The difficulties of obtaining satisfactory Tape Temperatures and of applying satisfactory Temperature Corrections when using Steel Tapes for Precise Traverses.

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1. The subject of this paper is a very important one which does not appear to have received sufficient consideration in the past. Text Books, Books of Instructions and Reports of work done are strangely reticent on the subject, and I can only conclude that it has been purposely avoided owing to the inherent difficulties, the absence of any definite information or data on the point and the lack of opportunity for proper investigation and experiments, to study and overcome the difficulties.

2. The paucity of information on the subject is probably also due, to a certain extent, to the paradoxical view, which is undoubtedly held by many surveyors, that it is perfectly simple to take a Tape temperature. These surveyors will tell you that you merely read the thermometer and apply the correction given in the Tables provided, and that, except in very long lines, the correction to any particular line is usually negligible.

3. It is not generally realised that the temperature taken is an air temperature and not a Tape temperature, that the temperature of the air changes very slowly in comparison with the temperature of the Tape and there may be as much as 40°F. difference between them, that it is
practically impossible in the field to take the temperature of the Tape except through the medium of the air, and that the negligible temperature corrections per line accumulate rapidly and are seriously accountable in respect of the whole Traverse.

4. Questions are still unsolved as to the most suitable type thermometer and how many thermometers should be used for each Tape length, where and how they should be held in relation to the Tape, how long the thermometer should be held in the prescribed position before taking the readings, and how to provide that the readings will represent actual Tape temperatures, even approximately, instead of air temperatures, and how the appropriate corrections for these temperatures can be applied with accumulative effect to the whole traverse.

5. Mr. J. E. Jackson, Assistant Superintendent of Surveys, Diyatalawa, was asked to make some experiments on the subject and send in a report on the matter. I now have the pleasure of embodying his report, entitled "Notes on some experiments with Thermometers and Steel Tapes," which contains a lot of very valuable information on the subject of this paper, although as Mr. Jackson says, owing to lack of time and the complexity of the subject, no very definite conclusions have been arrived at.

6. Mr. Jackson's experiments have been conducted in the midst of his ordinary work in the Trigonometrical Branch, and consequently they have been rather rushed and are by no means complete, but I think he deserves a great deal of credit for the originality of his experiments in an entirely new field, and for the useful results he has succeeded in placing before us.

7. The temperature readings recorded by Mr. Jackson shew some unaccountable discrepancies. These may be partly due to the fact that the readings of the 5 to 10 thermometers had to be taken very rapidly, by only 2 observers, in order to make the groups of readings as nearly simultaneous as possible, and partly to the rushed nature of the experiments, owing to the limited time at his disposal; but making allowances for these, and Mr. Jackson's modesty about his work.
I feel convinced that most of the unaccountable discrepancies are very real and show that Tape Temperatures are much more variable and much more difficult to obtain satisfactorily than most surveyors imagine.

8. The thermometer readings appear to differ unaccountably by varying amounts at different temperatures, even when the thermometers were placed in water under conditions which appeared to be similar. It is a question whether these discrepancies between thermometers are due to differences in their construction, in their mountings, in the constitution of the materials of which they are composed, in their environment at the time of the readings, or due to faulty graduations or readings, or to other causes unknown.

9. There is no doubt that glass is not a satisfactory material to use in the construction of Thermometers, as it is such a bad conductor of heat and is very apt to "blanket" the mercury column inside. It is true the "Bulb" of the thermometer is usually made of very thin glass, to make the thermometer as sensitive as possible, but the thickness, constitution and conductivity of the glass is bound to vary, in the stem as well as the bulb, and there are bound to be variations and unevenness in the bore of the thermometer, along which the mercury column has to rise and fall in the stem, when expanding and contracting with heat and cold, to register the temperature. Unfortunately transparency of the material is essential, which at present precludes the use of any other material than glass, but it may be possible, in time, for makers to supply thermometers made of some equally transparent but more conductive material than glass, which would be more manageable than glass, produce better consistency of material and accuracy of bore, in the manufacture of the thermometers, and which would incidentally be less breakable.

10. A new type of Synthetic Thermometer was constructed at the end of the experiments, as indicated in Figure 7, and when tried against the Synthetic Thermometers illustrated in Figure 1, over only a few readings, it was found to give better results. This thermometer, (Fig. 7), is cased in a holder or container made of bits of old
steel tape, with wire gauze in front of the graduations, to make them visible, and with fine iron filings, of the same material as the steel tape, surrounding the actual bulb, so as to give better contact all the time and read actual Tape temperatures, as nearly as possible. The advantages of this construction are obvious, and this type of thermometer certainly seems to give better results in actual performance than any of the Chain or Tape thermometers tried hitherto.

11. It is evident from Mr. Jackson’s experiments that to obtain suitable temperature corrections for Steel Tapes on Precise Traverses, the tapes should not rest on the ground but should be supported by Trestles, Posts, Forks or Labourers’ hands, at intervals of about 1 1/2 chain or 1 chain in each tape length, that the tape should as far as possible be shaded throughout its length and that the temperature should be determined from the readings of several synthetic thermometers, hung on the Tape supports, at intervals along its length.

12. It must be admitted at once that the temperature obtained in each case is more or less the temperature of the air in the vicinity of the Tape, and not the Tape temperature, which could only be obtained by means of a long cumbersome trough and using the Tape immersed in oil or water, or packed in ice, with the thermometers in the trough, as it is impossible to place a thermometer in satisfactory contact with a steel Tape. Air is not a good medium for thermostatic purposes and the experiments show that sunshine and shade, humidity, breezes, and environment may cause considerable discrepancies between the temperatures of the air and the tape, and even between several thermometers in close proximity to one another.

13. I agree with Mr. Jackson that his experiments indicate that dull cool weather, with absence of strong sunshine and shade, is the best time for running Precise Traverses, but in the Tropics, where hot sunny days prevail largely, it would mean a serious handicap to the progress of work, if the time for running precise traverses has to be strictly limited to dull cool weather, which, on the average, is available only for 3 or 4 months
in the year. As an alternative, the possibility of working early in the morning and late in the evening might be considered, to obtain dull cool weather to work in, but this has the great disadvantage that temperatures are rising rapidly in the morning and falling rapidly in the evening, which may actually produce worse results than working in hot sunny weather, with higher but more constant temperatures.

14. The Tables given by Mr. Jackson appear to indicate that the air temperatures as shown by the thermometers lag considerably behind the tape temperatures, when the general temperature is either rising or falling rapidly, and that when the general temperature is more or less constant, the air temperatures would give fairly accurate corrections for Tape measurements. It is no doubt true that in a sudden burst of hot sunshine, the temperature of the Tape would rise much more quickly than the temperature of the air, and conversely, in a sudden over-clouding of hot sunshine, the Tape-temperature would drop much faster than the Air-temperature. In these cases it would be impossible to measure their relativity but allowance might be made on a fixed scale for rising and falling temperatures, based on the lapsed time between the maxima and minima of the air temperatures, in order to correct for the lag in the air temperatures and arrive at a more correct tape temperature.

15. This same lag in tape temperature behind air temperature is a continuous source of trouble in the standardisation of Tapes in out-door uncovered Tape standards and, owing to this trouble, I am now making arrangements to construct an indoor Tape standard, which will be more free from this difficulty of rapid changes in temperature, due to sudden variations of sunshine and shade, wind and rain, and atmospheric humidity and pressure, which seriously affect the correct setting of tapes to the standard, and undoubtedly affect seriously all Tape temperatures read in the field, and consequently the temperature corrections dependant on them.

16. The variations in the readings of the different thermometers, both under the same conditions and different conditions, as shewn in Mr. Jackson's tables, prove that Tape temperatures
cannot be satisfactorily obtained from one thermometer and that either 3, 5 or 7 thermometers should, as a rule, be used for each Tape length. Moreover the Thermometers should be so placed at different points along the Tape that the mean of their readings will represent a correct mean with due regard to the portions of the Tape in sun or shade, over dry earth, wet grass, hot roads, water, brush-wood, young vegetation, dry leaves etc., and the thermometers should be as close as possible to the tape and approximately the same height from the ground and the same distance from adjacent rocks, buildings, etc., as the Tape.

17. Mr. Jackson states that he calibrated his thermometers and that they more or less agreed on calibration, showing that their discrepancies in the experiments must have been due to other causes, such as environment, currents, construction and constitution of the materials of which the thermometers are made, etc.

18. The use of Invar Tapes (or Tapes made of a similar material) instead of Steel Tapes, for running Precise Traverses has been considered and has a good deal to be said in its favour. With these tapes, the correction for temperature is practically negligible, under almost any working temperature, and all the considerable difficulties and labour of obtaining satisfactory Tape Temperatures and applying the temperature corrections are saved. Moreover it is probable that greater accuracy is obtained and at much less expense of time and labour. The main objections to the Invar Tapes are the questions of price and durability. They cost roughly £20 as against £3 for a steel tape; and the life of the Invar is much shorter, being about 10 years, when kept and used only as a standard, compared to about 30 years, for a steel tape, in constant and hard use. If the manufacturers could bring down the price, Invar tapes, would certainly be used more widely for precise work. There is no doubt the character of the material in Invar deteriorates rapidly and becomes soft and spongy and brittle, in about 8 to 10 years, and therefore, as a standard of precise measurement, it cannot be relied upon for more than 3 or 4 years without frequent tests and calibrations.
19. Invar Tapes have not as yet been subjected to hard service on Traverses, in Ceylon, and we have no experience as to how they would stand up to such work, as compared with steel tapes. I am inclined to think that the metal would deteriorate and become spongy, in considerably less than 10 years, if an Invar tape was to be subjected to hard and continuous use for Traverses, like a steel tape. This is a point however on which the manufacturers might be able to enlighten us with actual records.

20. If Invar Tapes are to be used regularly for Precise Traverses it will be necessary for manufacturers to graduate them throughout their length, and mark the graduations clearly at every link, every 10 links and every 50 links, with distinctive tallies, which can be easily and quickly read in the field, on much the same lines as a steel tape is graduated. Moreover handles would have to be fitted, and the handle at one end made adjustable, similar to the handles on a steel tape. The question of rapid repairs in the field to broken Invar Tapes would also have to be considered.

21. I have been considering for some time the possibility of applying Tape Temperature corrections to Precise Traverses as an accumulated "bloc" correction to the whole Traverse, on a "Bloc Temperature Correction System," instead of applying the correction tape-length by tape-length, and line by line, on the ordinary "Individual Temperature Correction System" as at present. The "Block Temperature Correction" for the whole Traverse is usually quite an appreciable quantity, averaging about 5 links, whereas the "Individual Temperature corrections" per Tape-length or per Line are usually very small, and inappreciable, averaging about .02 of a Link with the result that, working to the nearest Link or decimal of a Link, the accumulative effect of the Temperature corrections is liable to be lost, when each correction is dealt with individually, line by line.

22. The accumulated Tape Temperature correction for a whole traverse could be easily determined if the Traverse happened to be a continuous straight line, on the same bearing, and the Tape Temperature remained fairly constant throughout the Traverse. In practice
however, this never happens, and the bearing of each leg of a Traverse varies considerably from the last and the Traverse winds and deviates a lot from the general direction of the terminal points, some of the legs having to be run almost in a reverse direction to the general direction. Moreover the Tape Temperatures throughout the Traverse are far from constant and may have opposite signs on some of the legs.

23. The fact remains however that the accumulative effect of the Tape Temperatures applies ultimately to the direct distance between the terminal points and the mean of all the Tape Length temperatures (weighted for short lengths), if applied to the direct distance between the terminal points, as derived from the co-ordinates of the Traverse, will give the total temperature correction in co-ordinates for the whole Traverse, and this correction can be applied to the apparent misclosure, to determine the actual misclosure corrected for Tape Temperatures. The misclosure of the Traverse must, of course, be eliminated in the usual way.

24. The Booking of Tape Temperatures in the Field Books, against each line of a Precise Traverse, can be simplified and improved if the temperatures are observed and booked as "Temperatures per chain," regardless of the number of thermometers used and the temperature readings taken for any particular chain length or for the total length of any line. Thus if 2 thermometers are used on the 1st chain length, 2 on the 2nd and 1 from the 3rd, to the 5th, or 5 thermometers in all, on a line with total length 498 links, measured with a 5 chain tape, the temperatures could be booked and the "Temperature per Chain" for the whole line calculated, in the Field Book thus:

\[
\begin{align*}
1\text{st} \text{ Chain} & : 88^\circ \\
& \quad \quad 80^\circ \\
2\text{nd} & : 82^\circ \\
3\text{rd} & : 90^\circ \\
4\text{th} & : 90^\circ \\
5\text{th} & : 90^\circ \\
\text{Mean Temperature per Chain for} & \quad \text{the whole line} \\
\end{align*}
\]

\[
\begin{align*}
& \quad \quad \quad \quad \quad 88^\circ
\end{align*}
\]
25. It is generally recognised that whole lines should as far as possible be set out, when laying out the lines for the Traverse, to measure approximately a little less than a multiple of the whole Tape length, in order to avoid, for various reasons, having to measure small additional pieces of tape length at the end of the line. Thus, using a 5 chain Tape, it is obviously better to set out the line to measure 498 links or 996 links than 525 links or 1,025 links, to avoid the short end length of 25 links. If this rule is strictly observed, as it should be, the "Mean Temperature per Chain," for each line on the Traverse, as derived from the bookings in accordance with the above example, can be safely accepted without having to weight the mean for each line on account of short end lengths.

26. If, however, it is necessary to use a short end length on a line, the calculation of the mean Temperature per chain for the whole line must be weighted to allow for the short length, and calculated as shewn under (a) or (b) thus:

(a) Observed Means. Weights on Temperatures.

<table>
<thead>
<tr>
<th>Chain</th>
<th>Temperature</th>
<th>Means</th>
<th>Distance</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>88°, 86°</td>
<td>84°</td>
<td>× 4</td>
<td>336</td>
</tr>
<tr>
<td>2nd</td>
<td>90°, 82°</td>
<td>86°</td>
<td>× 4</td>
<td>344</td>
</tr>
<tr>
<td>3rd</td>
<td>90°, 90°</td>
<td>90°</td>
<td>× 4</td>
<td>360</td>
</tr>
<tr>
<td>4th</td>
<td>90°, 90°</td>
<td>90°</td>
<td>× 4</td>
<td>360</td>
</tr>
<tr>
<td>5th</td>
<td>90°, 109°</td>
<td>109°</td>
<td>× 1</td>
<td>109</td>
</tr>
<tr>
<td>6th</td>
<td>109°</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(short end length 25 links = ½ chain) 21 1,869

1,869 = 89°

21

"Weighted Mean Temperature per Chain for the whole line" = 89°.

or (b) Take 88°, the Mean Temperature per chain for the first 5 chains and add ¼ of ½ of 21° = 1°, making 89° for the "weighted mean temperature per chain for the whole line," which is the same result as the above.
27. The mean Temperatures per chain per line, weighted, when necessary for short end lengths, can then be easily entered in a special column on the co-ordinate sheets, against each line of the Traverse, and it will be a simple matter, given the number of chains, and the mean Temperature per chain for each line, to calculate the "average temperature per chain" for the whole Traverse and to apply the temperature corrections, for that temperature, to the total Traversed co-ordinate distances, in Latitude and Departure, between the terminal points, giving the temperature correction in co-ordinates for the whole Traverse, which can be readily applied to the misclosure of the Traverse.

28. Experiments have been made with this system of "Bloc" Temperature corrections on existing Traverses with gratifying results, as in every case the misclosure of the Traverse was considerably reduced by applying a "Bloc Temperature Correction" instead of the "Individual Temperature Corrections," and the experiments show that the Booking and Working out of a Traverse would be appreciably simplified and accelerated on the "Bloc" system of temperature corrections.

29. The new "Bloc" system has therefore every appearance of being simpler, more accurate and more effective than the old system of "Individual" Temperature Corrections.

30. I would summarise my recommendations regarding Tape Temperatures for Precise Traverses, as follows:

(1) Makers should be encouraged to try and produce suitable Invar Tapes on the lines indicated in paragraphs 18, 19 and 20 above, at a reasonable cost, for work on Precise Traverses, as distinct from Base measurement.

(2) Makers should be encouraged to try and improve the construction of Tape Thermometers on the lines indicated in paragraphs 9 and 10 above, for use on Precise Traverses measured with steel Tapes.

(3) The long narrow steel tape, 1/2 inch wide and 5 chains long, should be used for Precise Traverses in preference to the
short wide steel tape, 3″ wide and 3 chains long, as the former is less affected by changes of temperature.

(4) The Tape should be lifted off the ground and supported on light portable Trestles, placed at every half chain with detachable uprights and a light awning spread from Trestle to Trestle, where necessary, to cover the Tape and protect it and the thermometer from hot sun.

(5) Synthetic Thermometers, 3, 5 or 7 in number, according to the variety of Thermal conditions, should be used on each Tape Length, suspended or placed on the Trestles, under the same thermal conditions and as near as possible to the portion of the Tape on each Trestle, so as to give a reliable mean temperature for each Tape Length.

(6) The Thermometers should be in position for at least 5 minutes before they are read and booked.

(7) The Tape Temperatures should be arranged, observed, booked, and calculated as “Mean Temperatures per chain per line,” in the manner indicated in paragraphs 14, 16, 24 and 26 above.

(8) The Traverse lines should as far as possible be arranged and set out to measure a little less than a whole number of chains or a multiple of the Tape Length, as explained in paragraph 25 above.

(9) Temperature corrections should be applied as an accumulative correction for the whole Traverse on the “Bloc” system, instead of the “Individual” system, line by line, which loses the accumulative effect of the corrections and is more difficult and cumbersome to operate.

(10) “The Mean Temperature per chain per line” should be entered in a special column against each Line on the co-ordinate sheets, and the “Average Temperature per chain” calculated for the whole Traverse, and applied to the Traverse co-ordinate distances between the terminal points, to obtain the
Temperature Correction in co-ordinates for the whole Travers. The Temperature Correction co-ordinates should then be applied to the apparent Traverse Misclosure co-ordinates, to determine the actual corrected misclosure and, if it is within the limit of error allowed, the apparent Traverse misclosure should be eliminated in the usual way.

(II) Precise Traverses should as far as possible be run in dull equable weather to avoid hot sunshine and rapid changes of temperature.

31. In conclusion, I may point out that the above recommendations have not yet been put into effect in Ceylon and I have not yet had an opportunity of running an Actual Traverse on these principles, but the object of this paper is to invite discussion on the subject and to obtain the benefit of any investigations or experiments which may have been carried out and conclusions arrived at with regard to Tape Temperatures and Temperature Corrections, in other parts of the World.

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Surveyor-General's Office,
Colombo, 6th June, 1935.

NOTES ON SOME EXPERIMENTS WITH THERMOMETERS AND STEEL TAPES.

1. The question of the accuracy of the determination of the temperature of a steel tape as used in the field under various conditions was raised by the Surveyor General some time ago and was discussed by several officers of the Department. It was agreed that the simple method of hanging up a tape thermometer alongside the tape, or in contact with the tape or swinging in the air, while traversing was being carried on, was not sufficiently accurate. The Superintendent of the Observatory was of the opinion that the ordinary chain or Tape thermometer, enclosed almost completely in a massive brass case, could not be expected to register the temperature of a steel tape, correctly, and recommended that a thermometer removed from its case and enclosed
between pieces of old steel tape, similar to the steel of the tapes used in traversing, should be tried. Three of these thermometers were constructed and designated "Synthetic Thermometers," and some experiments to compare them with the ordinary tape thermometers were carried out. Fig. 1 is a diagram of a synthetic thermometer. The results of these experiments, and some other experiments closely related to the subject, are noted below.

2. A 3 chain steel tape was laid out along the top of a low cement wall and placed under 12 lbs. tension by means of a spring balance. Two fine marks were scratched on the tape 294 links apart: one mark was kept coincident with a fixed mark on the wall. Another fixed mark was established on the wall close to the other mark on the tape and the distance between these marks was measured with a travelling microscope. In this way the expansion of the tape could be measured. The synthetic thermometers, and 7 ordinary brass-cased thermometers, were put out alongside the tape. Readings of thermometers and microscopes were taken (1) in the early morning, in the shade (2) in the middle of the morning, in sunshine (3) at midday, in the sunshine. The results are given in the table below. The object was to compare the apparent expansion against the theoretical expansion calculated from the co-efficient \(-0.000007\), supplied by the makers of the tapes.

<table>
<thead>
<tr>
<th>Thermometer No.</th>
<th>Position</th>
<th>Tape minus &quot;standard&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(-5.72) mm</td>
</tr>
<tr>
<td>Synthetic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>lying on side, bulb shaded</td>
<td>84.2</td>
</tr>
<tr>
<td>2</td>
<td>&quot; edge, bulb in Sun</td>
<td>86.1</td>
</tr>
<tr>
<td>3</td>
<td>&quot; side, bulb shaded</td>
<td>86.5</td>
</tr>
<tr>
<td>4</td>
<td>standing (\frac{1}{4}) above cement, bulb shaded</td>
<td>85.5</td>
</tr>
<tr>
<td>5</td>
<td>lying on cement bulb shaded</td>
<td>86.2</td>
</tr>
<tr>
<td>6</td>
<td>lying on cement bulb shaded</td>
<td>86.8</td>
</tr>
<tr>
<td>7</td>
<td>standing (\frac{1}{4}) above cement bulb shaded</td>
<td>76.5</td>
</tr>
<tr>
<td>8</td>
<td>lying on cement, bulb in Sun</td>
<td>86.2</td>
</tr>
<tr>
<td>9</td>
<td>standing (\frac{1}{4}) above cement, bulb shaded</td>
<td>86.7</td>
</tr>
<tr>
<td>10</td>
<td>standing (\frac{1}{4}) above cement, bulb shaded</td>
<td>86.2</td>
</tr>
</tbody>
</table>

Thermometer reading
All the above quantities are the means of several readings. Graphs were drawn of tape lengths against thermometer readings for each thermometer; the graphs for thermometers 3 and 5 are shown in Fig. 2. If the thermometers read correctly their graphs should be parallel to the broken line: thus thermometer No. 3 reads more correctly than No. 5. It was found that the synthetic thermometers generally gave graphs approximating more nearly to the correct slope than the ordinary thermometers. Note that this experiment determines the relative accuracy of different thermometers but gives no indication of absolute accuracy of readings, except to show that errors must exist and must be appreciable.

3. A thermometer which was reading $72^\circ$ was placed on hot cement; it took 5 minutes to reach a steady reading ($110^\circ$).

4. By placing a synthetic thermometer partly in Sun and partly in shade it was found that heat was not conducted along the steel tape to any appreciable extent: the portion in shade was cool and the portion in Sun was hot, and the change of temperature occurred very rapidly, actually at the dividing point between Sun and shade.

5. Some readings taken to determine the variety of temperatures which could be simultaneously read in different position gave the following results:—

<table>
<thead>
<tr>
<th>Description</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>On damp grass in shade</td>
<td>$74^\circ$</td>
</tr>
<tr>
<td>On damp gravel</td>
<td>$75^\circ$</td>
</tr>
<tr>
<td>Air temperature</td>
<td>$71^\circ$</td>
</tr>
<tr>
<td>$8^\circ$ above damp gravel in Sun</td>
<td>$97^\circ$</td>
</tr>
<tr>
<td>$8^\circ$ dry grass in Sun</td>
<td>$98^\circ$</td>
</tr>
<tr>
<td>On damp gravel in Sun</td>
<td>$102^\circ$</td>
</tr>
<tr>
<td>On damp grass</td>
<td>$105^\circ$</td>
</tr>
<tr>
<td>On warm cement</td>
<td>$109^\circ$</td>
</tr>
<tr>
<td>On dry grass</td>
<td>$115^\circ$</td>
</tr>
</tbody>
</table>

6. Some more elaborate experiments, to determine the absolute accuracy of thermometer readings, have recently been made. The problem was essentially to get thermometer readings when the tape was at a known temperature: and it was solved by means of a trough of water in which the tape was immersed with the thermometers. The apparatus is shown diagrammatically in Figs. 3
and 4. The trough was made of wood, in two halves, which were bolted together for use, the joints being sealed with plasticine; and it was well tarred and pitched inside. Pulleys at each end enabled the tape to be threaded through and kept under water. The tape was fixed to two pegs driven into the ground, a few feet from each end of the trough, and was tensioned by a spring balance; all readings were taken with the tape under a tension of 12 lbs. The portion of tape between the two lower large pulleys hung in free catenary. Two measuring microscopes fixed on ___ shaped iron frames, which were in turn bolted to concrete blocks, were set up near each end of the trough and were focussed on fine lines scratched on the tape. The trough was supported under the microscopes by 2 wooden blocks, so as not to touch the microscopes or their supports. 3 Synthetic thermometers and 2 ordinary tape thermometers were held alongside the tape under the water by wire hooks hanging inside the trough. Using objectives giving an apparent magnification of about 10, the microscopes could be kept well clear of the water, and settings could be made, with the traversing screws, to 0.005 mm. with certainty.

7. The experiment was carried out as follows. The apparatus was set up as indicated, and hot water at a temperature of about 180° was poured into the trough till it was about 1 full. The tension of the tape was adjusted to 12 lbs. and the microscopes were focussed on the marks: some trouble was experienced with condensed vapour on the lenses, and a pad of cotton on a piece of wire had to be used to wipe off the drops of water. Readings of the 5 thermometers and 2 microscopes were taken alternately as quickly as possible until about 6 or 8 sets of readings had been obtained: the water was then allowed to cool to about 100° when several more sets of readings were made. The tape was then released and pulled out of the trough. The trough was raised slightly while the supporting blocks were removed, and then lowered to the ground: it was then drawn out from under the microscopes and removed out of the way. The tape was replaced under the microscopes, supported in catenary on two strips of wood and two wedges as indicated in.
Fig. 5: the marks on the tape were focussed by means of the wedges. The removal of the trough and replacement of the tape was done without disturbing the microscopes in any way. The thermometers were wiped dry and supported alongside the tape by means of a beam of wood with wire hooks projecting about 8° beyond its upper edge. Alternate readings of thermometers and microscopes were then taken as quickly as possible for about 10 or 15 minutes.

8. All thermometers used in these and other experiments were compared with a standard thermometer in a bath of water at various temperatures, and all readings given have been corrected for calibration errors. Corrections up to 5° had to be applied to one of the thermometers but the others were not out by more than 1° at any temperature.

9. The microscopes were both set up so that their readings increased from left to right when they were viewed from the normal position of an observer. Thus if R is the reading of the right hand microscope and L the simultaneous reading of the left hand microscope, the quantity R−L gives the variations of the length of the tape. The microscope readings are in millimetres. Now the observations taken with the tape in the trough give a correlation between values of R−L and the temperatures of tape. When the trough is removed and observations taken in air, the temperature of the tape can be deduced from the value of R−L and on comparing this with the thermometer readings the errors of the thermometers are determined. The values of R−L in air must be corrected to what they would be if the tape were immersed and subject to the buoyancy of the water: the weight of the whole tape (300 links) is 4½ lbs. The length between the microscopes was 22 links, so that the weight of the portion under measurement was (22/300)×(9/2)=0.33 lbs. Hence, the sag was 22×(0.33/12)²×1/24×7.92×25.4=1395 mm. But when the tape was in water its weight was effectively 7/8 of its weight in air: thus the sag in water was 49/64×1395=1068 mm. Thus values of R−L in air must be increased by 0.033 mm before being compared with values obtained under water.
10. A typical set of observations and calculations is tabulated below:

**Observations.**

<table>
<thead>
<tr>
<th>Thermometers</th>
<th>Microscopes</th>
<th>Mean Temp.</th>
<th>R - L</th>
<th>Mean Thermometer Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>145°</td>
<td>145°</td>
<td>147</td>
<td>144</td>
<td>145</td>
</tr>
<tr>
<td>144°</td>
<td>144°</td>
<td>141</td>
<td>142</td>
<td>141</td>
</tr>
<tr>
<td>140°</td>
<td>142</td>
<td>139°</td>
<td>141</td>
<td>142°</td>
</tr>
<tr>
<td>139°</td>
<td>139°</td>
<td>137°</td>
<td>139</td>
<td>139</td>
</tr>
<tr>
<td>137°</td>
<td>135</td>
<td>135</td>
<td>137</td>
<td>137°</td>
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<tr>
<td>135°</td>
<td>134°</td>
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<td>135</td>
<td>135</td>
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<tr>
<td>134°</td>
<td>135°</td>
<td>135°</td>
<td>134</td>
<td>134°</td>
</tr>
<tr>
<td>132°</td>
<td>135°</td>
<td>133</td>
<td>131</td>
<td>134</td>
</tr>
<tr>
<td>118°</td>
<td>119°</td>
<td>110</td>
<td>110</td>
<td>110°</td>
</tr>
<tr>
<td>109°</td>
<td>112°</td>
<td>112°</td>
<td>110</td>
<td>109°</td>
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<tr>
<td>110°</td>
<td>109°</td>
<td>109°</td>
<td>110</td>
<td>109°</td>
</tr>
<tr>
<td>107°</td>
<td>108°</td>
<td>108°</td>
<td>109</td>
<td>109°</td>
</tr>
<tr>
<td>109°</td>
<td>109°</td>
<td>107°</td>
<td>108</td>
<td>108°</td>
</tr>
</tbody>
</table>

- Removed trough, weather sunny, calm.

These results are plotted in Fig. 6. The circles are plotted from the first 2 groups of values of R-L, each value being taken to correspond with the mean of the two mean temperatures taken immediately before and after it; thus 6.686 is plotted against the mean of 145° and 142°, and so on. A straight line is then drawn through these points as closely as possible. Now in air the mean value of R-L was 5.971, which, corrected for buoyancy, becomes 6.004. This gives the point P, so that the mean temperature of the tape in air was 119°.

The mean thermometer readings in air are plotted as crosses. On this occasion, therefore, the synthetic thermometers were reading about 6° too low on the average, and the ordinary thermometers about 24° too low. Seven experiments were made with this tape, which was a steel tape 3/8° wide with blue surface: the results are tabulated below.

<table>
<thead>
<tr>
<th>Actual Temp: of Tape</th>
<th>Synthetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions</td>
<td>1</td>
</tr>
<tr>
<td>In shade 75</td>
<td>75°</td>
</tr>
<tr>
<td>Dull 86°</td>
<td>81°</td>
</tr>
<tr>
<td>Sunny, Calm 115°</td>
<td>115°</td>
</tr>
<tr>
<td>Sunny, Light breeze</td>
<td>112°</td>
</tr>
<tr>
<td>113°</td>
<td>113°</td>
</tr>
<tr>
<td>123°</td>
<td>118°</td>
</tr>
<tr>
<td>135°</td>
<td>120°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actual Temp: of Tape</th>
<th>Ordinary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions</td>
<td>1</td>
</tr>
<tr>
<td>In shade 75</td>
<td>75°</td>
</tr>
<tr>
<td>Dull 86°</td>
<td>81°</td>
</tr>
<tr>
<td>Sunny, Calm 115°</td>
<td>115°</td>
</tr>
<tr>
<td>Sunny, Light breeze</td>
<td>112°</td>
</tr>
<tr>
<td>113°</td>
<td>113°</td>
</tr>
<tr>
<td>123°</td>
<td>118°</td>
</tr>
<tr>
<td>135°</td>
<td>120°</td>
</tr>
</tbody>
</table>
Thus, in the sunlight, the synthetic thermometers gave readings from $0^\circ$ to $17^\circ$ too low and the ordinary thermometers were from $20^\circ$ to $35^\circ$ too low. In the shade and in dull weather, all thermometers were much closer to the truth.

A similar set of 4 experiments was made with a steel tape $\frac{1}{8}^\circ$ wide. Totally different results were obtained as will be seen from the table below.

<table>
<thead>
<tr>
<th>Actual Temp. of Tape</th>
<th>Conditions</th>
<th>Thermometer Readings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Synthetic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>90º</td>
<td>Sunny, hazy, calm</td>
<td>100.5</td>
</tr>
<tr>
<td>90º</td>
<td>bright, calm</td>
<td>115.2</td>
</tr>
<tr>
<td>90º</td>
<td>light breeze</td>
<td>100.3</td>
</tr>
<tr>
<td>90º</td>
<td></td>
<td>105.8</td>
</tr>
</tbody>
</table>

These experiments with the narrow tape show that the synthetic thermometers read too high and the ordinary thermometers about correctly. Another curious feature is that in two of these latter experiments, thermometer No. 2 reads much lower than the other synthetics, and thermometer No. 5 much higher than the other ordinary thermometer: the reason for this sudden change is a mystery. It may also be noted that in these experiments the sunlit portion of the tape was probably slightly hotter than the temperature given by the calculation: but errors on this account were not likely to have been more than $2^\circ$.

11. Most of these experiments with the trough incidentally gave determinations of the co-efficients of expansion of two tapes. For instance, referring to Fig. 4, the expansion for $40^\circ$ was $6.86 - 5.735 = 1.125$ mm. The length of tape between marks was 4395 mm. Hence the co-efficient of expansion was $0.0281 - 4395 = 0.000064$. The mean of 4 values for the wide tape was 0.000063, and the mean of 4 value for the narrow tape was 0.000064.

12. A screen was rigged up so that it could be raised or lowered quickly, and micrometer readings were taken at intervals of 20 seconds so as to determine how long a tape took to warm up or cool down after the screen was lowered or raised. It was found that the wide tape took $1\frac{1}{2}$ to 2 minutes to take up its temperature, and the narrow tape took 1 to $1\frac{1}{4}$ minutes.
13. Readings were taken every 20 seconds when the tape was hanging in the Sun in a light breeze. The length of the wide tape was found to fluctuate rapidly over a range that represented a range of about 18° F; in the case of the narrow tape a range representing about 8° F was found.

14. Experiments with a synthetic thermometer confirmed the previous result that the thermometer took 5 to 6 minutes to take up its temperature.

15. Some experiments were made with a differential expansion apparatus consisting of a strip of invar and a piece of steel tape placed alongside each other and fixed rigidly together at one end. The relative movement of the free ends was measured with the microscope. This apparatus could be used in various positions and at different heights above the ground. Although no very precise results could be obtained, the observations showed that when the apparatus and thermometers were lying in sunshine directly, on fairly smooth surfaces such as cement or hard gravel, the thermometers gave excessively low readings.

16. These experiments are by no means exhaustive, but they show how complicated the problem is. The different behaviour of the wide and narrow tapes is surprising. The rapid and considerable fluctuations in the temperature of the tape itself must prevent any precise measurements being made, even if a suitable design of thermometer can be evolved for each size of tape: to minimise the effect of these fluctuations each linear measurement should be made several times at regular intervals. It is difficult to arrive at any general conclusion other than that reliable traversing cannot be done with steel tapes except in dull weather. It is rather fortunate that most of our primary traversing has been done with the narrow kind of tape, which, through some curious coincidence of properties, gives more or less correct readings with ordinary tape thermometers.

17. There is evidently much room for further investigation into some of these problems, such as the effect of the dimensions and nature of the tape on the accuracy of the thermometer readings.

J. E. JACKSON,
Assistant Superintendent of Surveys.
FIGURE VII

FRONT VIEW

SECTION A

Wire gauze
Steel frame

Hole for hanging Thermometer

Brass wire gauze to protect glass tube & strengthen frame

Metal pod

Wire gauze cut away to read

Glass tube

Frame of steel tape

Casing made of steel tape

Metal filings

Bull of Thermometer

Bulb receptacle casing filled with fine metal filings of same metal as a steel tape

Glass tube passing through a cork

Casing made of blued steel tape same as a survey steel tape. (Not painted)

SIDE VIEW

FIG. 1

FIG. 2

FIG. 3

Sectional elevation of trough & microscopes
Engineering Surveys for Irrigation and Subsequent Allotment Surveys on Irrigation Schemes in Ceylon

By H. A. S. SMITH, M.A.
(Ceylon Survey Department)

At the Conference of Empire Survey Officers in 1931, Lieut.-Col. J. D. Campbell, D.S.O., R.E., and Leut.-Col. A. H. Gwyn, I.A., contributed a comprehensive paper on "Rectangulation Surveys for large Irrigation Projects in India," and on that occasion the discussion centred round the difficulties associated with meridian convergence when rectangulation covers very large areas. The surveys in Ceylon described in this present paper are incomparably smaller than the Indian ones, but there are many points of similarity between the objects to be achieved by the surveys in both countries. An adaptation of the rectangular system has, moreover, been used in Ceylon for contouring, but the scale of the work has been so much smaller than in India that the difficulty alluded to has not been encountered. On the other hand, the work in Ceylon has largely been carried out in dense jungle and, consequently, amongst other things, the theodolite has to be used for work which, in open country, could be done by simple chaining. There are, too, considerable differences between the Indian and the Ceylon systems of allotment which demand corresponding differences in methods of survey.

During the past four years the Ceylon Survey Department has been engaged in a number of surveys in connexion with Irrigation Schemes, both for the restoration of ancient and for the extension and improvement of existing works, including settlements of colonists in areas hitherto covered with jungle and practically uninhabited.
Twelve different schemes, comprising extents of over 100,000 acres and several hundred miles of irrigation channels, have either been finished or are still under survey by parties whose present strength is over 50 surveyors. A general system for this specialized type of survey has been evolved, but experiments with different methods in detail and with various instruments are still being carried out, so it is hoped that officers of other Empire Surveys, who may have experience of this type of work, will offer their comments and criticisms on the methods described in this paper.

The general aims of Irrigation Schemes.—Before touching on methods of survey, it is necessary to give a brief outline of the general aims of each of these schemes and to understand the exact purpose for which the finished plans are to be used. A typical scheme is the Minneriya Scheme. Minneriya Tank in the North-Central Province is very ancient and about the largest in Ceylon. Its full-supply capacity is of the order of 75,000 acre-feet or roughly 20 thousand million gallons of water, and it is capable of irrigating an area of approximately 20,000 acres for the cultivation of paddy. In 1931 there were only about 500 acres of annually cultivated land below this tank and the Government decided in that year to develop an additional 11,000 acres. By development was meant the provision of a network of new irrigation channels, a main agricultural road and cart tracks, and systematic allotment of the land to selected colonists from the other parts of the Island. The whole area had accordingly to be divided into lots of 5 and 10 acres suitable for this allotment.

The Survey Department was called upon to prepare large-scale plans of the area appropriate to the needs of Irrigation Department Engineers for lay-out of their channel and road system and for the division of the area into allotments. Nearly the whole of the area was covered with dense jungle, was fairly undulating, and had a mean slope of about 20 feet per mile along its greatest length.
Plans to be prepared.—Three sets of plans were therefore prepared:

(i) One set on the scale of 4 chains to one inch showed all natural and artificial features and contours of 1 foot and sometimes 2 feet, vertical interval.

(ii) Another set showed longitudinal and cross sections of channel and road traces together with plans of a few construction sites on a large scale for the detailed design of structures.

(iii) The third set showed the demarcation of the allotments, together with tenement lists which showed the number, description and extent of each lot formed; this set was issued to Revenue Officers for recording the names of allottees and terms of tenure.

Channel design and "Blocking out."—The contour plans (as the first set is commonly named) are used for two principal purposes, the lay-out of the channel and road system and the subdivision of the area into lots. These two operations are to a large degree inter-dependent because the channel system must suit the ground and the arrangement of lots (called locally the "Blocking Out"); the blocking out will determine, to some extent, the lay-out of the channels and roads. The Irrigation Department must design the channel system and so they too must "Block-out" the land and the two operations must proceed simultaneously.

Reliability of interpolated Contours.—The most important feature of any contour plan is the contours themselves; in this instance the irrigation engineers rely on them to decide the routes of channels and the lay-out of lots. If lots are described as irrigable, they must in fact be irrigable or there will be numerous applications for exemption from payment of water rates and consequent enquiries and waste of time; it will be embarrassing to an engineer to find that a channel has to go through a very deep cutting when the plan makes it appear to go through a cutting whose depth is the calculated full-supply depth, or to find that he must carry it between high double-banking and so subject to washaways. The test of accuracy
to be attained therefore becomes the practical one of finding on the ground the same levels as those shown on the plan as nearly as is required in engineering practice. Broadly speaking, the engineer requires contours to be generally correct and spot-levels to be correct to one-tenth of a foot. Interpolated contours are dependable when they pass between points of known height close together; their dependability will be proportional to the distance apart of spot-heights and will vary, too, according to whether the ground is regularly undulating or broken up by small spurs and ravines.

In thick jungle one cannot see what changes of slope occur between cleared lines, but the method described below ensures that errors in contours are localized and that the general direction is correct. Plate 1 shows contours interpolated between spot-heights at intervals of 150 links along parallel, cleared lines 4 chains apart.

A test of contour accuracy.—It happens that in the particular area shown in Plate 1 the accuracy of the contours was tested by tracing on the ground with a level the traces of channels within the reservation lots 380, 383, 392, 631, 592, and 595. This was taken as a test case, and the conclusions drawn from it were that the contours derived were accurate enough for all practical purposes and that contours in the remainder of the area were probably equally dependable. These conclusions have been further confirmed as construction proceeds.

Unit distances of 150 links and 4 chains between spot-heights are thus known to give thoroughly dependable contours in country which is, from the point of view of irrigation, quite steep. It is realized now that in flatter country than that shown in Plate 1 these units are too small, and so experiments are being made to find the maximum distances apart for any particular type of ground. Over very flat ground, distances of 8 chains and, for steeper ground, 5 chains are being tried. It is believed that these will give sufficient accuracy, and the increased distances will, of course, be economical.
The method of deriving contours.—To obtain even spacing of lines the following method has been found satisfactory:

The area is first divided into one-mile squares by grid lines set out from traverses, and the corners of each square are defined by large blocks of concrete which contain a bronze bolt as a reference point for position and height. The sides of these squares are oriented north-south and east-west, direction being controlled by azimuths from altitudes of the sun, correct to the nearest minute of arc.

Traverses closed between trig. points or other traverses are run along at least two sides of each square and, when the corners are fixed thereby, the other two sides are merely set out and cleared to form the closed figure. The one-mile squares are next broken down into four half-mile squares by lines set with a theodolite and cleared until they meet. From the half-mile squares lines are set at 4 or 5 chain intervals from two sides of the square and cleared by eye to meet in the middle. If they meet, their alignment is proved, and it may be said that they almost invariably do meet to within 20 links. These lines are set on bearings of 0° or 90°, whichever direction makes them most nearly normal to the general direction of the contours. Inspection of the area and an examination of the reduced levels of the control levelling will indicate the direction which is best for each portion of the area.

When clearing is complete the lines are picketed with small sticks, numbered and spaced at intervals of 150 links. Each one-mile line is given a number when north and south or a letter when east and west, and the intermediate lines are numbered as fractions. Plate 3 illustrates these operations and is self-explanatory.

All artificial and natural features are surveyed by means of theodolite traverses connected to the traverses from which the grid is set out. Detail is plotted first on the contour sheet and later on the blocking out demarcation sheet, if required to be shown. All traverses for contour survey are thus utilized for demarcation, and their standards of accuracy must be the usual departmental ones for cadastral survey.
The traverses by which the blocks at one-mile intervals are fixed are plotted by co-ordinates and thereafter the half-mile squares and contour levelling lines are scaled and ruled on the plans in straight lines. The 150-link intervals are next marked off and the spot-height corresponding to each picket is plotted in the manner shown in Plate 1.

The numbers of lines levelled, and the numbers of the pickets beside which readings are taken, are entered in every page of the levelling books, so that mistakes in plotting spot-heights are readily detected.

Control Levelling.—The datum of levels for schemes is the M.S.I. datum of the Geodetic Levelling of Ceylon. For the larger schemes new lines of secondary levelling between primary lines have provided accurate benchmarks within the areas surveyed, and closed networks of tertiary and minor levelling, based on these lines, provide all benchmarks required for the detail levelling. For smaller schemes tertiary, or even minor, levelling connected to the primary lines is sufficient.

Secondary lines are double-levelled with precise levels and invar staves. Tertiary lines are single-levelled with precise levels and invar staves, but the methods of reading and of booking are considerably modified. Both minor and detail levelling are done with ordinary Dumpy levels and wooden staves.

The standards of accuracy of the different classes of levelling are:

(i) Primary .005 $\sqrt{F}$ feet double-levelled.
(ii) Secondary .007 $\sqrt{F}$ feet double-levelled.
(iii) Tertiary .01 $\sqrt{F}$ feet single-levelled.
(iv) Minor .02 $\sqrt{F}$ feet single-levelled.
(v) Detail .10 feet for 1 mile or less, single-levelled.

When 1,000 $F$ is the distance in feet between benchmarks.

Demarcation of blocked-out lots.—The Irrigation Department does the blocking-out and forwards blue prints to the Survey Department for the demarcation of the new lots formed. These blue prints show boundaries without land marks,
provisional lot numbers, the sites of falls, sluices, outlets, etc., and hydraulic data for the information of the engineer in charge of construction. The new boundaries are transferred, by means of tracing paper, from the blue prints to the surveyors' Field Sheets, on which all traverse pickets have already been plotted. Bearings and distances are protracted and scaled and entered in pencil in a Field Book. When the lines have been set out, cleared and landmarks buried, the observed bearings and distances are entered in ink.

Plate 1 illustrates the blocking-out (in black) superimposed on the contour print (in brown). In actual practice the two surveys are plotted on separate sheets, but the combination of the two on one print is intended to illustrate the way in which the blocking-out is made to conform to the configuration of the ground.

It will be noted that allotment in Ceylon follows after the contour survey as a separate operation and, in this respect, differs from the Indian practice of cutting the area into rectangles and defining them during the contour survey. The Indian method is no doubt more economical, but it must be remembered that the Indian schemes covered millions of acres of more open and generally flatter areas than those dealt with in Ceylon. It will be seen from Plate 1 that the blocking-out is made to fit the configuration of the ground, whereas in India the equivalent of the blocking-out was apparently oriented to suit the irrigation plain but not to fit small variations of the ground surface. It appears probable that some of the rectangles defined in India were found to be unirrigable and others must have been absorbed or sub-divided by canals and channels constructed after the survey was complete, but, in dealing with great areas, the losses through these causes cannot have been large enough to matter. In Ceylon, however, the schemes are incomparably smaller, blocking-out is intensive and complete development of each area is aimed at. Lots which are unirrigable are devoted to habitations, or to crops which do not require irrigation; thus every lot formed by the blocking-out is utilized.

Contouring by direct methods and "profiles."—Two surveys in the vicinity of Colombo in con-
nection with schemes of flood protection and drainage and reclamation of swamps have recently been completed and deserve mention because of the novel system of "profiles" plotted over the contours. Plate 2 illustrates these profiles. The contours in these surveys are found instrumentally and are very accurate. The ground is very flat, mostly open and very valuable, so that the instrumental method is desirable for these several reasons. Two lines of the primary levelling net pass through the areas and provide ample control of heights; co-ordinated traverses control the survey of detail.

The value of profiles.—The value of the profiles is perhaps more apparent to an engineer than to a surveyor. In every flat country like this, drainage is difficult and the engineer has to take advantage of very small natural drainage line and of every favourable gradient; furthermore the land is nearly all under private ownership, so that strips required for any new works must be acquired at high cost—an additional reason why great detail of the configuration of the ground will help the engineer to prepare the most economical scheme. Profiles meet the case admirably, not only as pictorial representations of ground surfaces but, in addition, they provide a means of direct computation of earthwork quantities. The height shown on each profile must be equal to the contour value at all points when the two cross; hence the profiles incidentally provide a very good check on the contours.

The system of profiles plotted over the contours was introduced several years ago by Mr. W. M. Thyne, M.Inst.C.E., the Colombo Waterworks Engineer, and has been followed in surveys of catchment areas for the Labugama Reservoir as well as in the surveys described here.
EXTRACT FROM FIELD SHEET
SHOWING
PROFILES & DATUM LINES

HORIZONTAL SCALE : 132 FEET TO AN INCH
VERTICAL SCALE : 5 FEET TO AN INCH
Datum M. S. L.

REFERENCE
BLUE..... DATUM LINES
BROWN..... CONTOURS
BLACK..... OTHER DETAIL

Plate 2
Diagram showing a method of setting out level lines and of picketting for spot levels

Spot Level pickets 100 links apart

Remainder 50 links

Spot Level pickets 100 links apart

Remainder Nil

Alignment pegs

Direction of Clearing

Half block C/17

Theodolite station

Scale: 10 Chains to an Inch