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 deflection 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 beginning and close of the successive circuits of triangles. Large theodolites were invariably employed. Repeating circles were highly thought of by French geodesists at the time when the operations in India were begun; but they were not used in the survey, and have now been generally discarded. The principal theodolites were 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 arc required in measuring horizontal angles. The azimuthal circles had mostly diameters of either 36 or 24 in., the vertical circles having a diameter of 18 in. In all the theodolites the base was 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 varied. In some the vertical axis was fixed on the tribrach and projected upwards; in others it revolved in the tribrach and projected downwards. In the former the azimuthal circle was fixed to the tribrach, while the telescope pillars, the microscopes, the clamps and the tangent screws were attached to a drum revolving round the vertical axis; in the latter the microscopes, clamps and tangent screws were fixed to the tribrach, while the telescope pillars and the azimuthal circle were attached to a plate fixed at the head of the rotary vertical axis.

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 in. in diameter, filled with cotton seeds steeped in oil and resin, to burn under an inverted earthen jar, 30 in. in diameter, with an aperture in the side towards the ob­server. Subsequently this contrivance gave place to the Argand lamp with parabolic reflector ; the opague 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 reflection, 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.

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 werfe 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.

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.

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 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 arc 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 begins 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 ft. was about 0∙07, which diminished to 0∙04 above 18,000 ft., 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.

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 thc 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 *÷* *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,... 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, . . . for the differences between *M* and the single means, we have

*C=M + ⅛±⅛ + (1)*

and w = wι 4-w2 + (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

@@@1 The theoretical “ error of mean square ” = 1∙48 × "probable error.”