrey to his son, the poet's father, for his lifetime. Although the poet has always been most familiarly known as the earl of Surrey, he really held the title only by courtesy, succeeding to it on that footing in 1524, when his father became duke of Norfolk. In one of his poems he speaks of having passed "his childish years" at Windsor "with a king's son." This was Henry VIII.'s natural son, Henry Fitzroy, duke of Richmond, who was affianced to Surrey's sister, Mary, but died before he was out of his teens. It is sometimes said that the two were educated together at Windsor; but the sweet companionship to which the poem refers, when the two youths "hoved" in the large green courts "with eyes cast up into the maiden's tower," belongs to the last year of Fitzroy's short life. Whether or not Surrey was educated from literal childhood with a king's son, he was certainly educated with the care for literary culture which about that time became common in the households of English noblemen; and, as the fashion was, he was sent, after passing through Cambridge, to complete his education in Italy. The tradition that he made the tour of Europe as a knight-errant, upholding against all comers the superiority of his mistress Geraldine, has no extrinsic evidence in its favour. If Geraldine was, as is commonly supposed, Elizabeth Fitzgerald, a daughter of the earl of Kildare, she was but a child of seven or eight years when Surrey set out on his travels. The legend about his knight-errantry is probably only a sign of the extent to which his chivalrous personality and poetry fascinated the imagination of his own and the next generation. The eminence of the Howards at Henry's court was evidenced in many ways: in the festivities at the king's marriage with Anne of Cleves, Surrey was the leader of one of the sides at the tournament, and two years later his cousin, Catherine Howard, became the king's fifth wife. Surrey took an active part in the insignificant wars of Henry's later years, accompanied the expedition, led by his father, which ravaged the south of Scotland in 1542, and held a command in the French expedition of 1544. When the king's death was known to be near, the duke of Norfolk was suspected of aiming at the throne, and Surrey's own haughty and ostentatious manners countenanced the suspicion. A month before the king's death both were arrested and lodged in the Tower, and on 13th January 1547 Surrey was brought to trial for high treason. The main charge against him was that he had "falsely, maliciously, and treacherously set up and borne the arms of Edward the Confessor." His plea that the arms belonged to his ancestors was probably not accepted as an extenuation of the offence. A common jury found him guilty and he was executed on Tower Hill on 19th January.

His poems, which had been one of the occupations of his crowded life, first appeared in print in *Tottel's Miscellany* in 1557. On the title-page of this memorable publication Surrey's name stood first, but this was probably in deference to his rank; Wyatt was the first in point of time of Henry's "courtly makers" (see WYATT). Surrey, indeed, expressly acknowledges Wyatt, who was several years his senior, as his master in poetry. Seeing, however, that their poems were first published in the same volume, many years after the death of both, their names can never be disassociated, and it must always be hard to say which was the leader in the various new and beautiful forms of verse which *Tottel's Miscellany* introduced into English poetry. Surrey's only unquestionable distinction as a metrician lies outside the *Miscellany*: his translation of the second and fourth books of the *Æneid* into blank verse—the first attempt at blank verse in English—was published separately by Tottel in the same year. But his sonnets (in various schemes of verse), his elegy on the death of Wyatt (in elegiac staves shut in by a final couplet), his pastoral poem (a lover's complaint put into the mouth of a shepherd), and his lyrics in livelier measures are all extremely interesting experiments, and served as models for more than one generation of courtly singers and sonneteers. In form as well as in substance Surrey and his compeers were largely indebted to Italian predecessors; most of his poems are in fact translations or adaptations of Italian originals. The tone of the love sentiment was new in English poetry, very different in its earnestness, passion, and fantastic extravagance from the lightness, gaiety, and humour of the Chaucerian school. In this respect *Tottel's Miscellany* helped to educate the English muse for the triumphs of the tragic drama. Surrey's own contributions are distinguished by their copious and impetuous eloquence and sweetness.

SURROGATE is a deputy of a bishop or an ecclesiastical judge, acting in the absence of his principal, and strictly bound by the authority of the latter. At present the chief duty of a surrogate is the granting of marriage licences. Quite recently judgments of the arches court of Canterbury have been delivered by a surrogate. The office is unknown in Scotland, but is of some importance in the United States. In the State of New York the surrogate's court is a court of record, with jurisdiction over the administration of the personal estate of a deceased person and certain other matters. In New Jersey the surrogate is an official of the orphans' court, grants unopposed probates, &c.

SURVEYING

SURVEYING is the art of determining the relative positions of prominent points and other objects on the surface of the ground and making a graphical delineation of the included area. The general principles on which it is conducted are in all instances the same: certain measures are made on the ground and corresponding measures are protracted on paper, on a scale which is fixed at whatever fraction of the natural scale may be most appropriate in each instance. The method of operation varies with the magnitude and importance of the survey, which may embrace a vast empire or be restricted to a small plot of land. All surveys rest primarily on linear measures for direct determinations of distance; but these are usually largely supplemented by angular measures, to enable distances to be deduced by the principles of geometry which cannot be conveniently measured over the surface of the ground where it is hilly or broken. The nature of a survey depends on the proportion which the linear and the angular measures bear to each other; it may be purely linear or even purely angular, but is generally a combination of both methods. Thus in India there are numerous instances of large tracts having been surveyed by the purely linear method, in the course of the revenue surveys which were initiated by the native Governments. The operations were conducted by men who had no knowledge of geometry or of any other measuring instrument than the rod or chain, and whose principal object was the determination of fairly accurate areas; their methods sufficed for this purpose and were accepted and perpetuated for many years by the European officers to whom the revenue assessments became entrusted after the subversion of the native rule. In India, too, there are extensive tracts of country which have been surveyed by the purely angular method, either because the ground did not permit of the chain being employed with advantage, as in the Himalayan mountains and hill tracts generally, or because the chain was considered politically objectionable, as in native states where it would have been regarded with suspicion.

Surveys of any great extent of country were formerly constructed on a basis of points whose positions were fixed astronomically, and in some countries this method of operation is still of necessity adopted. But points whose relative positions have been fixed by a triangulation of moderate accuracy present a more satisfactory and reliable basis; for astronomical observations are liable, not only to the well-known intrinsic errors which are caused by uncertainties in the catalogued places of the moon and stars, but to external errors arising from deflexions of the plumb line under the influence of local attractions, and these of themselves materially exceed the errors which would be generated in a fairly executed triangulation of a not excessive length, say not exceeding 500 miles. The French Jesuits who made a survey of China for the emperor about 1730 appear to have been the first deliberately to discard the astronomical and adopt the trigonometrical basis. In India the change was made in 1800, when what is known as the Great Trigonometrical Survey was initiated by Major Lambton—with the support of Colonel Wellesley, afterwards Duke of Wellington—as a means of connecting the several surveys of routes and districts which had already been made in various parts of the country, and as a basis for future topography. This necessitated the inception of the survey as an undertaking calculated to satisfy the requirements of geodesy as well as geography, because the latitudes and longitudes of the points of the triangulation had to be determined for future reference,—as in the case of the discarded astronomical stations, though in a different manner,—by processes of calculation combining the results of the triangulation with the elements of the earth's figure. The latter were not then known with much accuracy, for so far geodetic operations had been mainly carried on in Europe, and additional operations nearer the equator were much wanted; the survey was conducted with a view to supply this want. Thus a high order of accuracy was aimed at from the very first. In course of time the operations were extended over the entire length and breadth of Hindustan and beyond, to the farthest limits of British sway; they cover a larger area than any other national survey as yet completed, and are very elaborate and precise. Thus, as triangulation constitutes the most appropriate basis for survey operations generally, a short account will be given of (1) the methods of the Great Trigonometrical Survey of India. This will be followed by accounts of (2) traversing as a basis for survey, (3) levelling, (4) survey of interior detail, (5) representation of ground, (6) geographical reconnaissance, (7) nautical surveying, (8) mapping, (9) map printing, (10) instruments.

I. Great Trigonometrical Survey of India.

General outlines. 1. *General Outlines.*—Primarily a network was thrown over the southern peninsula. The triangles on the central meridian were measured with extra care and checked by base-lines at distances of about 2° apart in latitude in order to form a geodetic arc, with the addition of astronomically determined latitudes at certain of the stations. The base-lines were measured with chains and the principal angles with a 3-foot theodolite, which, however, was badly damaged almost at the outset by an accident to the azimuthal circle. The signals were cairns of stones or poles. The chains were somewhat rude and their units of length

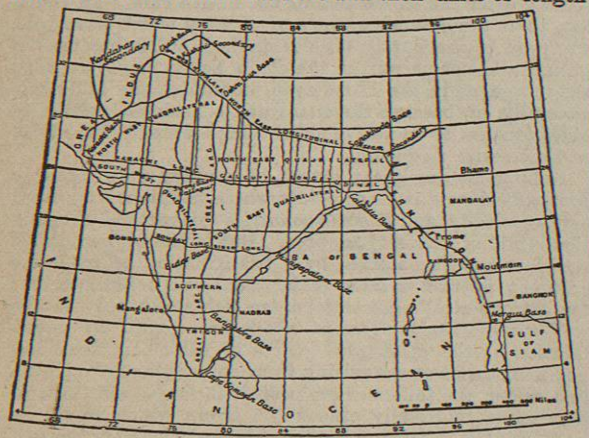

Fig. 1.

had not been determined originally, and could not be afterwards ascertained. The results were good of their kind and sufficient for geographical purposes; but the central meridional arc—the "great arc"—was eventually deemed inadequate for geodetic requirements. A superior instrumental equipment was introduced, with an improved *modus operandi*, under the direction of Colonel Everest in 1832. The network system of triangulation was superseded by meridional and longitudinal chains taking the form of gridirons, and resting on base-lines at the angles of the gridirons, as represented in fig. 1. For convenience of reduction and nomenclature the triangulation west of meridian 92° E. has been divided into five sections,—the lowest a trigon, the other four quadrilaterals distinguished by cardinal points which have reference to an observatory in Central India, the adopted origin of latitudes. In the north-east quadrilateral, which was first measured, the meridional chains are about one degree apart; this distance was latterly much increased, and eventually certain chains—as on the Malabar coast and on meridian 84° in the south-east quadrilateral—were dispensed with, because good secondary triangulation for topography had been accomplished before they could be commenced.

2. *Modern Base-Lines.*—All these were measured with the Colby apparatus of compensation bars and microscopes. Base lines. The bars, 10 feet long, were set up horizontally on tripod stands; the microscopes, 6 inches apart, were mounted in pairs revolving round a vertical axis and were set up on tribrachs fitted to the ends of the bars. Six bars and five central and two end pairs of microscopes—the latter with their vertical axes perforated for a look-down telescope—constituted a complete apparatus, measuring 63 feet between the ground pins or registers. For explanation of compensation see Earth, Figure of the, vol. vii. p. 599. Compound bars are necessarily more liable to accidental changes of length than simple bars; they were therefore tested from time to time by comparison with a standard simple bar; the microscopes were also tested by comparison with a standard 6-inch scale. At the very first base-line the compensated bars were found to be liable to sensible variations of length with the diurnal variations of temperature; these were supposed to be due, not to error in effecting the compensation, but to the different thermal conductivities of the brass and the iron components. It became necessary, therefore, to determine the mean daily length of the bars very precisely, for which reason they were systematically compared with the standard before and after, and sometimes at the middle of, the base-line measurement throughout the entire day for a space of three days, and under conditions as nearly similar as possible to those obtaining during the measurement. Eventually thermometers were applied experimentally to both components of a compound bar, when it was found that the diurnal variations in length were principally due to difference of position relatively to the sun, not to difference of conductivity,—the component nearest the sun acquiring heat most rapidly or parting with it most slowly, notwithstanding that both were in the same box, which was always kept under the cover of a tent and carefully sheltered from the sun's rays. Happily the systematic comparisons of the compound bars with the standard were found to give a sufficiently exact determination of the mean daily length. An elaborate investigation of theoretical probable errors at the Cape Comorin base showed that, for any base-line measured as usual without thermometers in the compound bars, the *p.e.* may be taken as ± 1·5 millionth parts of the length, excluding unascertainable constant errors, and that on introducing thermometers into these bars the *p.e.* was diminished to ± 0·55 millionths.

In all base-line measurements the weak point is the determination of the temperature of the bars when that of the atmosphere is rapidly rising or falling; the thermometers acquire and lose heat more rapidly than the bar if

their bulbs are outside, and more slowly if inside the bar. Thus there is always more or less lagging, and its effects are only eliminated when the rises and falls are of equal amount and duration; but as a rule the rise generally predominates greatly during the usual hours of work, and whenever this happens lagging may cause more error in a base-line measured with simple bars than all other sources of error combined. In India the probable average lagging of the standard-bar thermometer was estimated as not less than 0°·3 Fahr., corresponding to an error of −2 millionths in the length of a base-line measured with iron bars. With compound bars lagging would be much the same for both components and its influence would consequently be eliminated. Thus the most perfect base-line apparatus would seem to be one of compensation bars with thermometers attached to each component; then the comparisons with the standard need only be taken at the times when the temperature is constant, and there is no lagging.

3. *Factor of Expansion of Standard Bar.*—This was first determined in 1832 by measuring the increment in length between temperatures of 76° and 212° Fahr.; in 1870 the increment between 52° and 96° was measured; the results indicated an increase of expansion with temperature. They were therefore combined on the empirical assumption that the expansion is the sum of two terms,—the first x times the temperature, the second y times the square of the temperature; x and y were then determined from the two equations of condition given by the two sets of measurements. The resulting value of the expansion at 62° was found to be 5 per cent. less than the previously derived value at the mean temperature of 144°, thus showing the importance of employing a factor varying with the mean temperature of each base-line: and this was done in the final reductions.

4. *Plan of Triangulation.*—This was broadly a system of internal meridional and longitudinal chains with an external border of oblique chains following the course of the frontier and the coast lines. The design of each chain was necessarily much influenced by the physical features of the country over which it was carried. The most difficult tracts were plains of great extent, devoid of any commanding points of view, in some parts covered with dense forest and jungle, malarious and deadly, and almost uninhabited, in other parts covered with towns and villages and umbrageous trees,—the adjuncts and concomitants of a teeming population. In such tracts triangulation was impossible except by constructing lofty towers as stations of observation, raising them to a sufficient height to overtop at least the earth's curvature, and then either increasing the height to surmount all obstacles to mutual vision, or clearing the lines, both of which were laborious and expensive processes. Thus in hilly and open country the chains of triangles were generally made "double" throughout, *i.e.*, formed of polygonal and quadrilateral figures, to give greater breadth and accuracy; but in tracts of forest and close country they were carried out as series of single triangles, to give a minimum of labour and expense. Symmetry was secured by restricting the angles between the limits of 30° and 90°. The average side length was 30 miles in hill country and 11 in the plains; the longest principal side was 62·7 miles, though in the secondary triangulation to the Himalayan peaks there were sides exceeding 200 miles. Long sides were at first considered desirable, on the principle that the fewer the links the greater the accuracy of a chain of triangles; but it was eventually found that good observations on long sides could only be obtained under exceptionally favourable atmospheric conditions, which were of rare occurrence. The sides were therefore shortened, whereby the observations were much improved and accelerated. In plains the length was governed by the height to which towers could be conveniently raised to surmount the curvature, under the well-known condition, height in feet = $\frac{2}{3}$ × square of the distance in miles; thus 24 feet of height was needed at each end of a side to overtop the curvature in 12 miles, and to this had to be added whatever was required to surmount obstacles on the ground. In Indian plains refraction is more frequently negative than positive during sunshine; no reduction could therefore be made for it.

5. *Selection of Sites for Stations.*—This, a very simple matter in hills and open country, is often very difficult in plains and close country. In the early operations, when the great arc was being carried across the wide plains of the Gangetic valley, which are covered with villages and trees and other obstacles to distant vision, masts 35 feet high were carried about for the support of the small reconnoitring theodolites, with a sufficiency of poles and bamboos to form a scaffolding of the same height for the observer. Other masts 70 feet high, with arrangements for displaying blue lights by night at 90 feet, were erected at the spots where station sites were wanted. But the cost of transport was great; the rate of progress was slow; and the results were unsatisfactory. Eventually a method of touch rather than sight was adopted, feeling the ground to search for the obstacles to be avoided, rather than attempting to look over them; the "rays" were traced either by a minor triangulation, or by a traverse with theodolite and perambulator, or by a simple alignment of flags. The first method gives the direction of the new station most accurately; the second searches the ground most closely; the third is best suited for tracts of uninhabited forest in which there is no choice of either line or site, and the required station may be built at the intersection of the two trial rays leading up to it. As a rule it has been found most economical and expeditious to raise the towers only to the height necessary for surmounting the curvature, and to remove the trees and other obstacles on the lines.

6. *Structure of the Principal Stations.*—Each has a central masonry pillar, circular and 3 to 4 feet in diameter, Principal stations. for the support of a large theodolite, and around it a platform 14 to 16 feet square for the observatory tent, observer, and signallers. The pillar is carefully isolated from the platform, and when solid carries the station mark—a dot surrounded by a circle—engraved on a stone at its surface, and on additional stones or the rock *in situ*, in the normal of the upper mark; but, if the height is considerable and there is a liability to deflexion, the pillar is constructed with a central vertical shaft to enable the theodolite to be plumbed over the ground-level mark, to which access is obtained through a passage in the basement. In early years this precaution against deflexion was neglected and the pillars were built solid throughout, whatever their height; the surrounding platforms, being usually constructed of sun-dried bricks or stones and earth, were liable to fall and press against the pillars, some of which thus became deflected during the rainy seasons that intervened between the periods during which operations were arrested or the commencement and close of the successive circuits of triangles. In some instances displacements of mark occurred of which the magnitudes were not ascertainable, but were estimated as equivalent to *p.e.*'s of about ± 9 inches in the length and ± 2″·4 in the azimuth of the side between any two deflected towers; and as these theoretical errors are identical with what may be expected at the end of a chain of 36 equilateral triangles in which all the angles have been measured with a *p.e.* = ± 0″·5, the old triangulation over solid towers had evidently suffered much more from the deflexions of the towers than from errors in the measurements of the angles.

7. *Instruments for Measuring Principal Angles.*—Large theodolites were invariably employed. Repeating circles were highly thought of by French geodesists at the time when the operations in India were being commenced; but they were not used in the survey, and have now been generally discarded.

The principal theodolites are somewhat similar to the astronomer's alt-azimuth instrument, but with larger azimuthal and smaller vertical circles, also with a greater base to give the firmness and stability which are required in measuring horizontal angles. The azimuthal circles have mostly diameters of either 36 or 24 inches, the vertical circles having a diameter of 18 inches. In all the theodolites the base is a tribrach resting on three levelling foot-screws, and the circles are read by microscopes; but in different instruments the fixed and the rotatory parts of the body vary. In some the vertical axis is fixed on the tribrach and projects upwards; in others it revolves in the tribrach and projects downwards. In the former the azimuthal circle is fixed to the tribrach, while the telescope pillars, the microscopes, the clamps, and the tangent screws are attached to a drum revolving round the vertical axis; in the latter the microscopes, clamps, and tangent screws are fixed to the tribrach, while the telescope pillars and the azimuthal circle are attached to a plate fixed at the head of the rotatory vertical axis. The former system—called that of *flying microscopes*—permits the vertical axis to be readily opened out and cleaned, and presents the same clamp and tangent screw for employment during a round of angles; the latter—the system of *fixed microscopes*—necessitates the removal and replacement of all the microscopes, clamps, and tangent screws whenever the axis is cleaned, which is very troublesome, and it presents three sets of clamps and tangent screws for successive employment during a round of angles, which is a departure from true differentiality The vertical axis is perforated for centring over the station mark with the aid of a "look-down telescope" instead of a plummet. The azimuthal circle is invariably read by an odd number of microscopes, either three or five, at equal intervals apart. The telescope rests with its pivots in Y's at the head of two pillars of a sufficient height to enable it to be completely turned round in altitude. The vertical circle is fixed to the transit axis of the telescope, and is read by two microscopes 180° apart, at the extremities of arms projecting from one of the pillars. The stand is a well-braced tripod, carrying an iron ring on which the theodolite rests and may be turned round bodily whenever desired, as for shifting the position of the zero of the azimuthal circle relatively to the points under observation. The ring is 3 inches broad and of the same diameter as the circle of the foot-screws of the theodolite. In some instruments the foot-screws rest directly on the ring; but the instrument can be raised off the ring and turned round with the aid of an apparatus in the centre of the stand. In others they rest in grooves at the angles of an iron triangle which sits on the ring and can be shifted in position by hand; thus with the stand well levelled in the first instance the circle may be set within 1′ of any required reading. The centring over the station mark is performed by pushing screws placed either in the drum of the stand or at the angles of the triangle.

For travelling the theodolites were packed in two cases, the larger containing the body of the instrument, the smaller the telescope and the vertical circle; the stand constituted a third package. Each was carried on men's shoulders as the safest method of transport; the weights, of the heaviest 36-inch and of the lightest 24-inch instruments, as packed with ropes and bamboos, were, respectively, as follows:—body, 649 ℔; telescope, 130; stand, 232; total, 1011 ℔; and 300, 135, and 185, total 620 ℔.

8. *Signals.*—Cairns of stones, poles, or other opaque signals were primarily employed, the angles being measured by day only; eventually it was found that the atmosphere was often more favourable for observing by night than by day, and that distant points were raised well into view by refraction by night which might be invisible or only seen with difficulty by day. Lamps were then introduced of the simple form of a cup, 6 inches in diameter, filled with cotton seeds steeped in oil and resin, to burn under an inverted earthen jar, 30 inches in diameter, with an aperture in the side towards the observer. Subsequently this contrivance gave place to the Argand lamp with parabolic reflector; the opaque day signals were discarded for heliotropes reflecting the sun's rays to the observer. The introduction of luminous signals not only rendered the night as well as the day available for the observations but changed the character of the operations, enabling work to be done during the dry and healthy season of the year, when the atmosphere is generally hazy and dust-laden, instead of being restricted as formerly to the rainy and unhealthy seasons, when distant opaque objects are best seen. A higher degree of accuracy was also secured, for the luminous signals were invariably displayed through diaphragms of appropriate aperture, truly centred over the station mark; and, looking like stars, they could be observed with greater precision, whereas opaque signals are always dim in comparison and are liable to be seen excentrically when the light falls on one side.

A signalling party of three men was usually found sufficient to manipulate a pair of heliotropes—one for single, two for double reflexion, according to the sun's position—and a lamp, throughout the night and day. Heliotropers were also employed at the observing stations to flash instructions to the signallers.

Measuring horizontal angles.

9. *Measuring Horizontal Angles.*—The theodolites were invariably set up under tents for protection against sun, wind, and rain, and centred, levelled, and adjusted for the runs of the microscopes. Then the signals were observed in regular rotation round the horizon, alternately from right to left and *vice versa*; after the prescribed minimum number of rounds, either two or three, had been thus measured, the telescope was turned through 180°, both in altitude and azimuth, changing the position of the face of the vertical circle relatively to the observer, and further rounds were measured; additional measures of single angles were taken if the prescribed observations were not sufficiently accordant. As the microscopes were invariably equidistant and their number was always odd, either three or five, the readings taken on the azimuthal circle during the telescope pointings to any object in the two positions of the vertical circle, "face right" and "face left," were made on twice as many equidistant graduations as the number of microscopes. The theodolite was then shifted bodily in azimuth, by being turned on the ring on the head of the stand, which brought new graduations under the microscopes at the telescope pointings; then further rounds were measured in the new positions, face right and face left. This process was repeated as often as had been previously prescribed, the successive angular shifts of position being made by equal arcs bringing equidistant graduations under the microscopes during the successive telescope pointings to one and the same object. By these arrangements all periodic errors of graduation were eliminated, the numerous graduations that were read tended to cancel accidental errors of division, and the numerous rounds of measures to minimize the errors of observation arising from atmospheric and personal causes.

The following table (I.) gives details of the procedure at different times; in the headings M stands for the number of microscopes

over the azimuthal circle of the theodolite, Z for the number of the zero settings of the circle, N for the number of graduations brought under the microscopes, A = 360° ÷ N, the arc between the graduations, R the prescribed number of rounds of measures, and P = R × Z, the minimum number of telescope pointings to any station, excluding repetitions for discrepant observations:—

Period.	M	Z	N	A	R	P
1830-45	5	8	40	9° 0′	3	24
1845-55	5	10	50	7° 12′	2	20
1855-80	5	10	50	7° 12′	3	30
	3	12	36	10° 0′	3	36

Under this system of procedure the instrumental and ordinary errors are practically cancelled and any remaining error is most probably due to lateral refraction, more especially when the rays of light graze the surface of the ground. The three angles of every triangle were always measured.

10. *Vertical Angles. Refraction.*—The apparent altitude of a distant point is liable to considerable variations during the twenty-four hours, under the influence of changes in the density of the lower strata of the atmosphere. Terrestrial refraction is very capricious, more particularly when the rays of light graze the surface of the ground, passing through a medium which is liable to extremes of rarefaction and condensation, under the alternate influence of the sun's heat radiated from the surface of the ground and of chilled atmospheric vapour. When the back and forward verticals at a pair of stations are equally refracted, their difference gives an exact measure of the difference of height. But the atmospheric conditions are not always identical at the same moment everywhere on long rays which graze the surface of the ground, and the ray between two reciprocating stations is liable to be differently refracted at its extremities, each end being influenced in a greater degree by the conditions prevailing around it than by those at a distance; thus instances are on record of a station A being invisible from another B, while B was visible from A.

When the great arc entered the plains of the Gangetic valley, simultaneous reciprocal verticals were at first adopted with the hope of eliminating refraction; but it was soon found that they did not do so sufficiently to justify the expense of the additional instruments and observers. Afterwards the back and forward verticals were observed as the stations were visited in succession, the back angles at as nearly as possible the same time of the day as the forward angles, and always during the so-called "time of minimum refraction," which ordinarily commences about an hour after apparent noon and lasts from two to three hours. The apparent zenith distance is always greatest then, but the refraction is a minimum only at stations which are well elevated above the surface of the ground; at stations on plains the refraction is liable to pass through zero and attain a considerable negative magnitude during the heat of the day, for the lower strata of the atmosphere are then less dense than the strata immediately above and the rays are refracted downwards. On plains the greatest positive refractions are also obtained,—maximum values, both positive and negative, usually occurring, the former by night, the latter by day, when the sky is most free from clouds. The values actually met with were found to range from +1·21 down to −0·09 parts of the contained arc on plains; the normal "coefficient of refraction" for free rays between hill stations below 6000 feet was about ·07, which diminished to ·04 above 18,000 feet, broadly varying inversely as the temperature and directly as the pressure, but much influenced also by local climatic conditions.

In measuring the vertical angles with the great theodolites, graduation errors were regarded as insignificant compared with errors arising from uncertain refraction; thus no arrangement was made for effecting changes of zero in the circle settings. The observations were always taken in pairs, face right and left, to eliminate index errors; only a few daily, but some on as many days as possible, for the variations from day to day were found to be greater than the diurnal variations during the hours of minimum refraction.

11. *Results deduced from Observations of Horizontal Angles; Weights.*—In the Ordnance and other surveys the bearings of the surrounding stations are deduced from the actual observations, but from the "included angles" in the Indian Survey. The observations of every angle are tabulated vertically in as many columns as the number of circle settings face left and face right, and the mean for each setting is taken. For several years the general mean of these was adopted as the final result; but subsequently a "concluded angle" was obtained by combining the single means with weights inversely proportional to $g^2 + o^2 \div n$,—g being a value of the *e.m.s.*[1] of graduation derived empirically from the differences between the general mean and the mean for each setting, o the *e.m.s.* of observation deduced from the differences between the individual measures and their respective means, and n the number of measures at each setting. Thus, putting $w_1, w_2, \ldots$ for the weights of the single means, w for the weight of the concluded angle, M for the general mean, C for the concluded angle, and $d_1, d_2, \ldots$ for the differences between M and the single means, we have

$$C = M + \frac{w_1 d_1 + w_2 d_2 +}{w_1 + w_2 +} \quad \text{(1)}$$

and

$$w = w_1 + w_2 + \quad \text{(2)}.$$

$C - M$ vanishes when n is constant; it is inappreciable when g is much larger than o; it is significant only when the graduation errors are more minute than the errors of observation; but it was always small, not exceeding 0″·14 with the system of two rounds of measures and 0″·05 with the system of three rounds.

The weights of the concluded angles thus obtained were employed in the primary reductions of the angles of single triangles and polygons which were made to satisfy the geometrical conditions of each figure, because they were strictly relative for all angles measured with the same instrument and under similar circumstances and conditions as was almost always the case for each single figure. But in the final reductions, when numerous chains of triangles composed of figures executed with different instruments and under different circumstances came to be adjusted simultaneously, it was necessary to modify the original weights, on such evidence of the precision of the angles as might be obtained from other and more reliable sources than the actual measures of the angles. This treatment will now be described.

12. *Determination of Theoretical Absolute Errors of Observed Angles.*—Values of theoretical error for groups of angles measured with the same instrument and under similar conditions may be obtained in three ways,—(i.) from the squares of the reciprocals of the weight w deduced as above from the measures of such angle, (ii.) from the magnitudes of the excess of the sum of the angles of each triangle above 180° + the spherical excess, and (iii.) from the magnitudes of the corrections which it is necessary to apply to the angles of polygonal figures and networks to satisfy the several geometrical conditions (indicated in the next section). Let e_1, e_2, and e_3 be the values of the *e.m.s.* thus obtained; then, putting n for the number of angles grouped together, we have

$$e_1^2 = \frac{n}{[w]} \text{ and } e_2^2 = \frac{[\text{squares of triangular errors}]}{n};$$

also, putting W for the mean of the weights of the t angles

[1] The theoretical "error of mean square" = 1·48 × "probable error.