

## SECT. II.—OTHER SELECTED PAPERS.

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(*Paper No. 4318.*)

“ Railway Location.”

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THE purpose of this Paper is to describe and recommend a system for carrying out railway location work.

In deciding what the strength of a survey or locating party should be—a point on which much difference of opinion exists—there are three main elements to be considered, namely :—

- (a) Whether the route to be located is over flat, undulating, or mountainous country ;
- (b) Whether the progress of the work is to be hurried, or to be proceeded with normally ;
- (c) Whether the party is permanently or indefinitely in commission or not.

It has been the experience of the Author that, from the time authority is given to commence work, rapid progress is urged from headquarters. A chief of party will, therefore, be well advised to obtain a reasonably strong party of assistants, as, if the party is well handled, a saving of time must result.

The basis of a scheme of railway extension is the work of the locating party ; an inefficient unit not only takes considerably longer over that work, but may be, and generally is, a means of wasting many thousand pounds. The work, however, should not be unduly hurried from headquarters as, frequently, an extra £50 spent on location will save £1,000 on construction and often a permanent charge on maintenance and running.

Five is an economical number of assistants for ordinary work of lengthy duration, although this number might be reduced should the zone of a proposed extension be flat and heavily wooded ; on

the other hand, if a study of alternative routes is essential it may be increased with advantage.

Of the five, the first three should be trained and experienced men, and the other two, although they need not possess such comprehensive knowledge, should, at least, be able to take charge of any instrument should necessity arise.

In the Author's experience, a location party's personnel is generally drawn from various engineering fields, such as constructional, and permanent-way men, draughtsmen, and quantity surveyors, some of whom are on railway location work for the first time. Such being the case, the chief of the party will do well to spend 2 or 3 days at his base of operations in finding out the qualifications of his assistants, and incidentally in training his labourers or "peones" in chaining, holding staves, giving double points for the transit, etc. He will find that mistakes of many kinds occur within the first few weeks if the party is new to the work, and that a couple of days thus spent are well invested, as it is useless to attempt to accelerate progress until individuals become familiar with one another's duties. If the chief is in the happy position of being able to select assistants, he should, if possible, choose those who possess amongst them a knowledge of the following additional subjects:—Photography, geology, mineralogy, chemistry, agriculture, meteorology, elementary astronomy, and well-boring. A knowledge of Army signalling will save much horseflesh and time. All assistants should be able to ride and walk well, be sound in health, active, and able to swim.

Before leaving the headquarters of the railway, the chief of party must obtain from the Chief Engineer the general object and route of the proposed extension, the ruling curvature and gradient, the limiting radius of untransitioned curves, and his suggestions on maximum cuts and banks. The chief must bear in mind that any deviation may result in increased working-expenses with possibly the risk of commercial failure, especially should the proposed new route be a competitive one.

The chief will find out what types of bridges and culverts are in vogue, the class of track, turn-outs, and the standard plan of station-yards. He should obtain such plans of the district as may be in existence, together with information concerning it; also the latitude and longitude of the proposed point of "take off" (which should be checked upon the ground), the reduced rail-level of that point and a profile of existing track in the vicinity. He should then proceed to carry out the reconnaissance, taking with him for preference his second assistant, leaving his first with instructions to arrange the details of fitting out the party.

The operations of locating a proposed railway may be divided into four steps:—

- (1) Reconnaissance or exploration.
- (2) Preliminary line or lines.
- (3) Trial location or locations.
- (4) Final locations.

(1) *Reconnaissance*.—The method of carrying this out will depend on (a) the amount of knowledge possessed of the district to be opened up to railway communication; (b) the configuration of the country. The most difficult country to study is that which may be described as undulating, where optical illusions occur, and an easier gradient is expected than will eventually be obtained.

Alternative routes will present themselves, and, unless the chief of party can satisfy himself by the aid of hand instruments which is best, he will be compelled to locate preliminary lines; should the country be wooded, his difficulties are considerably increased, whereas in mountainous configuration his attention is almost wholly confined to valleys of suitable orientation, and in flat country to the avoidance of areas liable to floods.

Should the district be comparatively unknown, trouble and delay will be saved if the bearing of the proposed railway route is chosen to form the approximate course of reconnaissance for the distance to be penetrated. This base-line should then be followed with the sketch-board from eminence to eminence, distances being estimated by the pace of the horse (all reconnaissances should be carried out at a walking pace). At every eminence bearings should be taken on to all outstanding physical features, and lateral detours should be made in order to sketch in the salient topography, with remarks as to soil, vegetation, etc. Barometrical readings, with the shade temperatures of the intermediate air, should be observed periodically, and at all crowns and depressions, for the purpose of constructing a profile of the line followed.

The chief will find it advantageous to keep his assistant on the objective bearing, whilst he deviates to both right and left, this system being continued until the distance of the proposed extension has been covered. Each evening the barometrical altitude should be checked with a hypsometrical reading, for the aneroid is unreliable if long intervals of time elapse between observations. The Author recommends that, in addition to the two aneroids in use, a third should be carried for the purpose of a check, also that a careful man should be left at the railway take-off (i.e., at the known reduced level), with one or three aneroids whose readings

should be recorded every hour between sunrise and sunset, together with notes as to wind, clouds, temperature; this will be for subsequent comparison with those of the reconnaissance party, to reduce the meteorological oscillation to a fixed level.

On the return journey the party should be divided, the chief and his assistant returning by courses parallel to the outward route, a few miles to the right and left of it respectively, again recording the physical features of the country by compass and aneroid, and never failing to observe any visible points that were recorded when on the outward journey. On the return to the starting-point, sufficient information should have been collected to enable a report on the reconnaissance to be written that will recommend a route or routes to be studied by preliminary lines, and at the same time give an idea whether the prospects are favourable for the ruling gradient; the class of country traversed; its geological formation, rivers and streams to be crossed; with descriptions, traffic prospects and an approximate estimate of the length and cost of the proposed extension.

If a reconnaissance has to be carried out in mountainous country, chief attention must be paid to valleys with suitable orientation, noting narrow partitions between valleys with geological faults in places where tunnelling might be necessary. Wherever possible, the route of perambulation should be along the higher altitudes so that the greatest advantage may be taken of opportunities of viewing the configuration; bottoms of depressions and valleys should, however, be visited from time to time.

In extensive flat country special regard must be paid to dry lagoons and areas liable to flood, as it must be remembered that in some climates long droughts occur, and the unpractised eye may fail to observe large areas which in wet seasons will become sheets of water with sluggish currents.

Railway banks intersecting such country will eventually suffer disaster if sufficient openings are not allowed, and the flood-water on the up-side is likely to be impounded, accelerating the velocities at the openings. The Author's experience is that in such cases it is not the weight of the impounded water that causes the banks to give way, but wave-action due to wind, or scour on the lower side of the bank, caused by water overflowing the rails. The experienced locating engineer will know the higher lands from the slight difference in colour of the pasture, by the class of vegetation, and possibly by the remains or marks of a previous flood; but he will be wise to seek information on this and other points from the older inhabitants of the district. In cultivated

and closely-fenced country the most advantageous intersection of properties must be considered in sympathy with proprietors, whose claims must be respected.

In the interests of economy, a chief of party must keep the field-work continually in progress. The practice of carrying out field-work in the forenoon, and the plotting and calculations in the afternoon, is to be deprecated. The Author is of opinion that the practice of keeping an able assistant—not merely a draughtsman—continually occupied in the drawing-tent, where, if an intelligent and quick man, he will cope with the whole of the plotting of the field-work, and, in addition, will assist his chief in calculations and projections, is the better and more economical arrangement. Each assistant should be responsible for the correct adjustment of his instruments. It is not sufficient to adjust for collimation alone; the plane of rotation, horizontal bar, line of sight, and bubble-tubes must be corrected. A little reflection on working conditions in unknown country will emphasize this necessity. Aneroids and prismatic compasses should have their index errors noted before use, and chains, steel bands, tapes and staves should be tested before leaving headquarters.

The designation of assistants in order of seniority is advisable, as, when various sections of a field-party are working in combination, such incidents as the tacheometer or levels overrunning the transit, the check leveller overrunning the leveller, and so on, cause confusion and friction between individuals and interfere with the progress of the work; further, should an engineer be absent, the question of the discipline of the party is automatically solved. An engineer when delayed should employ himself in reducing his field-book; levellers especially, who suffer from delays, should avail themselves of such opportunities in order to determine the gradient in case it should be urgently required. Each assistant must reduce his field-book before handing it in at the office tent, and the reductions, which for an expert man should not take more than  $\frac{1}{2}$  hour, when not already done, ought to be completed during the evening. The practice of persuading the office assistant to effect the reductions is reprehensible.

The first assistant or transitman is responsible for the field-party leaving the encampment punctually in the morning, but he is not responsible for the equipment of other assistants. A good working system is for a list of the technical equipment required to be given to the ganger overnight, although this practice should not relieve each assistant of his individual responsibility.

The transitman should determine the luncheon place, inform his chief, and give the necessary instructions to the quartermaster.

(2) *Preliminary Lines.*—These are most advantageously carried out with the transit instrument in conjunction with the tacheometer. The degree of accuracy required for both distances and altitudes is well within the capabilities of these instruments and should not exceed 0·20 metre vertical and 10 metres horizontal per kilometre. A high degree of accuracy involves a sacrifice of speed, and is unnecessary for preliminary work.

This error may be doubled without materially affecting the projection for a trial location. The saving in labour, as compared with the system of theodolite and chain, with cross sections, is more real than apparent.

In the first case the following strength is needed (Appendix, Table II):—

Transitman.	Peg and Spademan.
Tacheometrist.	6 Rodmen.
2 Flagmen.	2 Orderlies.

as compared with—

Transitman.	Peg and Spademan.
2 Levellers.	Topographer.
2 Chainers.	4 Rodmen.
2 Flagmen.	2 Orderlies.

which means a saving of one engineer and one labourer in favour of the tacheometrical method, the outstanding advantage being the rate of progress, which is increased by between 50 and 100 per cent.

The office-work resulting from the use of the tacheometer is more laborious than that of the level-book, which balances and checks itself; but the Author has introduced a graphic Table from which the reduced level may be pricked off from the angle of elevation or depression, and the difference of the hairs (Appendix, *Figs. 3 and 4*), thus entirely dispensing with the use of Jordan's or similar Tables.

The tacheometer is not designed for a high degree of accuracy, and a matter of 0·05 metre in altitude on a preliminary line, and a similar amount in the reduction of the reduced level of intermediate observations, the error of which is non-accumulative, is of no account in practice. The change-points (*Fig. 1*), however, should be observed both ways in the field and should be reduced accurately. All tacheometrical reductions should be checked, as, in reading off the Tables, it is as easy to make a mistake of 5 metres as of 1 centimetre.

The engineer who is not conversant with the tacheometer is likely to disapprove of its employment; but, having once used it, he will not care to return to the system of cross sectioning.

If the tacheometer is not adopted, the survey of preliminary lines through country where the gradient is assured resolves itself into tracing the line with the transit, and cross sectioning on either side with levels. In heavy country the transit will set the ruling gradient; but, should the changes of direction be great, allowance will need to be made for compensation for curvature, and the transit must reduce its angle of gradient accordingly; otherwise, it will be found that the projection for the ruling gradient on the trial location will not fall or rise sufficiently to be contained within the zone of cross sections, and the work will consequently be wasted.

Reference to *Fig. 1* will give an idea for carrying out a preliminary line on the tacheometrical system, and it will be noticed that mounted flank topographers are introduced in order to cover a belt 3 kilometres in width in open country: this will almost invariably result in the supply of sufficient data for the projection of a trial location.

The system described has the merit that one preliminary line is generally found to be sufficient, that an advantageous deviation from the centre-line is anticipated, and that the resulting trial location will, in all probability, remain as, or be approximately, the final location.

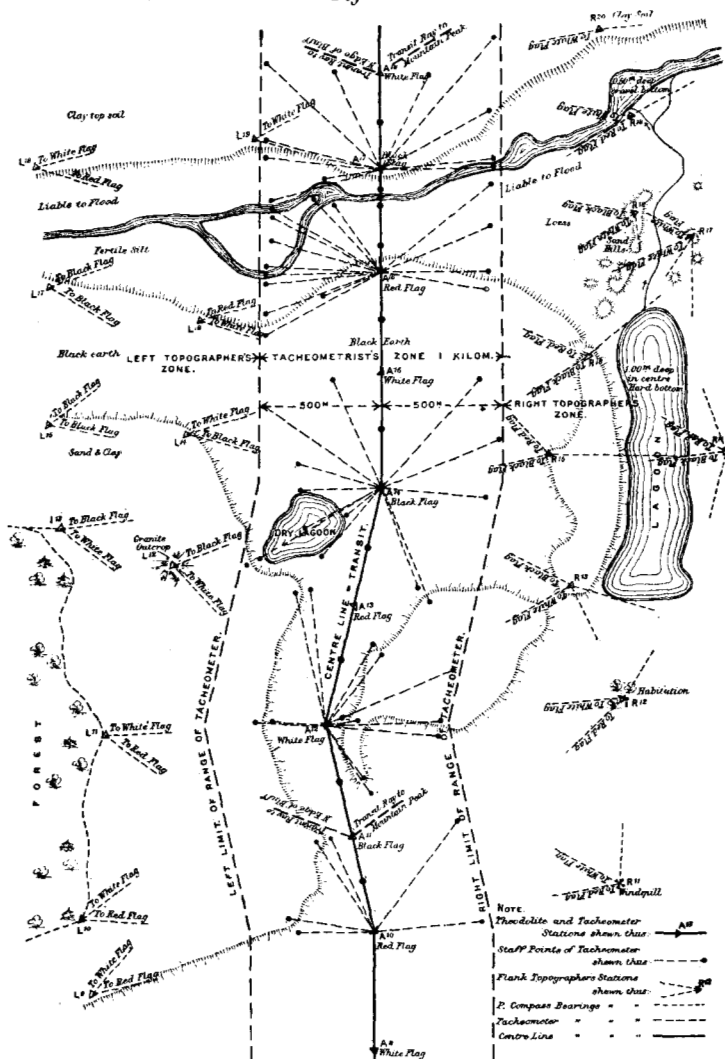
The progress of preliminary lines with an efficient party in open country should be not less than 5 kilometres per day. Each engineer should have two field-books, for alternate use, one of which will be in use and the other in the office at the encampment, in order that plotting may go forward with field-work.

The plotted field-books must be obtained from the office before unplotted ones are sent in, to ensure that, in case of delay to the messenger, the use of scraps of paper containing data is avoided.

When preliminary lines have to be carried over flat country to a fixed point, such as a bridge-site or railway-connection, and especially if heavy brushwood or forest intervenes, it is a satisfactory practice to send forward an assistant with three to six rockets, which should be fired at night at a prearranged time, when the bearing will be observed by the transit-man. This method is reliable for about 12 miles on equal altitudes, but with rising ground for the objective it may be adopted up to any reasonable distance provided the rise more than compensates the earth's curvature.

*Individual Duties on Preliminary Lines (Fig. 1).*—The chief of party indicates the route.

*Fig. 1.*



RAILWAY LOCATION, PRELIMINARY LINE. EXAMPLE OF FIELD-WORK.

The first assistant, or transit-man, who is in charge of the field-party, traverses the course indicated, keeping his change-points at



intervals of approximately 500 metres. He numbers these points in sequence  $A^1$ ,  $A^2$ ,  $A^3$  and so on. At the index letter A of this particular preliminary line, he drives a light wooden stake and marks it with red pencil. He instructs his front flagman to plant ranging poles at these points, carrying red, white and black bunting alternately, so that the flank topographers, described later, may be enabled to take prismatic compass observations with no risk of mistake. In addition to the work of tracing the centre-line and recording the topography in the vicinity, with estimated distances, he should take observations of all salient points, in order to relieve the tacheometrist of any work beyond that of recording data for the projection of profiles.

The second assistant remains at the encampment and plots the field-work as it progresses. It is his duty to reduce the tacheometrical observations and revise the level-books, which should be initialised by him as correct, as should also each page, when once the contents have been plotted. He is responsible for the record of meteorological observations, morning, noon, and night, and is in charge of all work pertaining to the office.

The third assistant carries out the tacheometrical observations. His base points will have been determined by the transit-man. He should keep two of his rodmen always on the centre-line for the backward and forward readings of base distances, and his remaining four men should be divided, two on each side of the centre-line. The radius of observations, with staves graduated to 10 centimetre divisions, extends to 500 metres. It will be observed from *Fig. 1* that detail observations are taken at every other station only, i.e.,  $A^{10}$ ,  $A^{12}$ ,  $A^{14}$ , etc., the intermediate ones being change-points through which to carry on the tacheometrical levels and distances.

The duties of the fourth and fifth assistants are identical, one taking the right-hand side of the centre-line and the other the left. Each should keep about 1 kilometre from it when range of vision allows, and should record with prismatic compass and aneroid barometer all topography of importance contained within a belt of land 1 kilometre in width which his course intersects. The inside limit of each zone will, therefore, abut on that of the tacheometrist. The temperature of the intermediate air should accompany all aneroid observations in order to make the necessary correction when reducing for altitude.

The station-points have been flagged (as mentioned above) so that these topographers may observe them from convenient hillocks, or other points of vantage, within their respective zones. The index error of both prismatic compass and aneroid, as compared

with the centre-line, should be distinctly marked in red in the topographers' field-books. Reference to *Fig. 1* will elucidate their mode of procedure, progress, and co-ordination with the tachemetrists.

(3) *Trial Location*.—A trial location is the tracing, on the ground, of a projection which results from a preliminary line.

The preliminary work having been plotted to a scale sufficiently large to interpolate contours of 1 metre altitude, a *paper* location is projected, either directly on to the squared paper plan or, to save confusion of lines, on a covering tracing-paper. Experts will probably prefer to lay their projection directly on the original plan, but the less experienced will do well to project on tracing-paper. The chief of party will often be able to leave the field-party for half a day, having previously determined points ahead of the transit to keep the party employed, when he must carry out this work of projecting the trial location. He will find that his first projection can be best traced on the plan by setting the dividers to some convenient distance, say 100 metres; then, if his ruling gradient is 1 : 100 or 1 per cent. he should intersect the metre contours with the distance contained by the dividers, making any necessary allowance for compensation where curvature has to be introduced. The Author has compiled a Table for these allowances in order that the equivalent, according to the rate of compensation (or degree of curvature in American practice), may be projected without the hindrance of working each one out separately as it occurs (Appendix, Table VII).

When the initial projection has been completed in the foregoing manner, the profile should be plotted from the contours, which will demonstrate the cuts and banks; and his work will then be to reduce these to a minimum, allowing the banks to exceed the cuts in the ratio of 5 to 3. If these earthworks remain too formidable he must attempt further projections on the data supplied, until he obtains a satisfactory profile, failing which, he must try other preliminary lines; and, if there is no prospect of obtaining an improved profile, he has perforce to obtain a reduction in the ruling gradient and perhaps in the curvature. It is well to emphasize that the latter must be adopted to suit the speed requirements and the fixed wheel-base of the rolling stock, and it is safe policy to give as large a radius as possible in the minimum curve at the expense of an increase in embankment. The minimum straight between reverse curves should be sufficient to run off the superelevation, plus twice the length of the longest carriage.

In setting out curves, the Author has found that a considerable saving of time results if the detail is prepared in the

office, arranging the first full tangential angle of the chord to correspond to  $360^\circ$  on the vernier.

A satisfactory paper trial location having been obtained, it is traced on the ground by means of the transit (theodolite), level, and check level, only using pegs for instrument points and intersection points BC, CC and EC (beginning, centre and end) of curves. Each hundred metres of the chainage should be marked by a spit of earth and each kilometre by four spits of earth. It is convenient to add a spit of earth on either side of an instrument point.

The field-party is made up by the third or tacheometrical assistant becoming topographer to the transit, whilst the two flank topographers of the preliminary lines become leveller and check leveller respectively (Appendix, Table III). The chief of party should be in rear of the trial location, in order to see how his paper location reveals itself on the ground; he should especially note points of maximum cut and bank, river- and stream-crossings, proposed culverts, with detailed information to assist in the calculation of spans and headway, station-sites, level-crossings, etc.

Excavation should be made at the points of greatest cuts to at least their depths, also at proposed station-sites, recording the soils in each case.

The plotted trial location should coincide approximately with the paper profile from which it is derived. Minor improvements may suggest themselves in the tracing of the centre-line, and, if confirmed, should be adopted in the final location.

(4) *Final Location*.—The final location should be carried out on the principle of the trial location, except that a high degree of accuracy is to be observed. It should be commenced from the existing railway with zero at the tangent-point, or BC of the turn-out curve. All tangent-points, i.e., BC and EC, of curves should be staked on the ground with three hardwood pegs, a nail on the centre peg corresponding with the centre-line of the location. These pegs should be  $40 \times 5 \times 5$  centimetres. The intersection-point of curves should be staked by five similar pegs, a nail marking the point of deflection on the centre one. The stake at each 100 metres should be  $35 \times 4 \times 4$  centimetres, and may be of pitch-pine. Each kilometre peg and bench-mark peg at, say, 10 metres from the centre-line should be of hardwood and of the larger scantling. Each hectometre should carry its initial figure on a zinc plate nailed to the peg, and each kilometre peg its number in full in a similar manner. In addition, each 100 metres and instrument point should have a decided spit of earth turned up on each side of the peg; and each kilometre two spits on each side. These spits

enable the line to be picked up at any time during later months, but it must be remembered that, in most countries, after a year has elapsed the peg will probably be overgrown and the spit will have disappeared. The void, however, from which the spit was formed, will remain much longer in evidence.

The trial location should coincide with the final location for the greater part of its length. In wooded country the advantage of having a trial location based on a well-studied preliminary will result in the saving of much axe-work.

Topographer and levellers are employed as in the trial location. The former keeps the field-book and should measure accurately all topography within 150 metres of the centre-line; outside of that distance he need not concern himself, as for small scale plans there should be sufficient information in the data obtained on the preliminary and trial locations. The error between the leveller's and check leveller's results should not exceed 0·03 metre and on no account must this difference be reduced to a mean: their respective level collimations must continue throughout the length of the proposed extension without exceeding this error. It is a good rule that, when this difference is exceeded, the check leveller should go back to the last peg within the limit, and thence onward, the one who was in error should be the one to return and relevel when next an excessive difference occurs. Each peg, and not every other peg, is to be checked. Reading off the same staff by leveller and check leveller must be prohibited.

Each assistant of the party should record his opinion of proposed bridge- and culvert-openings in the margin of his field-book.

Throughout location the leveller should confine his attention to the centre-line, and, in addition to the 100-metre pegs, he must observe all crown-, bed- and flood-levels. The check leveller, in addition to carrying out the check, should take a short cross section at each kilometre and, on sides of hills, spot levels at 100 metres from the centre-line both up and down all watercourses, giving the bed, water, bank and maximum flood-levels. With regard to the system of levelling to be adopted, the Author is in favour of the Rise and Fall method as compared with that of the Height of Instrument, as in the latter the field-book may be reduced without exposing a possible mistake in the reduction of the intermediate levels.

The top soil must be frequently examined for the presence of salts, to guide the engineer in deciding between steel or hardwood sleepers when earth ballast is contemplated; bushes of various kinds peculiar to salt districts will assist the locating engineer in this.

On completion of the field work the chief should review all field-books and initial them; the work should then be plotted and the proposed line graded. On steep gradients, such as mountain or quarry lines, vertical curves should be introduced at changes of gradient.

When it is the duty of the locating party to prepare working-drawings, the chief must make himself conversant with the laws of the country as regards preparation of plans. When the plans are completed he should write a general report on the whole of the work, omitting no information that may be of use and interest. A synopsis of the knowledge and opinions expressed can be made should the document be too ponderous, whereas a restricted report cannot be amplified except by its author.

The efficient administration of the Transport and Commissariat is a factor all-important to success, and it should be in charge of a quartermaster responsible to the senior engineer for this duty and for camping arrangements.

*Soundings.*—Soundings are required for various purposes, and, although they are within the duties of the railway locating engineer, they pertain equally to those of maintenance and constructing engineers. They are indispensable for the location, design, and construction of moles, sewage-outfalls, piers, and breakwaters with their access channels, and from time to time, when the works have been executed, as a record of the presence or change of subaqueous silt and scour.

In rivers of capricious floods and currents, where the banks are low and of sandy formation, it is necessary to sound at least 1 kilometre above a proposed railway crossing, noting the currents and velocities, with their direction, and the water-levels on each day that soundings are carried out. In rivers such as the Tamar, at the Great Western Railway bridge at Saltash, and the river Neuquen at the bridge of the Buenos Aires Great Southern Railway, levels may differ considerably from one bank to the other, and the discrepancies may vary at different heights of the river, especially if it be one affected by tides. The engineer, therefore must be careful not to accept water-levels on one side of a river only for reducing the altitudes of his soundings. It is advisable to enclose the area of water under consideration in a levelled polygon, driving a peg at each vertex, from which the water-level may be recorded at any time.

The procedure in carrying out soundings varies according to the river or harbour to be sounded and the staff and means available. On railway reconnaissance work, the engineer will

probably be able to record only rough depths and information. In unknown country, if no boat is available, he may have to rely on swimming and diving for his preliminary information; the results will enable him to decide what equipment will be necessary (Appendix, Table VI).

If a river is fordable in all parts, the shallow soundings may be observed advantageously by tacheometry, but if not, a boat is essential, with a sounding party made up as follows:—

No. 1 or double oarsman.

„ 2 „ sounder.

„ 3 „ recorder to sounder.

„ 4 „ flagman and relief oarsman.

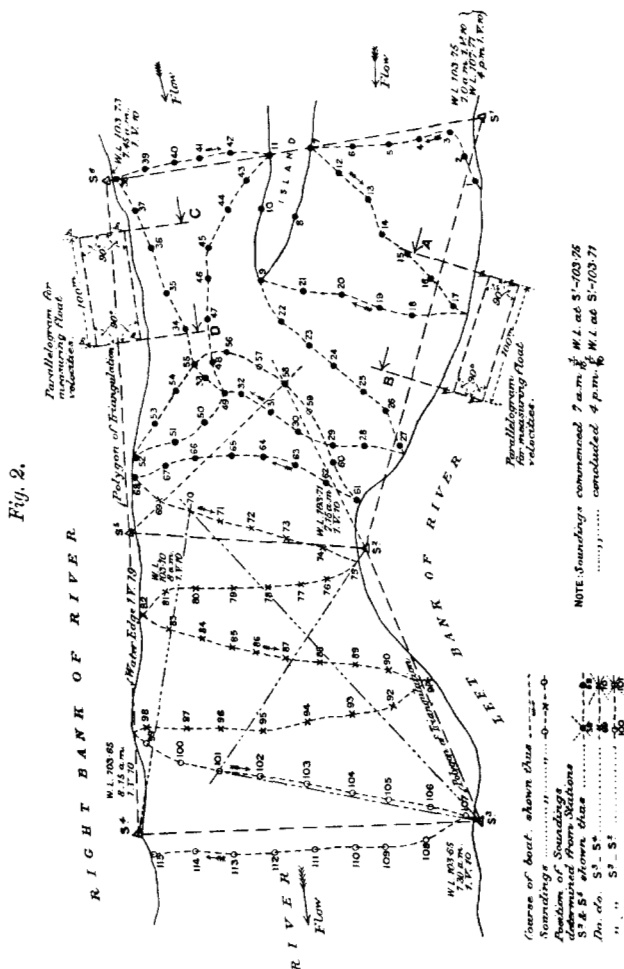
The chief of the party should be in the boat, in order to direct the course and positions of the soundings.

On shore, trigonometrical points which command the field of view need to be selected along the river-bank or edge of the harbour, at intervals of about 300 metres, and may be either the vertices of, or connected to, the polygon introduced for the purpose of water-levels, each point being lettered in sequence  $S^1$ ,  $S^2$ ,  $S^3$ , etc. (*Fig. 2*). Two assistants with theodolites are necessary, at stations which should be near to one another, each with the vernier clamped at its accumulated bearing, for facility when plotting, and aligned on the neighbouring point. The upper plates are then released in order to follow the course of the boat and to determine the position of each sounding by intersection. The depth of soundings should be measured with a pole or line. In rivers, especially with swift currents, the former is the more reliable, but in harbours, owing to the greater depths, the latter will have to be employed. Both must be graduated in the measure to which the soundings have to be reduced (sea work is generally in feet or fathoms, and railway work in foreign countries in metres), in order that the depths may be read off clearly and quickly.

The bottom of the sounding-pole or line should be encased in, or attached to, a lead shoe which is concave on its under side, the cavity being filled with grease, so that a sample of the river-bed may be obtained for analysis. The soundings should be taken at sufficiently long intervals that the assistants at the theodolites may have time to align the ray, read the vernier, record the observation, and return to the ready.

On being ordered to sound, No. 2 will let out the pole or line with alacrity and, as soon as it attains a vertical position, call out the depth, which No. 3 will record. No. 3 should also keep his eye

on the pole or line, to check No. 2. On sounding, No. 4, who should be seated next to and on the up-stream side of No. 2, raises his flag, a ranging pole with bunting attached, to a vertical position, thereby providing a definite objective point for the two theo-



dolites on the shore. Having allowed sufficient time for the instrumental observation, the flag is lowered until the next sounding is taken.

No. 1 should follow the course in such a manner that the bow of

the boat is kept as much up-stream as is compatible with progress (the slower the movement, within reason, in the required direction, the better), and thus nullify the effect of the current.

It is a good plan to record the soundings in groups of five corresponding with the observations of the engineers at the land stations: thus, at each termination, a prearranged signal is made and must be answered by the orderly in attendance at the respective instruments.

The positions of small islands and sandbanks may be determined by No. 4 landing and holding his flag at water-level at a number of points to be indicated by the chief of party, the engineers on land recording the positions.

The water-level of the river or tide must be recorded at a known point within each series of soundings in order to calculate the reduced levels. In tidal work this must be done every 10 minutes while soundings are being carried out, but on rivers it will generally be found sufficient to observe the water-level at the commencement and at the conclusion of the day's work (*Fig. 2*).

Current-velocities must be recorded on all important stretches, and it must be remembered that a surface or float velocity has to be multiplied by a coefficient, usually about 0.8, to obtain the mean velocity of the stream. These velocities will serve as a basis on which to calculate discharges, and the engineer will find it interesting to verify the value of  $n$ , the coefficient of roughness in Kutter's formula, from data at his disposal; it will assist him in determining the discharge at maximum-flood level.

Marine sounding, where river-currents have not to be contended with, may be satisfactorily carried out by substituting beacons or ranging-poles of distinctive colours, and by observing two subtended angles at the boat or raft by sextant, arriving at the solution on the three-point principle.

The chief of party must be careful in the case of rivers to navigate the boat so that the rays by the theodolites do not form ill-conditioned intersection angles; this also applies to the subtended angle in the case of the sextant in marine work. A flat-bottomed boat will be found best for river work, and one with a keel, with a larger number of oarsmen, for marine work.

River-soundings should be taken during the months of low water, i.e., when the current is at its weakest. The locating engineer should therefore obtain, at the Meteorological or Ways and Works Offices of the country, information on this head.

Should a steam or naphtha launch be available, the soundings are carried out in a similar manner, with the exception that No. 1



is displaced by a mechanic, and the duty of No. 4 is entirely manipulation of the flag.

The soundings are subsequently reduced to a common datum, making due allowance in their reduction for the fall of the river, and are plotted with a sufficient degree of accuracy by the use of a protractor. To attempt to determine the position of each point by trigonometrical formulas is unwarranted, seeing that the allowable horizontal or position error is about a metre. Should a sounding be required at any particular point, the boat must be anchored for the observation and its position ascertained trigonometrically. When once the soundings have been converted into altitudes in relation to a known datum, they are plotted and the contours are interpolated and recorded by proportion between each pair of levels. These contours should be at such altitudes as will suit the purposes of the work, generally 0.50 metre, and it is an advantage to colour the intervening space between contours with distinctive tints to emphasize siltings and scourings, especially for comparison with a plan of the same site executed at a previous date.

When soundings are at, or near, the zero or datum of the district, it is often desirable to add a round figure to the readings to eliminate negative reduced levels.

*Bridge Sites.*—The selection of a railway-bridge site for a river-crossing is an important, if not the most important, problem in location work. In the first instance, i.e., on reconnaissance, the river should be perambulated throughout that part of its length which intersects the zone to be served by the proposed railway, and notes and descriptions should be recorded of all reasonable sites. The ideal site consists of banks above the maximum-flood level, with easy access gradients, and containing the river within a relatively narrow gap. The many sites observed in the reconnaissance are generally reduced, by one cause or another, to one, two, or perhaps three. Assuming that two sites remain to be studied in detail, if they be so situated as to affect the whole railway location, or so close to one another that the proposed railway extension is common to both sites, the chief of party should send out two sections of his party, one to each site, in order to determine their relative merits.

This work comes in the category of Preliminary Lines, with its corresponding degree of accuracy, and with the exception of finding the wetted perimeter and the discharge of the river, may be wholly and advantageously carried out with the tachometer.

The salient points for comparison are the gradient obtainable into and out of the valley with the earthworks, the class of banks and cuttings, the amount and altitude of bank across the valley with

the maximum-flood level, a geological section if possible, the amount of linear metres and square metres of opening that will be required for the main bridge, together with similar calculations for any additional flood-openings in the valley, and a decision as to whether relatively short or long spans will be the more economical. It must be remembered that it is undesirable to adopt timber trestling across areas that are liable to fire. Investigation must be made as to whether the river has the habit of periodically changing its course and, if so, whether it is advisable to give preference to a site where changes of this kind are less pronounced. A site with hard rocky banks should have preference over one where the banks are liable to erosion.

When floodable areas are crossed, the banks should be stone-pitched on both up- and down-stream sides, or at least planted with bushes on the upper side to protect them from wave-action; as, provided the railway bank is sufficiently strong to resist the static forces of the impounded waters, disintegration is generally caused by the flood water overflowing the rails and scouring the bank on the lower side.

In storm torrent courses the stress on a bank may be relieved or protected by side ditches to convey the storm-water to the nearest bridge or culvert: in such cases aprons are needed at these points.

Stone ballasting of the track will be found a great preventative to destruction of banks over stretches of line which are liable to be submerged.

*Meteorology, Geology, and Mineralogy.*—The locating engineer's knowledge of meteorology should be sufficient to enable him to record the characteristics of the climate of the district through which the proposed line will pass. His stay in it will be too short, and his party too mobile, for highly satisfactory results; nevertheless, systematic observations carried out at the base encampment under the second assistant will be of much value for comparison with others made in a known neighbouring climate. The observations should be continued by the constructing engineer, and a system should be permanently organized when once the line is handed over for exploitation. It is, however, the initial meteorological knowledge required with which this Paper is concerned, and that is more a matter of punctual routine than intricate work.

A rain-gauge should be installed and records taken at a fixed time once every 24 hours; automatic gauges, which record the fall during any interval of time, are desirable, to give ideas of the gravity of cloud-bursts and the necessity for the introduction of openings in the bank, side ditches, pitching and aprons.

Complicated devices, however, are apt to become damaged in transport, and the ordinary 24-hour gauge may be adopted, with the addition of notes, to record any phenomenal downpour.

Records of rainfall will also be required for calculating the approximate discharge, yield from the catchment-basin, and floods, and to give an idea of the agricultural and commercial value of the district.

Thermometer readings should be recorded every day at frequent and regular intervals. The automatic recorder has advantages, but the rough handling that occurs when changing encampment is against the employment of delicate instruments; reliance will probably have to be placed, therefore, on ordinary wet and dry thermometers with maximum and minimum readings, from which a curve may be drawn showing the temperature and relative humidity of the atmosphere.

A wind-gauge should be installed to record the direction and force of the wind, not only for general information but also for comparison with the oscillations of the barometer. The latter instrument should be an aneroid for mobile purposes, and either an aneroid or an automatic barometer, with temperature reading, for the base encampment. This is the most important meteorological instrument for locating purposes. When an aneroid is used, observations should be recorded every 2 hours between sunrise and sunset, its index error should be checked, and its altitude should be determined.

A record of the rise and fall of a river, even for a temporary stay, gives a warning in case of floods and serves as a check to any sounding-operations of the field-party. In mountain districts a record of snowfall with information as to its natural drifts is required to determine whether snow-screens will be required for the protection of a proposed railway.

In addition to these actual observations by the location party, inquiries should be made of old inhabitants regarding water-levels, with dates, etc.

A knowledge of geology is a necessary part of the scientific equipment of the locating engineer. In mountainous districts where tunnelling is proposed it is desirable to project through anticlines in preference to synclines, as there will be less likelihood of trouble at the crown of the heading and later less cost in maintenance of the tunnel; further, the longitudinal vertical plane of the crown of the anticline should form the ideal route, especially if the anticline is of short radius, as it forms a natural arch, thus dispensing with the

necessity of lining the tunnel. Percolation of water is also largely obviated, for the natural tendency of water percolating between strata is to gravitate towards the synclines.

Faults of all descriptions should be avoided; they not only cause trouble and expense on construction but are also a source of ever-recurring expense of maintenance.

In the case of the tunnel at Kicking Horse Valley, Canadian Pacific Railway, the route under Cathedral Mountain intersected a "shearing fault" at a very acute angle, with quartzite on the one side and limestone on the other, and gave considerable trouble.

The geological formation may vary considerably within a degree of latitude, and in the projection of transcontinental routes in new countries, where mountain ranges have to be crossed, a zone of hard formation may be discovered in close proximity to one that is in a continuous state of disintegration; 60 or even 100 miles deviation in a long pioneer route would be of but little account in hundreds of miles of railway, and need not necessarily interfere with the objective points. The Author knows of an instance of such changes in the mountain formation of the Cordilleras, or Andes, in South America between lat.  $37^{\circ}$  and  $38^{\circ}$  S.

Exposed faults on mountain sides overhanging a railway are a source of trouble and danger. The water contained within the voids will freeze in winter and with the succeeding thaw the rock will disintegrate. On some mountain railways this evil is negated to some extent by building strong rubble walls at the foot of the slope which stop falling detritus.

Mineralogy being the basis on which the selection of natural building materials depends, it is obvious that the locating engineer should not only report on their existence or non-existence, but should know the good from the indifferent. To be able to record this information he must study the composition of the materials. A clerk of works can say whether a material serves its purpose or not when he has tried it, but the engineer should recognize these things without recourse to experiment, which he cannot hope to do unless he has studied the subject.

He should know the various kinds of stones, the more valuable minerals, and their ores, when he sees them, and be able to determine their hardness, cleavage, lustre, streak, colour, crystal form, and specific gravity; also, if necessary, to carry out rough chemical and blowpipe tests. He should be acquainted with the uses of all minerals for commercial purposes.

## GEOLOGICAL OUTFIT.

1 Geological hand hammer.	Platinum foil. 0·10 × 0·5 metre.
1 Magnet, bar form.	10 pieces of Charcoal, 0·10 × 0·05 × 0·5 metre.
1 Blowpipe, with platinum mouthpiece.	1 Forceps, with platinum points.
Platinum wire. 0·50 metre.	1 Agate mortar and pestle.
1 Cl Pestle and mortar (small).	1 Steel pliers.
1 Spirit lamp, with screw cap.	2 Files, small triangular.
Wick to ditto. 0·30 metre.	12 Glass tubes, 1 cm. diameter.
Methylated spirit. 0·50 litre.	6 Glass rods, 5 mm. diameter.
Refined Colza oil. 0·50 litre.	

*Re-agents.*

Borax powdered crystals.	Tin foil.
Microcosmic salt.	Copper wire.
Carbonate of soda.	Litmus papers. 1 Block.
Nitrate of cobalt.	Silver nitrate.
Hydrochloric acid.	Permanganate of potash.
Sulphuric acid.	

*Prospects.*—Traffic prospects cannot be technically included in the training and duties of a locating engineer, though it is incumbent upon him to collect as much information on this subject as possible, in order that he may be able to give his opinion on the prospects of commercial success of the proposed railway.

Information should be recorded of the chemical composition of the top soils and, if salts exist, their kinds; whether the immediate lower stratum is impervious or not; the areas of forest and brushwood, with the names of trees and bushes; the specific gravity, porosity, colour, etc., of the different timbers; the presence and outcrop of stone and other minerals, with mineralogical descriptions of them; also the general fauna and flora of the country. In the populated and cultivated districts which it is proposed to open to railway communication, details should be obtained from the colonists as to yield, quantity, and kind of crops, areas sown, cattle, carrying capacity of the pasture per hectare or acre, rental and values of holdings, labourers' wages, road freights, class of roads or tracks, markets, population, local customs, industries, and prospects of developed industries.

The existence of water at any point within the zone of the proposed line should be recorded, the water being classed under three headings:—

- (1) Suitable for locomotive boilers;
- (2) Potable, but unsuitable for locomotive boilers;
- (3) Suitable for cattle and agricultural purposes.

It will be very difficult for the locating engineer to determine (1) in unknown country, as there are not likely to be any bores

or wells. Upon the water of rivers and streams, however, he will be able to report. He must remember that running water may carry organic matter, may also be charged with an appreciable amount of inorganic matter, which may vary according to the time of year. During flood time rivers may be charged with large quantities of mineral matter, which may considerably change the colour of the water; care should therefore be taken that the sample is selected when the river or stream is at its normal state. In partly populated zones artesian and open wells will probably exist; the former type is the more reliable for a sample as it doubtless extends below the first water stratum, and there is not so much likelihood of the water being polluted from the exterior. It should also be borne in mind that in a porous soil a well may drain in the shape of an inverted cone as far as 100 metres from its head, and may therefore become contaminated by matter lying within that radius.

Even in the case of artesian wells, cesspits, etc., in the near vicinity may cause pollution by gravitation between two strata or along a geological fault. The water of open wells in congested districts is unsatisfactory for human consumption, though it is the means of supply for the majority of country districts.

The quality of the organic matter is important. If the ratio of nitrogen to carbon is low, the impurity is probably of vegetable origin and comparatively harmless, but if high, it indicates pollution from animal matter and must be regarded with suspicion.

The presence of chlorides is not necessarily harmful, but is an indication that the water may be contaminated by sewage; the class of district will probably enable the locating engineer to satisfy himself on this point. In the neighbourhood of brine deposits, perceptible quantities of sodium chloride, or common salt, may be present and still the water may be potable. The Author has known a locating party to be sustained on hard brackish water for many months without its actually affecting the men, though signs of scurvy showed after six months.

A rough and ready test for potability and for the presence of organic matter is the addition of sufficient permanganate of potash to turn the water pink. If this colour remains unchanged, the water may be accepted as potable, but should it turn to a dirty red or brown the water is unfit for human consumption.

Chlorides give a white precipitate with nitrate of silver (common caustic). A good water should not show more than a slight milkiness.

In mountainous districts streams may contain salts of tin or antimony which give an attractive sparkle to the water, but render

it unfit for drinking; their presence can only be detected by a chemical test, and the water cannot be purified without distillation.

Chemistry assists the locating engineer in geology, and especially in water-analysis, and in this way saves the trouble and delay of despatching samples to an analyst. It also helps the mineralogist in the classification of minerals and in reducing with blowpipe and reagents.

It enables him to describe chemically the soils suitable for agricultural purposes, and any salts that he may find deposited on their surfaces.

The value of a camera—preferably one with a specially strong lens—for the purpose of taking technical views to elucidate a report on new country, cannot be overestimated. For that reason one assistant at least should be an expert photographer. Developing and printing accessories should be part of the equipment.

Photographs should be taken of possible bridge-sites, lakes, coast-line, settlements, heavily broken country, forests, classes of cultivation, etc. Views of undulating country are deceptive, and give the impression that the country is easier for railway location than it is in reality. The photographs to accompany a report should be described in print on the face, in order to be self-explanatory.

The Paper is accompanied by six sun-prints from some of which the Figures in the text have been prepared.

## APPENDIX.

TABLE I.—STAFF AND EQUIPMENT FOR A RECONNAISSANCE PARTY.

<i>Staff.</i>		<i>Camp Equipment.</i>	
Chief of party.		Cart, light, capacity 1 ton . . .	No. 1
Assistant.		Shaft, harness . . . sets	1
Foreman.		Traces „ . . . sets	4
Orderly.		Water-cart . . . . .	1
Cook.		„ harness . . . sets	1
Driver.		Saddlery complete . . . sets	5
Stableman.		Horses, draft . . . . .	12
		„ saddle . . . . .	10
		Tent, 3 metres by 2·5 metres .	1
		Tarpaulin, large . . . . .	1
		„ small . . . . .	1
		Axe, large . . . . .	1
		„ small . . . . .	1
		Spanner . . . . .	1
		Fence keys . . . . .	4
		Camp bedsteads . . . . .	2
		Blankets . . . . .	6
		Pillows and slips . . . . .	2
		Table, folding . . . . .	1
		Chairs „ . . . . .	2
		Lamps, with tubes and wick .	1
		Hurricane lamps . . . . .	3
		Kerosene . . . . . case	1
		Saddle soap . . . . . tins	3
		Whips, cart . . . . .	2
		Hammer . . . . .	1
		Screwdriver . . . . .	1
		Pincers . . . . .	1
		W1 wire . . . . . kgs.	5
		Nails, assorted . . . . . kgs.	5
		Rope, spare . . . . .	..
		Mess equipment . . . . .	..
		Cooking utensils . . . . .	..
<i>Technical Equipment.</i>			
Aneroids . . . . .	No. 6		
Compasses, prismatic . . . .	2		
Field glasses . . . . .	2		
Hypsometer . . . . .	1		
Sketching boards . . . . .	2		
Camera, Kodak . . . . .	1		
Films . . . . .	6		
Sketch books . . . . .	4		
Stationery (as required) . . . .	..		
Royal Geographical Society's handbook . . . . .	1		
Text-books (as desired) . . . .	..		
Medical case . . . . .	1		
Shot-gun and cartridges . . .	1		
Rifle, Winchester, and cartridges	1		
Geological cabinet . . . . .	1		



TABLE II.—STAFF AND TECHNICAL EQUIPMENT FOR PRELIMINARY LINES.  
FIELD-PARTY ONLY.

Engineer.	Occupation.	Men.	Equipment.
Chief of party (mounted)		1 orderly (mounted)	Field glasses, aneroid, prismatic compass, thermometer, note-book, 2 horses, 2 sets saddlery.
1st assistant	Transit	1 orderly	5-inch tacheometrical transit.
		1 front flagman	12 ranging-poles with bunting, 1 spade.
		1 rear (mounted)	
		1 peg and spademan	Pegs, field book, hand flag, red pencil, tin tacks, 1 horse, 1 set saddlery, 1 axe, 1 machet.
2nd assistant	Employed at base drawing-tent		
3rd assistant	Tacheometer	1 orderly	1 tacheometer.
		6 rodmen	6 tacheometrical staves, 1 steel pocket tape, 1 field-book, 1 hand flag, red pencil, machet.
4th assistant	Right flank topographer (mounted)	1 orderly (mounted)	1 prismatic compass, 1 aneroid, field glasses, 1 thermometer, field-book, 2 horses, 2 sets saddlery.
5th assistant	Left flank topographer (mounted)	1 orderly (mounted)	As for right flank, topographer.

Total Staff.—Engineers, 6 ; men, 14.

TABLE III.—STAFF AND TECHNICAL EQUIPMENT FOR FINAL LOCATION.<sup>1</sup>  
FIELD-PARTY ONLY.

Engineer.	Occupation.	Men.	Equipment.
Chief of party (mounted)		1 orderly (mounted) <sup>3</sup>	Field - glasses, note-book, 2 horses, 2 sets saddlery.
1st assistant	Transit	1 orderly	5-inch theodolite (transit)
2nd assistant	Employed at base drawing tent		
3rd assistant	Topographer	2 chainmen	12 ranging-poles (with bunting).
		1 front flagman	Box sextant 50 m. chain and 10 arrows.
		1 rear (mounted)	25 m. chain for curve chords.
		2 pegmen	Field-book, H.W. pegs.
		1 spademan	P.P. pegs, zinc disks.
		1 "topogman"	Hand flags, tin tacks, 2 machets, 1 axe, 25 m. tape.
4th assistant	Leveller	1 orderly	1 15-inch level, 2 staves.
		2 rodmen <sup>2</sup>	1 machet, field book.
5th assistant	Check-leveller	1 orderly 2 rodmen <sup>2</sup>	As for leveller.

Total Staff.—Engineers, 6 ; men, 16.

<sup>1</sup> With slight modifications in equipment serves also for trial location.

<sup>2</sup> On occasion this number might be increased to 3 with advantage.

<sup>3</sup> Employed as messenger.



TABLE V.—CAMPING EQUIPMENT OTHER THAN TECHNICAL EQUIPMENT FOR RAILWAY LOCATION PARTY (See Table IV.).

6 Engineers, 1 Quartermaster, 2 Gangers and 24 Men.

	No.		No.
Engineers' tents, 4 metres by 3 metres with poles, ridges, sun awning, floor tarpaulin, pegs and wind guys . . . . .	3	Hand hammer . . . . .	1
Tents, 3 metres by 2·5 metres, with ditto . . . . .	5	Spare handles to ditto . . . . .	..
Tents (men's) with poles, ridges, pegs and wind guys . . . . .	6	Saw . . . . .	1
4 - wheeled carts; capacity, 2 tons . . . . .	4	Spades . . . . .	2
Sets harness to ditto . . . . .	4	Spanners . . . . .	12
4-wheeled cart; capacity, 1½ tons . . . . .	1	Primus stove . . . . .	1
Sets harness to ditto . . . . .	4	Horse brand . . . . .	1
4-wheeled water-cart; capacity, 500 litres . . . . .	4	Machetes . . . . .	2
Sets harness to ditto . . . . .	4	Whetstones . . . . .	2
Light trap . . . . .	1	Large file . . . . .	1
Set harness to ditto . . . . .	1	Small „ . . . . .	1
Draught mules or horses . . . . .	50	Large screwdriver . . . . .	1
Trotting horses (sulky) . . . . .	4	Small „ . . . . .	1
Saddle horses . . . . .	20	Sheep-shears . . . . .	1
Sets of English saddlery . . . . .	7	Pincers . . . . .	1
„ Native „ . . . . .	4	Cold chisel . . . . .	1
Tarpaulins for cart . . . . .	5	Assortment of carpenters' tools . . . . .	..
„ „ trap . . . . .	1	Funnels . . . . .	2
Cart whips . . . . .	9	Punch . . . . .	1
Trap „ . . . . .	1	Set steel numbers . . . . .	1
Dandy brushes . . . . .	12	Lasso . . . . .	1
Curry combs . . . . .	6	Hand pump for water cart . . . . .	1
Tins saddle soap . . . . .	12	Tubing to ditto . . . . .	..
Saddle room cloths . . . . .	7	Scissors, to cut tin . . . . .	1
Camp bedsteads . . . . .	8	Besoms . . . . .	2
Mattresses to ditto . . . . .	8	Milk tins . . . . .	4
Blankets . . . . .	24	Demijohns . . . . .	6
Linen sheets . . . . .	16	Reading lamps and wicks . . . . .	6
Portable boring set . . . . .	1	Spare tubes to ditto . . . . .	24
Drawing table with trestles . . . . .	1	Hurricane lamps and wicks . . . . .	6
Mess „ „ „ . . . . .	1	Buckets . . . . .	12
Writing „ „ . . . . .	1	Water bottles . . . . .	8
Portable canvas tables . . . . .	4	Medicine chest . . . . .	1
„ chairs . . . . .	8	Sailmakers' needles . . . . .	3
Stools . . . . .	6	Canvas baths . . . . .	2
Axes large . . . . .	2	Wire, kilogrammes . . . . .	5
Spare handles to ditto . . . . .	4	Kerosene, cases . . . . .	2
Axe, small . . . . .	1	Colza oil, litre . . . . .	1
Spare handles to ditto . . . . .	2	Machine oil, litre . . . . .	1
Sledge hammer . . . . .	1	Kitchen utensils . . . . .	..
Spare handles to ditto . . . . .	2	Mess „ . . . . .	..
		Foodstuffs . . . . .	..
		Forage . . . . .	..
		Timber scantlings . . . . .	..
		Old tarpaulin . . . . .	..
		Rope . . . . .	..
		Nails, kilogrammes . . . . .	5
		Cart-grease, kilogrammes . . . . .	10

Note.—This list includes the camping equipment shown in Table I.

TABLE VI.—STAFF AND EQUIPMENT FOR A SECTION FOR MARINE OR DEEP RIVER SOUNDINGS IN CONNECTION WITH RAILWAY LOCATION.

Engineer.	Occupation.	Men.	Equipment.
Chief of party	Directing soundings from boat	No. 1, Oarsman <sup>1</sup> ,, 2, Sounder ,, 3, Recorder ,, 4, Flagman	Sounding-pole, 5 metres in length, sounding-line, 10 ditto, 1 pair of oars, 50-metre towing-rope, 1 machet, 1 axe, 13 ranging-poles, 1 square metre red bunting, 1 boat-hook, 1 vessel for baling, 1 painter, 10 metres in length, 1 boat, small, with rudder and pair of thole-pins, note-book, spare pegs and tin-tacks, 1 level complete, 2 level-staves.
Assistant.	With theodolite	1 orderly	Theodolite complete, field-book, ranging-pole with bunting, 1 machet.
Assistant.	With theodolite	1 orderly	Theodolite complete, field-book, ranging-pole with bunting, 1 machet.

*Note.*—For shallow soundings the tachometer is most advantageously employed in conjunction with wading. For staff and equipment see “3rd assistant, preliminary lines, Table II.”

<sup>1</sup> Number may need to be increased, with corresponding equipment, according to size of boat.

TACHEOMETRY. GRAPHIC DIAGRAM (*Fig. 3*) WHICH DISPENSES WITH  
THE USE OF JORDAN'S TABLES.

$$\text{Formula : Altitude} = l \times 100 \left( \frac{1}{2} \sin 2a \right).$$

*Note.*—For readings in field of more than 200 metres, graduations of 0·1 metre are necessary on Tacheometrical Staff.

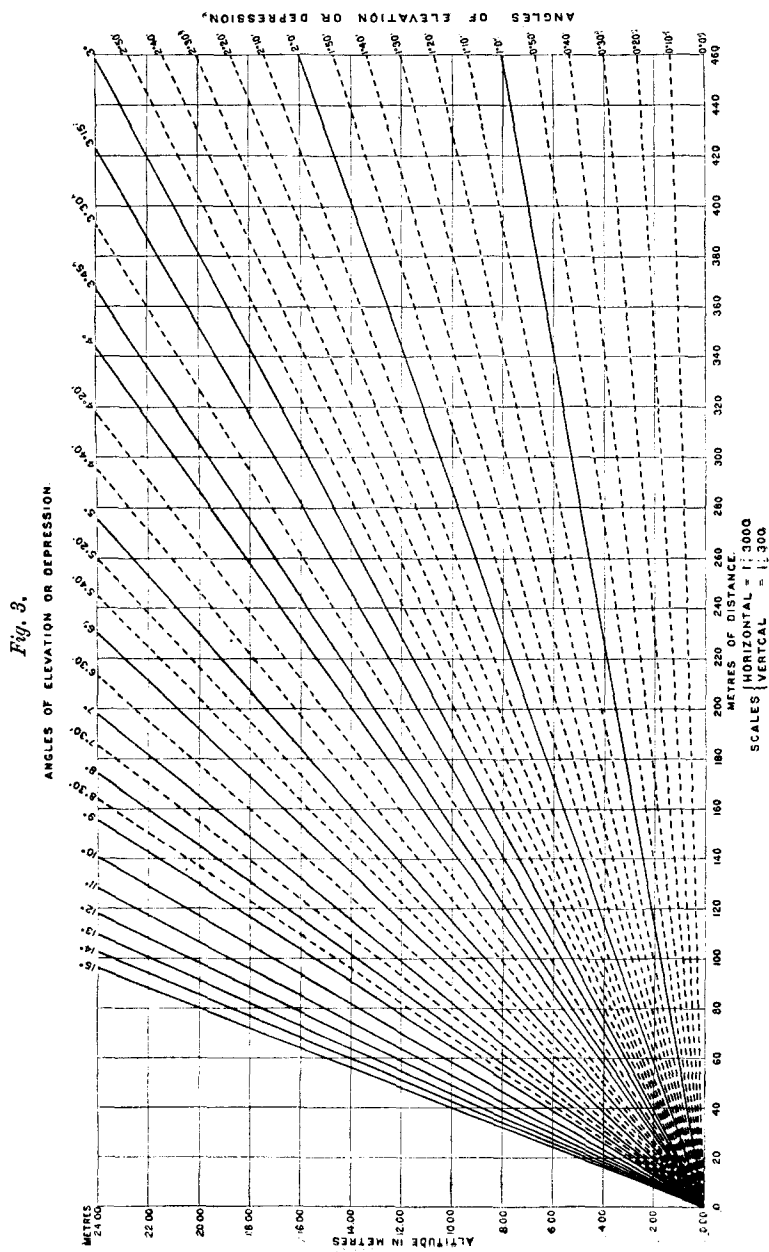
	Vertical Arc.	Hairs.
<i>1st Example</i> :—Tacheometer Field Book reading =	91° 32'	0·48
(For fall) Correction =	90°	2·52
	<hr/> 1° 32'	<hr/> l = 2·04

Then on diagram find intersection of 1° 32' with distance 204 metres,  
and read off altitude = 5·46 metres.

	Vertical Arc.	Hairs.
<i>2nd Example</i> :—Tacheometer Field Book reading =	87° 15'	0·3
(For rise) Correction =	complement	2·7
	<hr/> 2° 45'	<hr/> l = 2·4

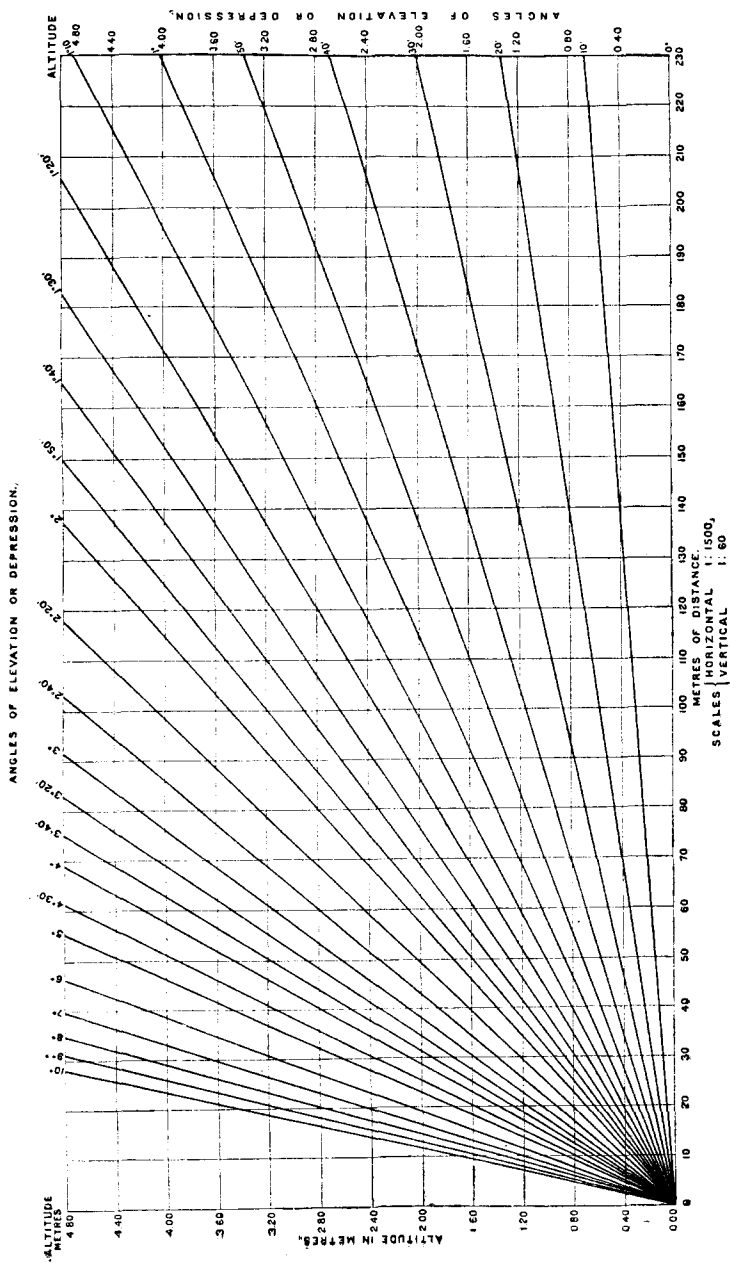
Then on diagram find intersection of 2° 45' with distance 240 metres,  
and read off altitude = 11·5 metres.

*Fig. 4* (p. 371) is used in a similar manner, but gives more accurate results than *Fig. 3* when the angle of elevation or depression is small.



GRAPHIC TABLE FOR DEDUCING REDUCED LEVELS FROM TACHEOMETRIC READINGS.

Fig. 4.



GRAPHIC TABLE FOR DEDUCING REDUCED LEVELS FROM TACHEOMETRIC READINGS.



TABLE VII.—RAILWAY LOCATION GRADIENTS ON CURVES AND THEIR COMPENSATED EQUIVALENTS.

Compensation = 0.04 per cent. per degree of curvature.

Formula :—Grade per metre —  $\left( \frac{0.6934}{\text{radius}} \right)$  = Compensated Grade.

Radius.	Equivalent in Degrees of Curvature.	Grade (On Straight) 1 : 100 = 0.01 per Metre.	Grade (On Straight) 1 : 126 = 0.008 per Metre.	Grade (On Straight) 1 : 150 = 0.003 per Metre.	Grade (On Straight) 1 : 175 = 0.00371 per Metre.	† per Cent. Grade (On Straight). 1 : 200 = 0.005 per Metre.
Metres						
1,000	1.746	1 : 107 <sup>s</sup> = 0.00930	1 : 137 <sup>o</sup> = 0.00730	1 : 167 <sup>s</sup> = 0.00597	1 : 199 <sup>e</sup> = 0.00501	1 : 232 <sup>s</sup> = 0.00430
950	1.837	1 : 107 <sup>s</sup> = 0.00927	1 : 137 <sup>s</sup> = 0.00727	1 : 168 <sup>s</sup> = 0.00593	1 : 200 <sup>s</sup> = 0.00498	1 : 234 <sup>s</sup> = 0.00427
900	1.940	1 : 108 <sup>s</sup> = 0.00922	1 : 138 <sup>s</sup> = 0.00720	1 : 169 <sup>s</sup> = 0.00589	1 : 202 <sup>s</sup> = 0.00493	1 : 236 <sup>s</sup> = 0.00422
850	2.054	1 : 108 <sup>s</sup> = 0.00918	1 : 139 <sup>s</sup> = 0.00718	1 : 170 <sup>s</sup> = 0.00585	1 : 204 <sup>s</sup> = 0.00489	1 : 239 <sup>s</sup> = 0.00418
800	2.182	1 : 109 <sup>s</sup> = 0.00913	1 : 140 <sup>s</sup> = 0.00713	1 : 172 <sup>s</sup> = 0.00579	1 : 206 <sup>s</sup> = 0.00484	1 : 242 <sup>s</sup> = 0.00413
750	2.328	1 : 110 <sup>s</sup> = 0.00907	1 : 141 <sup>s</sup> = 0.00707	1 : 174 <sup>s</sup> = 0.00574	1 : 209 <sup>s</sup> = 0.00478	1 : 245 <sup>s</sup> = 0.00407
700	2.494	1 : 111 <sup>s</sup> = 0.00900	1 : 142 <sup>s</sup> = 0.00700	1 : 176 <sup>s</sup> = 0.00567	1 : 212 <sup>s</sup> = 0.00471	1 : 250 <sup>s</sup> = 0.00400
650	2.686	1 : 111 <sup>s</sup> = 0.00893	1 : 144 <sup>s</sup> = 0.00693	1 : 178 <sup>s</sup> = 0.00559	1 : 215 <sup>s</sup> = 0.00464	1 : 254 <sup>s</sup> = 0.00393
600	2.910	1 : 113 <sup>s</sup> = 0.00884	1 : 146 <sup>s</sup> = 0.00684	1 : 181 <sup>s</sup> = 0.00550	1 : 219 <sup>s</sup> = 0.00455	1 : 260 <sup>s</sup> = 0.00384
550	3.174	1 : 114 <sup>s</sup> = 0.00873	1 : 148 <sup>s</sup> = 0.00673	1 : 185 <sup>s</sup> = 0.00539	1 : 225 <sup>s</sup> = 0.00444	1 : 268 <sup>s</sup> = 0.00373
500	3.492	1 : 116 <sup>s</sup> = 0.00860	1 : 151 <sup>s</sup> = 0.00660	1 : 189 <sup>s</sup> = 0.00527	1 : 232 <sup>s</sup> = 0.00431	1 : 277 <sup>s</sup> = 0.00360
450	3.880	1 : 118 <sup>s</sup> = 0.00845	1 : 155 <sup>s</sup> = 0.00645	1 : 195 <sup>s</sup> = 0.00511	1 : 240 <sup>s</sup> = 0.00416	1 : 289 <sup>s</sup> = 0.00345
400	4.365	1 : 119 <sup>s</sup> = 0.00835	1 : 160 <sup>s</sup> = 0.00625	1 : 203 <sup>s</sup> = 0.00492	1 : 252 <sup>s</sup> = 0.00396	1 : 307 <sup>s</sup> = 0.00325
350	4.988	1 : 125 <sup>s</sup> = 0.00800	1 : 166 <sup>s</sup> = 0.00600	1 : 214 <sup>s</sup> = 0.00467	1 : 269 <sup>s</sup> = 0.00371	1 : 333 <sup>s</sup> = 0.00300
300	5.820	1 : 130 <sup>s</sup> = 0.00767	1 : 176 <sup>s</sup> = 0.00567	1 : 230 <sup>s</sup> = 0.00434	1 : 295 <sup>s</sup> = 0.00338	1 : 374 <sup>s</sup> = 0.00267
250	6.984	1 : 138 <sup>s</sup> = 0.00721	1 : 191 <sup>s</sup> = 0.00521	1 : 258 <sup>s</sup> = 0.00387	1 : 342 <sup>s</sup> = 0.00292	1 : 452 <sup>s</sup> = 0.00221