

NOTES ON THE FIELD WORK
RAILWAY LOCATION.

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INTRODUCTORY.

The author proposes to deal with Railway Location, as distinguished from Railway Surveying, and the details of the final or permanent surveys before construction will not be discussed.

Some attention will be given to the methods employed in surveying, as far as they are applicable to Location; but these and the instruments used are only a means to attain the desired end, and, provided that this is accomplished, nothing else is of vital importance.

The selection of suitable methods of work will result in large savings of time and expense.

The actual work of location may be divided into three parts or stages—Exploration, Preliminary Surveys, and Final Traverse and Location.

Of these, the two first are the most important, and make the largest demands on the knowledge and skill of the Engineer.

They may be considered as an art rather than a science, as the personal equation is a controlling factor.

The third stage consists of much purely mechanical work, but nevertheless, provides much scope for the application of judgment and experience.

This paper has been written practically without reference to text-books, but acknowledgments are made to two authors from whose works the writer has received much enlightenment and assistance in the past.

The two works referred to are: Wellington's classic treatise "The Economic Theory of Railway Location." and a smaller book, by Gribble, on "Preliminary Survey and Estimates."

I.—EXPLORATION.

This will generally be limited to a rapid examination of the country, from the starting place to another fixed point, or in a given direction, and is quite distinct from the minor explorations, which will be necessary in the second stage of the work.

The object of the exploration is to determine, within reasonable limits of error, the length and cost of the proposed line, and the grades and curves which will be necessary.

The selection of a route for actual survey will largely depend on the results of this exploration, which should therefore extend over as great a width as the time available will permit.

It will usually be better to make a rapid examination of two or three possible routes than to spend the same time and labour on the first line, which appears practicable. The best map of the district, which can be obtained, should first be carefully studied. A line should be drawn between the two ends of the proposed railway and the position of all main roads, rivers, principal watercourses, and mountain ranges, examined with reference to this line, so that a fairly accurate picture of the chief features of the country can be carried in the memory.

If the map is a good one, and the elevation of a few main points is approximately known, it may be possible, before leaving the office, to select several routes for examination.

When previous surveys have been made in the locality, much useful information may be obtained from them.

The exploration may then be commenced, and may be made in a vehicle, on horseback, or on foot, according to circumstances, and the services of a guide, with a good knowledge of the country, may prevent much loss of time and delay.

The instruments necessary for the work are an aneroid barometer, a compass, and an ordinary watch, to which may be added with advantage a hand level, the line of sight of which can be accurately set to any desired grade.

A roomy notebook and the aforesaid map will complete the outfit.

During the first examination it is not desirable to spend too much time over details, the main object being to obtain a knowledge of the principal features of the country as far as they are likely to control the location.

Aneroid readings should be taken frequently at river crossings; depressions, gaps in ranges; saddles and summits of road grades; and the corrected elevations should be marked on the map. The method of taking, recording and correcting these readings will be fully explained in the section on preliminary surveys.

Any alternative lines which appear to be practicable should be examined in the same way, and a route for further examination may then be selected. The map should now show a chain of points, whose elevation is known, and which are so selected that

a uniform grade between two consecutive points could be obtained without rising or falling unduly above or below the surface of the ground between them.

The steepness of this grade is not of primary importance, as there are several expedients by which the length of the line may be increased in order to flatten the grade.

Having selected the route which appears most promising, it may be possible to divide it into sections of varying difficulty. It is not uncommon to find two long stretches of easy country divided by a high and steep range, in which case it is obviously desirable to decide on the grade most suitable for the greater part of the line, and to make every effort to carry the same grade through the mountain section.

The expenditure, which is justifiable for the purpose of obtaining easy through gradients, will depend upon the object for which the railway is projected. In the case of a short branch line ending in a "cul-de-sac," which is never likely to be extended, steep grades will probably be adopted, unless the traffic is likely to be exceptionally heavy.

On the other hand, large increases in the first cost of portion of a line, which may ultimately form part of a trunk railway, will not make the average cost per mile much greater, and will almost certainly be repaid, by lessened working expenses and larger facilities for handling heavy traffic.

The choice in rough country will probably be between grades steeper or flatter than about 1 in 60.

Considering a long ascent by itself, such, for instance, as might be required in the development of a mining proposition to connect mines with treatment works, or with an existing railway or port, it would appear that 5 miles of 1 in 40 will be cheaper both to construct and to work than 10 miles of 1 in 80.

It is true that train loads can be doubled on the latter, but if the speed is the same, the time of journey will also be doubled.

In descending, the extra length of the easy grade will be a disadvantage, and the charges for interest and maintenance will be increased.

This reasoning assumes that the 1 in 40 grade is naturally adapted to the country, and cannot be reduced without corresponding increase in length.

The selection of the most economical grade for any given case is a matter of great difficulty, and should receive careful consideration.

The grade having been determined, the map should be carefully studied, to decide what increase of length is required between any two controlling points, to obtain the ne-

cessary rise or fall. If the country is open, and proper attention has been given to the surrounding features, an approximate line can be laid down, and an estimate of cost, based on experience of similar lines, can be furnished without further examination.

In very rough or thickly timbered country, further explorations of the worst sections should be made, following the methods described in the section on preliminary surveys.

In estimating cost, it should be remembered that rails, sleepers, ballast, and sidings are to be considered as a fixed charge on each class of line, which is scarcely affected by the roughness of the country.

Earthworks, bridges and culverts, on the other hand, will vary in cost considerably.

The following figures may be of some use as a guide for preliminary estimates in Australia:—

Lines of 2ft. gauge, suitable for mining development, can be built through quite rough country for about £2000 per mile. Standard gauge lines, without ballast, have been constructed in New South Wales for between £2000 and £3000, but the present tendency is for a better class of line, and it is not likely that these can be built in the easiest country for less than £4000.

Heavy earthworks may increase these figures largely, but the cost should not exceed £7000, unless the country exceptionally difficult.

Practicable Grades.—The steepest grade which can be satisfactorily worked with adhesion locomotives, may be put at about 1 in 20, but should not be more than 1 in 30 for lines intended for passenger traffic.

The use of a rack rail, as in the Abt. System, of which the author had three years' experience, will enable the grade to be increased to 1 in 12 or 1 in 15.

The effect of the inertia of a moving train in reducing resistance of short grades, should always be considered. This question is fully dealt with by Wellington, and it is only necessary to point out that in undulating country, steeper grades may be used than in a long ascent.

Curves.—The smallest radius of curve which can be used, will depend upon the gauge of the line, and the type of locomotive and rolling stock to be employed.

The maximum axle-loads will vary approximately with the gauge, and help to fix the minimum radius of curve.

The three gauges of which the author has first-hand knowledge, with the usual or probable wheel-loads, and the radius of curve which has been found unobjectionable, are given below.

Gauge	Wheel load	Radius	Remarks
2ft. 0ins.	2 to 2½ tons	1½ chains	Various Mining Tramways
3ft. 6ins.	4 to 5 tons	5 „	Queensland Railways. Mount Lyell Railway
4ft. 8½ins.	8 to 10 tons	10 „	N.S.W. Government Railways

These figures show approximately the relation between gauge, wheel-load, and radius of curve, and it may be noted that the radius varies approximately as the square of the gauge.

If the wheel-loads are much increased in any particular case, very heavy wear may be expected on rails and flanges, unless the radius is enlarged proportionately.

Gauge.—It is not proposed to discuss the merits of various gauges in detail. In the case of an isolated line such as a mining railway, quite heavy traffic can be carried on the 2ft. 0in. gauge, including heavy machinery and material, and the low cost of construction favours such a choice.

Where a branch line is run to connect with an existing line of standard gauge, the cost of transshipment of the anticipated freight from on the narrow gauge, should be set against the annual charges for interest and repayment of increased first cost of a line of standard gauge.

Each case must be considered on its merits and decided accordingly.

II.—PRELIMINARY SURVEYS.

We will assume that as a result of the exploration described, a trial survey of the line is to be made. For the purpose of illustration, the hypothetical case previously mentioned, of a mountain range separating two stretches of easy country, will be dealt with, and the methods to be adopted in the survey discussed in detail.

A further rapid examination of the explored line should first be made to verify the conclusions arrived at after the exploration.

Any alternative lines which have been overlooked or neglected, should be examined, and a route should be finally selected for survey before the detail work is commenced.

Enquiries should be made for any gaps in the range that have not been noticed, and the previous exploration checked and verified as far as possible.

A few days devoted to this work will seldom be wasted, and at the worst, we will have gained the knowledge that the first route is the best available.

On the other hand, if a better route can be found, it is well to find it before any actual surveying is done, and there will be less risk of having to abandon a line on which much money and time have been spent.

It is not unlikely that expenditure already incurred might prevent the adoption of the better line.

By assuming that the explored line is *not* the best available, and entering on the preliminary survey with the intention of finding the better line which probably exists, the Engineer has greater chances of success than if he follows blindly in his own or another man's tracks.

A route having been finally selected for survey, the mountain section should be examined in more detail, in order to determine whether the direction of approach through the flat country is approximately correct; and to decide this with certainty, it will be advisable to roughly grade a line from the summit to the foot of the range. In open country it is possible, with some practice, to walk or ride approximately on the grade desired, using aneroid heights and time measurements of distance at intervals of about 20 chains, as a check on position. Any corners of properties, marked trees, or fences should be noted, and compass bearing to visible landmarks taken where possible.

When it is desired to pass through a particular gap, the grading should be started there, and carried down hill. This rule should generally be adhered to, except in the rather unusual case of a range with a level summit, which can be crossed at any point. It may then be advisable to start at the bottom and work up.

The methods used in this examination will vary according to the nature of the country. The author has been able to grade, with some accuracy in rough country, with the aid of an aneroid alone, but prefers a modified form of the ordinary hand-level or clinometer, arranged so that the line of sight can be accurately set to the required grade, and used in the following manner:—

The observer, standing at the summit of the range, or at such a height as will give the desired cutting, sends a man forward to some convenient distance, and then waves him up or down the hill until the line of sight cuts his body or face at the same height above ground as the observer's eye. The spot on which the man stands, may be marked with a stake, to which the observer moves forward and takes up his new position.

The operation being repeated as often as necessary, the grade is carried through to the level country.

Particular attention should be given to the general direction of the line and the nature of the country.

Care should be taken that allowance is made for curves of the desired radius when rounding points or turning in the heads of gullies. Practice alone will enable the Engineer to determine whether a given curve can be fitted to any particular valley or spur without excessive earthwork. If there is any doubt about this, provision for the probable shortening of the line may be made by reducing the grade at suspicious angles, or by introducing a few chains of level at these points. In ordinary country it is not likely that the grade will be shortened more than 25% by fitting in the curves, and it will generally be sufficient to reduce the grade by this amount at the worst points. The hand level described will do remarkably accurate work, and the author has frequently run grades several miles in length in this way, and finished with an error of a few feet only.

As much as 6 or 8 miles of grading can sometimes be done in a day if the country is open and not too difficult, and a good knowledge of the ground is thus obtained.

A Theodolite is frequently used for preliminary grading, but the loss of time in setting-up, the physical exertion of carrying a heavy instrument over rough ground, and the close attention which the instrument demands, all tend to distract the Engineer from the real object of his work, which is rather to enlarge his knowledge of a wide belt of country on each side of the line, than to mark out a mathematically exact grade, which will later be freely departed from.

In very rough country, a traverse with compass and chain, however roughly and rapidly made, will show at a glance whether the grade as marked out will be practicable with the curves demanded.

In grading down a long spur, note should be taken of any gaps or saddles which are passed. If the spur begins to fall away faster than is desirable, it may be possible, by returning to such a saddle, to pass to the other side of the spur, turn back towards the starting point, and head the next valley, which is then followed to the end of the grade.

This is the simplest form of "development," and it will be noticed that the higher ground is always kept on the same hand. An example is shown in Fig. 1, in which the first unsuccessful attempt ended at A, where the spur is too narrow to be turned with a curve, and the valley below too deep to be crossed.

It is quite possible, when the desired grade is flatter than the country favours, that a long development of this kind will carry the line too far to one side of the point B, through which it is essential that it should pass.

A case of this kind is shown by the dotted line in the figure, where the grade ends at H, on about the same level as B.

Here the length BH is of no assistance to the grade, and adds considerably to the cost of construction.

It may therefore be necessary to look for an opportunity to introduce a development of another form, which requires much more skill and experience than that described.

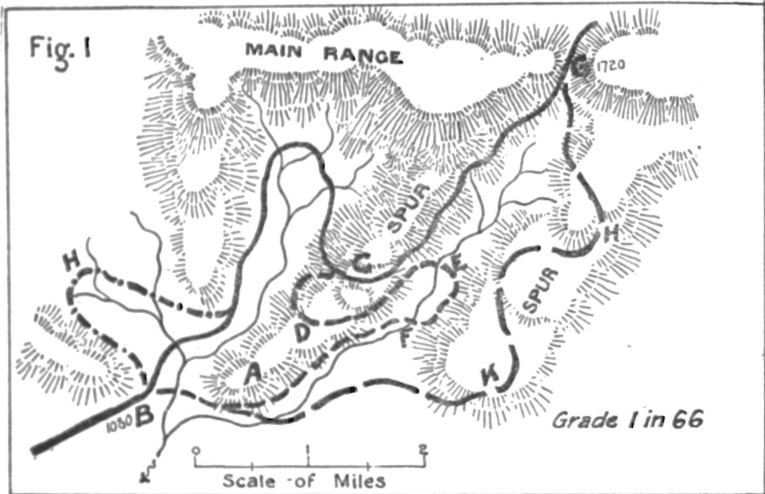


Figure 1 shows a second line in the same country as the first, and of approximately the same length.

The line passes, as before, through saddle C, but bears away from the main range, crosses the spur again at D, and at E, turns in the valley, which is crossed a second time at F.

The double crossings of a single ridge or valley are characteristic of this development, and it should be noted that the ground falls by turns to the left and right

In the case illustrated, a valley runs from G to B, in which the required grade can be easily obtained from B to E, but which rises too rapidly between E and G.

A satisfactory line has already been obtained from G to C, and the length required in the loop CDE is dependent on the difference of elevation between C and E.

The possibility of a development of this nature can seldom be discovered by running grades, but a careful study of the map, aided by an active imagination, will be likely to produce a satisfactory solution, and prevent the abandonment of a good line, or the unnecessary sacrifice of an easy grade.

Two variations of the foregoing may be mentioned here:-

The Zigzag used by our early Engineers in the Blue Mountains, need not be described. It has the great merit of providing whatever length is required without departing too far from the straight line between terminal points; but causes considerable risk and delay with heavy traffic.

The substitution of loops for the dead-ends of the Zigzag, which will usually involve long tunnels, gives an extremely useful variation of the second form of development, and enables any desired grade to be obtained in the very worst country.

This method is applicable not only to steep hillsides, but also to gentle slopes rising somewhat more rapidly than the desired grade.

An instance of this kind is given in Fig. 1, where the slope of the ground on the dotted line GHK is 1 in 50, and the grade is fixed at 1 in 66. The length is increased in the manner shown by successive crossings of the flat ridge. The third-class of development is the spiral, and is usually a desperate and costly expedient. It has been used a good deal by American Engineers, whose employment of very high timber trestles, cheaply constructed of material obtained close to the work, has given opportunities not available in other countries.

The examination which precedes the more detailed work of the preliminary surveys, should be continued until a route has been selected, which appears to be the most suitable.

Developments of the first-class should be carefully explored, and recourse need not be had to the more difficult forms unless they are absolutely necessary, or promise a considerable saving in cost.

The author is opposed to the use of precise methods until the possibilities of the country have been exhausted by exploration and grading.

On the other hand, this preliminary work should be so carried out as to give a definite result, and no pains should be spared to obtain this. It is not sufficient to wander aimlessly over hills and valleys and conclude with the vague hope that some kind of line will be found when the theodolite is brought into action. Such a course may involve the surveying of lines, which finish up against obstacles, and have to be abandoned.

The spiral can be used with advantage where a long and narrow ridge gives the only possible hope of a successful location and, like the Zigzag, with looped ends, will enable any desired length to be secured, but at the heavy expense involved in the construction of long tunnels.

It may often be necessary to make two or more alternative traverses of the whole or a part of the line, and to carry these out in full detail; but a survey, bristling with dead-ends, is seldom a credit to the system employed.

The examination having been concluded, the more accurate methods should now be applied. A traverse should be made of the explored line, a section taken along the traverse and the slope of the ground on both sides should be measured.

This result may be obtained with the maximum of labour with the theodolite, chain and level, in three distinct operations. The same ground has to be covered three or four times, and this method, which is in general use, cannot be recommended, except for the final traverse, on which the permanent survey is based, and will therefore be described in detail when that stage of the work is discussed.

The Theodolite, fitted with Stadia wires, and as many specially graduated staves as there are men in the party, will enable all necessary information to be obtained as the traverse proceeds.

The accuracy of the work, if properly carried out, will be such that no errors will be large enough to be visible on the plan.

The methods of obtaining such accuracy will be described presently, but the object in view is to obtain the elevation of a sufficient number of points on the centre line, and for some distance on each side of it, to enable a complete contour plan to be made if required.

If the work is properly done, it should never be necessary to set up the instrument more than once at each station, and a check will be obtained on the levels at the end of each day's work.

Instruments and methods of work applicable to the preliminary survey will now be described.

The Aneroid is indispensable, and when used with due precautions against errors due to atmospheric changes, will give quite accurate results.

Books on surveying generally emphasize the importance of correcting readings for changes of temperature, but unless two instruments are used, one of which is kept under continuous observation at a base, while the second is carried to the points whose elevation is required, these corrections may be safely omitted in Railway work.

An observer can seldom be spared for the stationary instrument, and the two should be compared night and morning, which can hardly be managed when the exploration is being carried through a long distance in a short time.

While corrections for temperature may be neglected, those errors due to changes of air pressure should be guarded against. The most important of these, inasmuch as it is of daily occurrence, is caused by the Diurnal Barometric Wave, a regular rise and fall of pressure occurring twice in twenty-four hours, which, as far as the author knows, is not mentioned in any text-book. The existence of this wave is well known to meteorologists, and it can be plainly traced on any Barograph records. A diagram of the Indian wave is given in Molesworth's Pocket Book without comment.

In New South Wales, the wave is of such a form that corrections between 8 a.m. and 6 p.m. are quite easily applied.

Mr. Kennedy, Engineer for Surveys in the Public Works Department, informed the writer some years ago that it was his practice to deduct 10 feet from the recorded height for each hour after 8 a.m. And this has given satisfactory results.

Working in North Queensland, where the variations are very regular and large, changes are rare; the author constructed a curve from actual observations, and obtained the corrections for the Diurnal Wave from the diagram.

A further source of error, more dangerous than the last, is that due to the great changes of pressure, which are shown by the movement of Isobars across the daily weather charts of the Commonwealth.

If the observer can return to his base each evening, the change can be noted and distributed over the day's readings without a separate allowance for the Diurnal Wave.

In the course of an extensive exploration which is being carried forward continuously, this method is inapplicable; but a useful check can be obtained from the weather charts of the daily papers, a series of which, covering the full period of the survey, should be obtained.

This method was applied to some observations extending over several days, during which large changes of pressure occurred with the results shown in the following table, and while it is seldom that such accuracy can be obtained, it is evident that errors will be greatly reduced by its application.

Place.	Time	Date	Aneroid reading	Barometer from Chart	Correction	Corrected height	Actual height	Error	
A	a. m. 9.0	2/5/13	440	30.2	0	440	442	+2	
B	p. m. 1.15	"	245		70	175	173	-2	
"	a. m. 8.0	3/5/13	300	30.05	130	170	"	-3	
C	9.20	"	340		140	200	206	-6	
D	9.20	4/5/13	290	none	270	20	19	+1	
C	p. m. 3.40	"	560		350	210	206	+4	
D	12.15	6/5/13	290	30.00	260	30	19	+11	
E	12.45	"	290		268	22	10	+12	Newcastle
F	2.10	"	285		234	51	41	+10	Wyong
G	3.30	"	850		250	600	594	+6	Hornaby

} In train