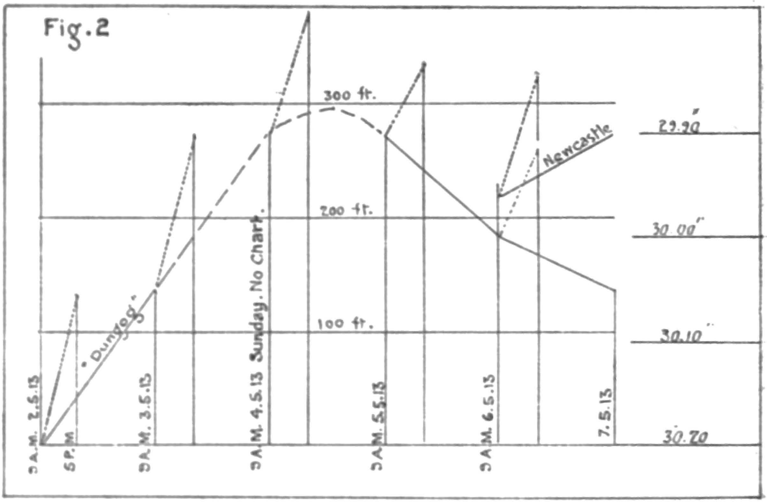
To apply corrections in this way, a diagram should be made with a time-scale as a base. The barometer readings taken from the chart should be converted into the corresponding elevations in feet above sea level, and these should be plotted as ordinates at the proper intervals.

Through the points thus obtained, a curve is drawn, and on the curve, as a base, the corrections for the Diurnal Wave during working hours are plotted.

A horizontal line is drawn at such a height that the distance from it to the final correction curve, when added to or subtracted from the observed elevation at the starting point, will give the true or assumed level of that point.

The correction to be applied for any hour, shown on the curve, is then directly obtained by scaling on the proper ordinate between this horizontal line and the final curve. Such a diagram for the period covered by the table, is shown in Figure 2.

Fig. 2



Good results may be expected unless sudden local changes of short duration have occurred, which are not shown on the charts. The shape and spacing of the Isobaric lines, at the locality of the observations, will be an indication of the occurrence of such changes.

Where the lines are smooth and widely spaced, smaller errors may be expected than where irregular curves and steep barometric gradients occur.

Where time allows and doubt exists as to the correctness of the curve, a second series of observations should be made in better weather.

If the tract of country explored is not extensive, a recording barometer at the base of observations will give even better results than the method described; but its use is not always practicable.

The theory of Stadia measurements is fully explained in the text-books, and will not be discussed.

A good theodolite, free from excentricity and fitted with stadia wires to intercept a length of one foot on a staff at a distance of 100 feet less the instrument constant, should be used. The distance of the stadia wires from the central wire should be precisely equal. The staves used should be specially divided in feet and tenths. A finer graduation is unnecessary, and cannot be read at long distances. In rough country the staves should be fitted with a small level or plumb line, to ensure that they are held vertical.

The method of conducting the survey will now be described. The centre line has been roughly staked out, the successive stations being numbered 1, 2, 3, and so on.

The theodolite is centred over Station 1 and properly oriented on the adopted azimuth. The height of the line of sight above the station peg is measured and recorded. It should only be necessary to measure this height at the first and last station of the day's work, unless it becomes necessary to move the instrument from a station before the observations are completed.

A staff should be held on Station 2, the central wire should be set on the 5ft. mark, and a reading taken with the upper wire. The distance so obtained must, of course, be doubled when the observations are reduced.

This reading, with the horizontal bearing and vertical angle, are then booked in the proper columns of the field book.

The instrument is then directed to each of the other staves, which are held in such positions as to show any large irregularities in the ground, such as tops of ridges and beds of watercourses. The number of sights necessary will depend on the nature of the country.

When all the desired points have been observed and recorded, the instrument should again be directed to Station 2, the azimuth checked, and the horizontal circle firmly clamped, so that it can be carried to the next station without disturbance.

The instrument is then set up on Station 2, its place being taken by a staff, and is carefully oriented on Station 1, the bearing shown on the circle being checked by the field book, and corrected if necessary. One vernier only should be used if the instrument is a good one, and the microscope should now be removed to the other side of the instrument, to avoid reversals of bearings. The telescope should never be turned over, and a strap or string tied across the standards will prevent this being done unintentionally. The reason for this is that the vertical circle is generally divided in quadrants, two of which read from the horizontal and two from the vertical plane.

In country with slopes of less than 1 to 1, angles of more than 45% will indicate elevation, and angles of less than 45% depression, or vice versa, according to the side of the circle which is uppermost. There will then be no chance of booking a rise as a fall or the reverse, and errors will be avoided.

With the exception of the measurement of height above station peg, the operations of the first station are repeated. The staff on Station 1 is first read, and the distance thus checked, the vertical angle of the 5ft. mark is recorded, and serves to determine the new instrument height, from which elevations of observed points will be computed.

After removing to Station 3 in the same manner, the instrument height will be determined by an observation on Station 2, the elevation of which has been measured from Station 1.

The result will be that a horizontal traverse has been made, with two distinct measurements of each line.

A check on azimuth may be obtained roughly by compass bearings, or if greater accuracy is desired, by long check sights or astronomical observations.

In addition to the horizontal traverse, two distinct vertical traverses have been made.

The first traverse fixes the levels of the Stations 2, 4, 6, etc., commencing from a known level at 2, and the second in a similar way determines the levels of Stations of 1, 3, 5, etc.

At the end of the day, the instrument height at the last station will connect the two traverses, and give a check on their accuracy.

For convenience, the graduation of the staves should commence at 5 feet from the lower end, and this point should be marked zero.

The speed of the work will depend on the number of points which must be observed, and may vary from 20 chains to five miles per day, according to the country and the skill of the observer.

This traverse, if properly carried out, will enable an accurate feature map of the route to be made, on which the location can be studied at leisure.

In order to save labour in reducing the observations, a special form of slide rule should be used, which will show horizontal distance and elevation by a single setting.

A circular rule devised by Mr. Kennedy, is more satisfactory in use than the ordinary straight rule of the instrument-makers.

The method described will give a result which is accurate enough for requirements. Any probable errors in distance will be so small that they cannot be detected by scaling on the plan, and errors of level will not be large enough to affect the grade.

The plotting of the work should, if possible, be kept well up to the actual survey; but it is not advisable to attempt to fix a location on the plan until the grade is completed.

The plan may be on a scale of 4 chains to an inch in moderate country, and 2 chains to an inch where the difficulties are great, or when it is desired to reduce earthwork to a minimum. Elevations of all stations and observed points should be shown in red, with a dot of the same colour marking the positions of staff. Traverse stations should be shown by small circles, and numbered in black. It is advisable, but not necessary, to ink in the actual traverse line.

If the country is rough, and developments of the second-class are expected, contour lines 10 feet apart should now be drawn with the help of the levels shown, but otherwise this will not be essential.

When it is obviously impossible to obtain a natural grade as in the case shown in Figure 2, secondary traverses should be made to cover the whole area of country in which the grade will be developed. Great detail is not necessary, and it will be sufficient to fix the direction and height of ridges, valleys and other features.

The plan having been made as described, a tentative location may be laid down in pencil.

If the first grade has been obtained without difficulty, the traverse line will be followed closely, and the necessary curves fitted to it as closely as desired. This projected line should then be marked off in chains or suitable lengths, and the level of ground at each division read from the contour lines or observed points. These are then plotted a convenient scale, and will show the true section of the projected centre line.

When extensive developments are necessary, or the traverse departs considerably from the required grade, the contour plan is a great assistance, and is used as follows:—

The length in which the grade will rise 10 feet is calculated, and a pair of dividers set to this distance. Starting from one end of the grade, the level of which is known, the dividers are stepped along the line and the successive positions of the points marked with a pencilled cross. The contours will be a guide to selection of a place for the front leg of the dividers, when it is remembered that each line represents a step of the height corresponding to the stride taken.

A line with curves of the requisite radius may then be sketched in keeping as near to the marked points as possible, and a section made of this line in the manner already described.

This projected line should then be carefully examined on the plan, to see what improvements can be made either by reducing earthworks or avoiding unnecessary curvature, according to the class of line required. This process of revision should be repeated at least once, and in difficult country as many times as may be necessary.

It will often be necessary to extend the area covered by the first survey to meet requirements which are discovered as the location proceeds, and will continue to present themselves to a critical eye, until, by a process of exhaustion, a satisfactory result is obtained.

The section finally adopted should then have the grade line drawn on it, the quantities of cutting and bank should be approximately estimated, and a disposal of earthwork made to determine whether the contents of any cutting will need to be hauled to an excessive distance.

A small alteration of the centre line will sometimes greatly reduce the average cost of the earthwork.

The preliminary survey has now been concluded, but the chosen line should be carefully examined, and any possible improvement considered. A good line can often be improved, and the extra cost of survey incurred will be repaid a hundredfold.

III.—FINAL TRAVERSE.

If the permanent staking of the line is to follow immediately on the trial survey, and if the location does not depart to any great extent from the traverse, no further preliminary work will be necessary.

In rough country, especially when a long time is likely to elapse before the construction is undertaken, it will always be advisable to make a final traverse of the selected route.

In such a case, the ordinary methods of survey should be adopted.

The centre line, as projected on the first plan, should be set out on the ground, in a succession of short lines lying approximately in the curves and straights, which have been decided upon. A traverse should be made of this with Theodolite and Chain, and a longitudinal section taken with level and staff. Numerous cross sections, one or two chains in length, should be taken, preferably by the Stadia method.

A new plan and section should be plotted, and a final location should be made with the help of the cross sections.

If the preliminary work has been well done, the improvements possible will be very slight, consisting of small reductions of earthwork or curvature.

The question of compensation for curvature or grades, which should have been provided for in the preliminary location, can be gone into more thoroughly.

A convenient rule for the amount of compensation, applied to the English nomenclature of curves and grades, is the following:—

"Divide 2.60 by radius in chains. The result is the amount of compensation necessary in decimals of a foot, and this quantity must be deducted from the rise per chain on the ruling grade, to give the equivalent rise on the given curve."

Example: Ruling Grade = 1 in 44, or 1.50 feet per chain.
Radius of Curve = 18 chains.
Compensation = 2.6 ÷ 18 = .14ft.
Compensated Grade = 1.32 feet per chain, or 1 in 50.

Transition Curves should always be provided for.

The particular form of curve employed is not a matter of great importance, provided that the radius of the curve is changed gradually. The cubic parabola, as used in New South Wales, is easily applied to all curves given in the tables supplied by the Works Department to its surveyors. The actual work of setting out the curves is considerably increased on account of the large number of points which have to be fixed, and in the case of a curve of radius different from those given in the tables, the transition curve will have to be computed for the case in question.

In making the final location, and, indeed, in all the preliminary work, provision should be made for transition by introducing the necessary length of straight between ends of reverse curves.

Where two curves of the same "hand" adjoin closely, they should be connected by a short curve of slightly larger radius, or one of them should be altered until they have a common tangent.

In the case of narrow gauge or short private lines, where speed is likely to be moderate, transition curves may be provided by leaving a short length of straight, and swinging this slightly on its central point to miss the circular arcs by a convenient amount. The transition curve may be put in by offsets, or a good approximation can be made by the eye.

This method may not give a perfect curve, but it is to be preferred to the platelayer's "transition," which is obtained by sharpening the curve near its ends.

The final traverse should be marked with substantial pegs, trees on the line should be blayed, benchmarks of a durable nature should be established at suitable intervals, and check levels should be run between these.

All traverse stations should be numbered as shown on plan.

A report should be prepared, giving the following information:—

Length of line.
Ruling grade and sharpest curve.
Number and position of stations required.
Nature of material likely to be found in cuttings.
Large and small bridges necessary.
Materials available locally, such as timber, stone, gravel, sand, etc.
Position of possible water supplies.

In addition, if the line is not a Government undertaking, an estimate of cost, probable traffic and its nature, and working expenses should be provided.

The writer, in conclusion, presents this paper with apologies for its shortcomings, but ventures to hope that it may be of use not only to students, but also to some of the members of the Society who may be called upon to make railway surveys without the help of previous experience.

DISCUSSION.

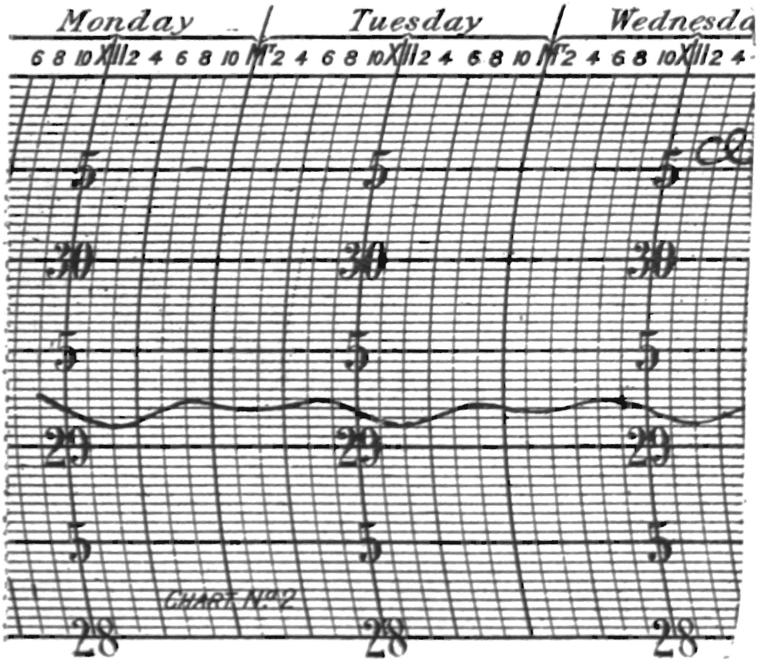
Mr. W. POOLE had listened with great interest to Mr. Stephen's paper. As one who had been keenly engaged in the various phases of railway location, both in actual field work and as a lecturer, he felt gratified to find that the result of Mr. Stephen's experience so closely coincided with his opinions.

Many defective locations had been made in past surveys. Many of the early railway surveyors had been trained on a different class of work, viz., the ordnance survey of Great Britain. The principles of economical location were not then clearly recognised. A more fruitful source of defective work was the desire to attain a good mileage of survey work per month. Frequently, so long as the location kept within the limit laid down for maximum grade and sharpest curve, little effort was made to secure a better line during the trial survey. The result was that haulage of traffic was often spoilt by the presence of maximum grades, which might reasonably have been avoided.

Many of the principles governing the proper location of railways have been successfully applied to the location of ordinary roads in hilly and rough country. As the traffic on a main railway line across a mountain range becomes heavy, it may pay to re-locate the sections with long heavy grades, as is now being done in many places in New South Wales, e.g., between Waterfall and Clifton, or even to build an entirely new line, e.g., it may in the future pay to build a line across the Blue Mountains by passing up one of the valleys where a moderate grade might be obtained; but the earth works, and therefore cost, would be enormously heavy.

Rush grades are frequently used in Queensland in crossing depressions where the impetus attained on the down-grade is sufficient to carry the train to the top of the up-grade. These grades are frequently as steep as one in 30, whereas the ruling grade on inclines that can only be surmounted by a steady haul may not exceed one in 50.

It was exceedingly useful to have stadia wires fitted to theodolites. An error of a foot, or even a few feet, in distance was seldom of importance in the preliminary work of railway location. There was no necessity to have special stadia staffs. He had found that an ordinary level staff could be read by a tacheometer to 1-100th of a foot under ordinary atmospheric



Portion of Barographic record exhibited by Mr. Poole, to show variation of pressure throughout the day, at Charters Towers, Queensland. The rest of the records extended over a period of two months, but reproduced precisely the portion here shown for two days.

conditions at distances up to 600-700 feet, and of 1-10th of a foot at distances up to 1,500 feet. Special tables greatly facilitate the work of reduction of results.

The aneroid barometer may be of great value in exploration and preliminary location surveys. To obtain good results it is necessary to allow for the daily double barometric wave. In the tropics this wave is very marked and regular, and meteorological irregularities of pressure are usually conspicuous by their absence. A barograph record taken at Charters Towers was exhibited, showing the daily wave for 10 consecutive weeks taken on the same sheet. It appeared as a wavy brand across the paper. In higher latitudes the daily waves progressively decreased, while the irregularities became very marked. If a table of hourly corrections for different months is prepared for any district in the tropics, aneroid levelling may be undertaken with surprising accuracy, instead of being "hopelessly inaccurate," as it was held to be before the influence of the daily barometric wave was understood by surveyors.

Mr. W. E. COOK stated: Money expended on preliminary surveys is often well spent. It sometimes happens that the trial survey has been rushed through, and, later on, owing to political pressure, the final survey is hurried through, so that it differs but slightly from the trial survey, and contains most of its defects. The St. Gothard's tunnel is approached from both the Italian and Swiss sides by means of spiral tunnels, and also by zig-zags having looped ends instead of sharp dead-end angles. The latter development is also largely used. Another mountain line with open loops is near Geneva.

He had not had much success in using an aneroid barometer. He had not known that it was necessary to make corrections for the daily wave of variation.

Stadia work had been highly successful on surveys such as that of the railway line to Crookwell after ordinary means of surveying had almost been a failure.

Mr. C. T. STEPHENS, in reply, said that he considered that the early surveyors had done very good work considering their limited training at a period when no literature existed on this subject. He had seen "'rush grades" of as steep as one in ten put in on the Chillagoe line in Queensland, to enable creeks to be crossed until the bridges were completed. These grades had been used without accident. Wellington, in his book on "Economic Railway Location," severely criticised the use of spiral curves on the St. Gothard approaches, as equally good grades could have been obtained without them, and their use savours of an ostentatious display of skill by the engineers who used them. Mr. Stephens said that he had himself been looking for an opportunity where he might reasonably employ a spiral, but had always found that he was able to do better by means of open looped location.

In Australia most railway lines leading from the coast to the interior cross a coast plain with easy grades, then climb a steep range followed by country with easy grades. He considered it very desirable to pay great attention to properly locating the line on the range, so as to obtain easy grades, as although this length of line may be costly per mile, the extra cost per mile for the whole length of line will be small.