SECT. II.--OTHER SELECTED PAPERS.

(*Paper No. 3414.*)

“Notes on Railway Surveying.”

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THE Author, having spent a considerable portion of his professional life on surveys connected with railway-lines and their location, presents the following notes in the hope that they may be of some assistance in enabling engineers engaged in similar work to avoid the unnecessary labour that appears to be still devoted to some of the operations involved. It is premised that the observations to be made apply principally to lines in mountainous countries, where the location frequently runs along hill-sides having a steep transverse slope, intersected at intervals by ravines, and possibly covered by dense forest, impeding the view of measuring-instruments.

After the general direction of a survey has been determined, and some idea of the gradients has been obtained, the first thing to be done is to run a trial-line. For this purpose, in the case of country overgrown by forest, or in broken ground, no advantage is to be gained by using a theodolite; an ordinary compass will suffice to take the bearings of the lines, and by this means all felling of trees is avoided and the cutting is limited to that required for the measurements and for clearing the view of the level. It is of no consequence if, when the permanent location-lines are plotted, it is found that the point aimed at does not coincide exactly with the corresponding point on the compass-line, so long as care is taken at the end of each day's work to plot the line and levels, laying down the approximate curves needed, so that there may be no accumulated error of line or level. For the same reason extreme accuracy in the measurements is not required, and they can be made with an ordinary tape; it must, however, be held as nearly as possible horizontal, and constant use should be made of plumb-bobs. From such a line a fairly close estimate can be made, and the whole of the work can be done by one observer, who takes the bearings and levels while the chaining and cutting are proceeding. Cross-sections may be taken if required, although this

may generally be deferred until the traverse-lines are run, as it often happens that they are of no use in very broken country, where all that can be done is to keep up in the hollows and out on the spurs as far as possible. A convenient method of plotting cross-sections is to put them on the centre-line of the plan, when the slope of the ground can be seen at a glance.

The level need not be taken below the grade-line at ravines further than is necessary for the sight across, the depth being ascertained by a hand-level. In a hollow where the slope is steep and strewn with boulders, a very small deviation of the level-staff at the bottom may cause a difference of 2 feet or 3 feet, so that there is nothing to be gained by going down one side and up the other with the more accurate instrument, while the multiplication of short sights is likely to lead to error. In the same way if a sharp spur can be rounded in two or three sights the height of the summit can be taken by the hand-level—a much shorter operation—but, of course, this can only be done on bare ground.

After the compass-lines have been run, the definite traverse-lines can be set out; these may either coincide with the compass-lines, or may be traced in more convenient directions, but will almost certainly be in the right place. No theodolite-work will then be thrown away, as often happens when a line carefully run over and round obstacles is found to be useless. The greater the care taken with this part of the work, the easier will be the permanent setting-out. For the last two operations all possible accuracy should be aimed at. If there is any doubt as to the accuracy of the transit-instrument, a mark should be set up at the camp for verifying the adjustment every morning before starting out, and all the measurements should be taken with a light chain tightly stretched by men provided with plumb-bobs. A length of 25 feet will be found convenient for the chain, which should be made of steel links of the ordinary form, as such a chain is better suited for rough handling amongst rocks than a metal band.

The setting-out of curves by angles of intersection in open and flat or undulating country is of course a perfect system, as a definite proof is afforded of the exactitude of the work, but this method is quite unsuitable in rough country, where the intersection-points are often inaccessible. Various means are employed for overcoming the difficulties encountered, and if the number of intersection-points is increased indefinitely, or subsidiary lines are run, no doubt the curves can be set out on this principle, but a tedious amount of calculation, chaining, and setting-up of the instrument is involved, with at least as much

chance of error as in setting out the curve by deflection-angles from the tangent-point, removing the theodolite to any convenient point that can be seen, and then continuing from a fresh tangent fixed on the circle of the instrument. It may be objected that there is no check on the correctness of the work done in this manner, but by taking great care in the adjustment of the theodolite, and in the chaining, all but insignificant errors will be rare. In any case, if doubt is entertained, the curve can be run over again in very much less time than would be occupied by the method of intersection-points, for if a mistake is made in the chaining of one of the tangents or in measuring the intersection-angle, it cannot be discovered until the curve has been run, when perhaps the whole of the operations have to be gone over again. An instance may be cited of the location of a length of 12 miles of railway having numerous curves of small radius on steep and very broken ground, where the calculated bearing of the last tangent did not vary by more than $\frac{3}{4}$ degree from the needle-bearing. On the same survey, at a place where one stretch of the line was above another on the same hillside, after development for gaining height, cross-lines were run from one to the other, and no appreciable error was found either in distance or angle, thus proving the reliability of the chaining.

A fruitful source of error and loss of time is the difficulty of seeing the bottom of the poles through the telescope, or of having them held vertical. One-half of this can be eliminated by replacing the back pole by three poles tied together near the top, from which is suspended an adjustable plumb-bob. The man in charge, on arriving at the peg, sets up the plumb-bob over the tack, and any part of the string that is visible serves for the sight.

One of the advantages claimed for setting-out by intersections is that of convenience in future reference; but it so frequently happens in rough country that the point is cut away during the progress of the works, or is invisible from the ends of the curve, that it is much more convenient to fix the position of the tangent by pegs placed anywhere upon it, the beginning and end of the curve being fixed by a line at right-angles to it or at any other angle, also out of the way.

The American system of denoting curves by the angle at the centre subtending a chord of stated length at the circumference appears to possess special advantages for rugged ground. If the laying-out is done as described in the foregoing, the work not only in the field, but in the office afterwards, may be much simplified by arranging for the curves to begin and end at an even subdivision

of a chain. It will be found that not only can this be done, but also that curves of an even number of degrees may be employed. For example, with a chord of 100 feet, curves of 1, 2, 4, 6, 8, 10, 12, 14 and 16 degrees would probably serve for nearly the whole of a long line of railway. The required subdivisions of a 100-foot chain would then rarely involve a deflection of less than $\frac{1}{4}$ degree, thus avoiding the necessity for making a list in the field. With this system the difficulty of using transition-curves is much reduced, as it is only necessary to set out a length of flat curve, and then, with the instrument set up at the end of this curve, to begin the sharper one; any desired gradation can thus be introduced. The frequent setting-up of the instrument may be advanced as an objection to this method, but this is of little importance on ground such as that now treated of, where the theodolite would probably have to be moved, on an average, every 50 feet, or oftener. Although the working-out of tangents and deflection-angles is simple, it is of great importance that the transit-man should be as free as possible for the manipulation of his instrument, attending to the measurements, and noting the features of the country, and the calculations become laborious if not uncertain when carried out under a burning sun or in pouring rain, when it is difficult to consult books and tables, and more so when perhaps only a precarious footing can be maintained on a steep slope. By taking the precautions suggested, a day's work in the field may often be done without reference to any tables or lists. The calculation of gradients may be simplified in much the same way, by beginning and ending at a station (chain-peg) and, if possible, at an even foot for the heights, but if the metre is used these even figures cannot be so readily obtained.

In levelling, every care should be observed in taking the readings at the changing-points, the level-staff being held on a nail having a rounded top similar to a rivet-head, and waved backwards and forwards during observation. If the staff divided into hundredths of a foot is used, the readings are generally taken to hundredths, not only when the instrument is shifted, but also at the intermediate points. Whatever may be required at the changing-points, it is certainly not necessary to record the readings at the intermediate points more closely than to the nearest tenth of a foot. The levels of a line of railway would probably be considered satisfactory if there were no error of more than $\frac{1}{10}$ foot per mile; therefore the reading at any peg might vary by $\frac{1}{10}$ foot, and, as in rough sloping ground the difference made by holding the staff on one side or

other of the peg might easily be more than this amount, the level of the ground would not be determined nearer than $\frac{1}{8}$ foot. To hold the staff on the top of the pegs does not give the level of the ground unless they all project the same distance above it, and much time would be spent in securing this. For every note of the intermediate sights, therefore, extra figures have to be written in the level-book and on the section.

It would be interesting to ascertain by actual experiment the effect on the accuracy of levelling produced by the size of the divisions on the level-staff. It is generally supposed that the work done with a French staff is as reliable as that with an English staff, and no advantage is gained by estimating the nearest half-centimetre. It follows, therefore, that $\frac{1}{100}$ foot is a smaller division than is necessary. It is difficult for a leveller to read correctly to $\frac{1}{100}$ foot at a distance of more than 200 feet, and there can be no question as to the increased comfort, certainty, and rapidity of reading the larger division of 1 centimetre. A staff divided into tenths of a foot, with a mark at each twentieth of a foot, would probably give as good results, the hundredths being estimated at the changing-points.

Much time can be saved by plotting the section on squared paper. If the 100-foot chain is used, a convenient scale is 1 centimetre to 100 feet horizontal, and 1 millimetre to 1 foot of vertical height; paper decimally divided on any other scale may, of course, be employed, but is not so easily procurable abroad. In this way the section, even in very broken ground, however frequently the readings may be taken, can be plotted as fast as the heights can be read out of the level-book, and on fairly flat ground, not very irregular, at the rate of 6 miles to 8 miles an hour, where the ordinary stations are 100 feet apart. The permanent section can then be plotted in camp as soon as the final location is run; no scale is required nor any drawing of vertical lines, except for gradients.

For the location of railways the foot is generally a more convenient unit than the metre, because its subdivisions are more easily dealt with and have not to be carried so far. The English chain of 66 feet, divided into links, has not been referred to, as with it the disadvantage arises of having one measure for length and another for height.