USE OF COMPUTERS IN SURVEYING ARCHAEOLOGICAL SITES.

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Introduction.

The two methods of surveying described in this paper are particularly suitable for certain archaeological applications. The fieldwork is quick and requires very few people but the processing of the results by traditional methods is long and tedious. The calculations are not complex but many accurate repetitions of trigonometrical formulae are required. Hence the methods are particularly suitable for exploitation by computer, making the office routines quicker than the field routines so considerably reducing the overall survey time from field to final plot.

Angular Intersection.

The principle of this method is probably very familiar to everyone. Using a theodolite bearings are taken from two known points A and B to a point P, which can then be fixed relative to A and B. The basic problem is shown in Fig. 1.

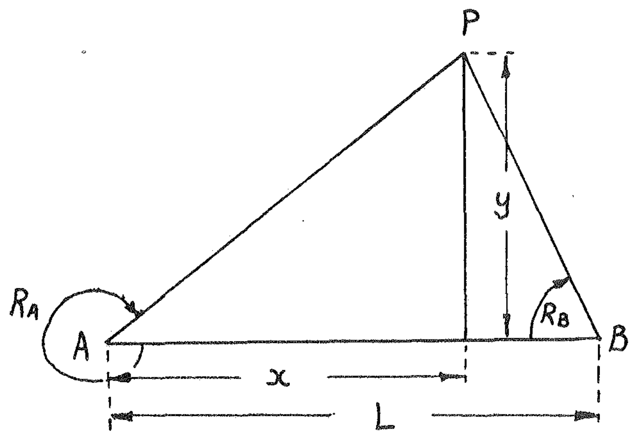

Fig. 1.

On sloping sites it is difficult to measure horizontally using tapes, and it becomes more difficult in windy conditions. However using the intersection method from a horizontal base, or one which has been corrected to the horizontal, the calculations will give the horizontal distances to the point P. Furthermore theodolite observations are less susceptible to the effect of wind.

Field Operations.

The observer on the theodolite at one station reads the angles to a series of points. These are indicated by an assistant who moves around holding a ranging pole or surveyor's arrow on the points in a pre-arranged sequence. When readings have been taken to all the points the theodolite is transferred to the second station and the whole procedure is repeated. It is important to ensure that the points are taken in the same sequence as the first set. A better system is to have a theodolite set on each station so that the readings can be taken simultaneously on to each point as it is visited. For a 50% increase in manpower a 100% increase in productivity results. In such a case, if points are closely spaced, the two observers may get out of sequence in the numbering of their readings. This arises as speed increases. It is a wise precaution to check after each betch of 10 to 20 points with some mutually agreed signal between observers and assistant. If any error in sequence has arisen then the area of search is restricted to those points subsequent to the last check.

The assistant must be thoroughly briefed on the general task, and the importance of holding the ranging pole vertical in those conditions where the bottom of the pole will not be visible from the theodolite. Then he must be briefed on the points to be visited. It is best to do this in blocks covering particular sections of the work.

A very detailed sketch of the site will be required on which the points observed can be marked. This ensures that no feature is overlooked, and it is invaluable for producing the final plot.

The base line should be set out in the higher part of the site. This gives the theodolite a good command of all the points to be observed, and in many instances the ranging pole foot can be observed on the required point. An experienced team will be able to maintain an overall average rate of work of 40 points per hour.

Computing.

Refering to Fig. 1, the values of x and y can be found by the application of elementary trigonometry. The usual solution would be in terms of the base line length L, and the angles A and B. The theodolites would usually be zeroed along the base line, towards the other station. Thus while the reading on one instrument will be the value normally used, the other reading will be 360 - the angle to be used. While it is easy to make this conversion it is more convenient to incorporate this in the solution and let the computer handle it. Consequently instead of dealing with both internal angles A and B, the solution presented here is in terms of theodolite readings R_A and R_B. If R_A = A then R_B = 360 - B and vice versa, depending upon which side of AB the point P lies.

By the Sine Rule $AP = \frac{L \times \sin R_B}{\sin(R_A - R_B - 180)}$

and then

$x = AP \cos R_A$ and $y = - AP \sin R_A$.

It is a simple programming job to input the base line length and the corresponding pairs of readings, and then to output the pairs of co-ordinates x and y. Wherever P lies in relation to AB the co-ordinates will be given the correct sign, assuming A to be the origin and AB the positive x axis.

A small extension to the programme will cater for the situation where A and B are points on a larger site grid. In this case the programme will give the overall grid co-ordinates.

With only a little more effort matters can be arranged so that in addition to the numerical output a graph plotter will produce a drawing with all the points marked and numbered.

It is worth giving some thought to the input format. Then the field readings can be booked directly on to a computer coding sheet, so saving the labour of transcribing them. If the format is arranged so as to leave a large part of the sheet blank, then this space can be used for the field sketches. This means that after taking the readings and booking them in the field there is nothing more to do until the plot of the points comes back from the computer.

Applications.

An ideal trial of this method was afforded to us on the Brough of Birsay in Orkney. For several seasons a joint programme of work was undertaken on this site by the Universities of Bradford and Durham. Much of the site lies on a comparatively steep slope, with a lower level area close to the sea. There are a number of Viking long-houses on the slope, and on the level portion there is a cathedral complex outlined by the lower courses of the walls.

Individual plans of those long-houses which had been excavated and consolidated were available, but no overall large scale plan existed. Part of our surveying brief was tp produce a large scale plan of the area to link the various elements together and at the same time to check the accuracy of the individual plans which existed.

We put the main base line for the grid at the top end of the site and at right angles to the line of slope. The two main points on this base line gave an excellent command of the site. From them angles were taken simultaneously to pre-selected points on the long-houses. Sufficient points were taken on each house for a completely new drawing to be made if necessary. The computer plots were done to the same scale as the available plans and the two matched up. Almost without exception the fit was very good. Any discrepancies were usually due to an error in punching up the data or in transcribing from the field books.

The Cathedral area was treated as a new survey. In consequence a number of dimensions were taken by steel tape and details of wall thisknesses, doorway openings etc. were measured in the same way. At the same time much of this detail was recorded from the theodolites. This formed a very useful check because most of the masonry was well defined. Here again the agreement was better than we had expected and any differences were not of a magnitude that could be plotted.

Tacheometry.

When using a theodolite or level it will usually be apparent that as well as the main cross wires running horizontally and vertically right across the telescope field of view, there are two short horizontal lines equally spaced above and below the main horizontal as shown in Fig. 2. These are stadia lines and they enable the instrument to be used as a tacheometer.

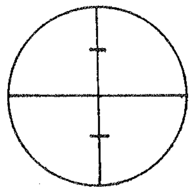

Fig. 2. Stadia Lines.

The simplest application of tacheometry is when using a level, but it is not as flexible as when a theodolite is used. However it forms a good introduction to the principles involved. When a staff is sighted through a level the line of sight is horizontal and the staff is vertical. The staff is at right angles to the line of sight and under these conditions as illustrated in Fig. 3.

D = 100 (SH - SL)
SH = Highest Staff Reading
SL = Lowest Staff Reading
D = Distance

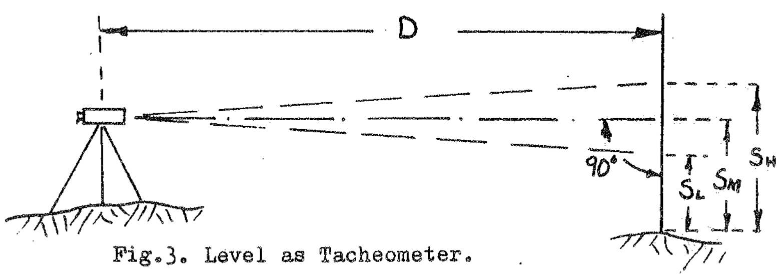

Fig.3. Level as Tacheometer.

If the staff readings are 2.173 and 2.018, then

$$D = 100 \times (2.173 - 2.018) = 15.5$$

The value of the multiplying constant, 100, depends on the optical design of the instrument, and very rarely is any other value used.

There are two things to note here. The first is that the units for D are the same as the units in which the staff is marked. A metric staff gives the result in metric and an Imperial staff will give an Imperial result. The second thing to note is that the accuracy of the result depends upon the accuracy with which the staff is read. This in turn depends on the power of the telescope, the distance of the staff and the lighting conditions. Sight distances should not exceed 175m. as at this range accurate staff readings become impossible. Any in accuracies in staff reading are also multiplied by 100, so that the measurements are not in the precision class. The accuracy in distance will be about 1/400 to 1/500. However as long as the method is used with discretion in locating features which by their nature are not precise, it will be found to be of great power and flexibility. Of course it may also be used when the scale of the final plot is so small that the inaccuracies of measurement are below the threshold of plotting accuracy. If contours or spot heights are required they may be obtained with little extra work. A good standard procedure is to take all readings as though levels are required. It is almost as quick to do this as it is to remember to omit part of the routine, and sometimes the extra information comes in useful.

Inclined Sights.

The method as described so far has been for a horizontal line of sight, but this of course is very restrictive. The critical points of observation often lie above or below the telescope's field of view. With a theodolite the ability to tilt up or down greatly increases the area covered. However, as with all benefits a price has to be paid, and in tacheometry the price is an increase in the calculations to be done.

Although the line of sight may now be inclined to the horizontal the staffman keeps the staff vertical, and corrections are made by including the angle of the tilt of the telescope in the calculations.

Formulae.

Before the era of the electronic calculator and the computer tacheometric calculations, although simple, were tedious to do, even with tables to help the work along. Now the position is different and the calculations can be done at a speed to match that of the fieldwork. A competent programmer can quickly and easily write a suitable program .

For an inclined sight as shown in Fig. 4. let the staff readings be

higher stadia SH
lower stadia SL
middle line SM

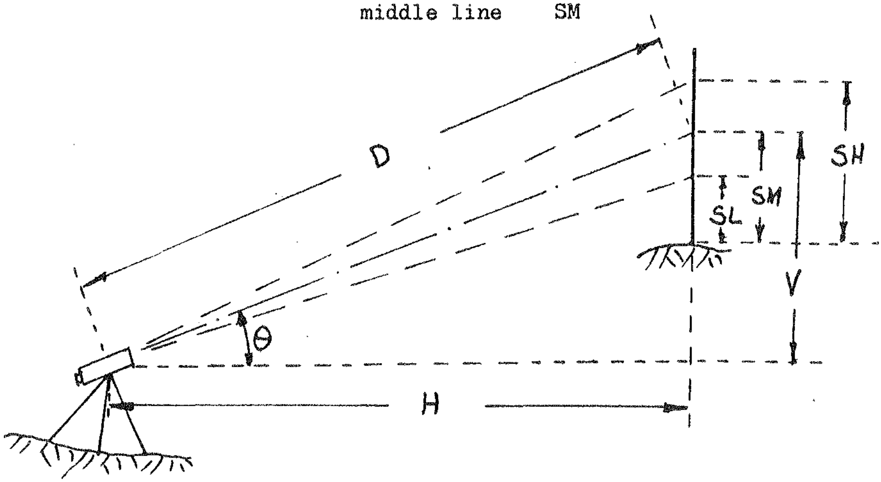

Fig. 4.

Let the angle of inclination of the telescope, up or down from the horizontal be θ, then

$$\text{sight distance } D = 100\ (SH - SL) \cos\theta$$

The horizontal distance H from the vertical through the theodolite t the staff is given by

$$H = 100\ (SH - SL) \cos\theta$$

The vertical distance V from the horizontal through the theodolite t the reading of the middle line on the staff is given by

$$V = 100\ (SH - SL) \cos\theta \sin\theta$$

If as in Fig. 5 the instrument is set at a height h above a station reduced level Ls, then the reduced level of the point at which the s is held Lp, is given by

$$Lp = Ls + h \pm V - SM$$

The or - sign in front of the V arises because the sight mey be inclined upwards or downwards.

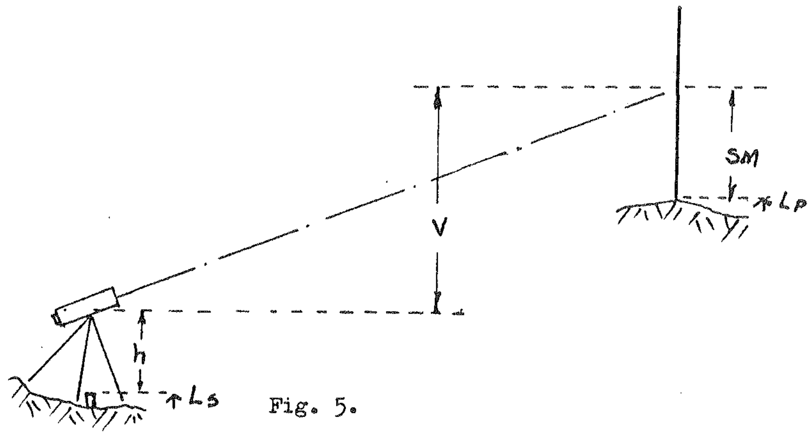

Fig. 5.

Application of method.

Once the instrument and calculating techniques are understood they can be put to use within a general surveying framework. Tacheometry is part of the tactics of surveying, but the overall framework in which it is used is the strategy, and both are important in producing the final result.

The positions of the survey stations from which the tacheometer will be used may be fixed by any surveying method which will give the required accuracy. The absolute position of each point must be known within an error which will not be apparent on a plot at the largest likely scale to be used. The stations must be so distributed over the area that no tacheometric measurement will contain an error that will be apparent on the plot. Usually if the points are carefully chosen to command an area of detail without using long sights it will be found that the work proceeds faster anyway. A simple triangulation system will often be most suitable, and two people can do this quite quickly. It is important to walk all over the site at the beginning, two or three times, putting in ranging poles in tentative positions, then they can be moved and adjusted to give the best layout. Care and thought at this stage pay dividends later in simplifying and speeding up operations.

Station Routine.

Tacheometric work at a station begins by taking a zero reading for the horizontal angles onto some convenient Reference Object. The R.O. is usually one of the other main stations, not necessarily the nearest one. If the R.O. is a long way off it will keep the angular error small when sighting it. Then the readings are taken on the points of detail which are to be surveyed. This is done to an agreed plan and based on a good sketch of the area around the station. As well as taking the stadis line readings on the staff, and the vertical angle it is necessary to take the horizontal reading. This will give the direction to the point, which combined with the horizontal distance H fixes the position of the point. The points should be numbered consecutively over the whole site. In this way a point number can mean only one unique spot. When all the tacheometer readings have been taken the R.O. should be sighted and the zero angle checked. If there are a lot of points to observe from one station it is prudent to check the zero reading periodically then should an error be discovered the number of reading thrown into doubt is limited. In a day's work up to a hundred sets of readings may be taken so it is important that the booking be done neatly and in an orderly manner, supported by a good, detailed, annotated sketch.

Computing.

At the lowest level of computer use each station can be treated as the origin and the direction to the R.O. as the direction of the x-axis. The output can then be in the form of the local x and y co-ordinates. When doing this it should be remembered that theodolites are gradua ed clockwise, so that to apply the usual sign rules of trigonometry the theodolite reading is subtracted from 360 . Plotting can be done directly on to the main plot, or each station's work can be plotted on to graphpaper. Each little sub-plot can then be correctly aligned on the main plot and the detail traced off.

At the next level of computer use information about each station location is input to the machine. Then the output can be in the form of global co-ordinates.

With a graph plotting facility either station plots or global plots can be produced. This is a tremendously helpful step. If contouring or other work with levels is being done then the points on the plot can have the levels written against them. It is also convenient to have another identical plot of points with the serial numbers written against them. This saves a lot of time in identifying and checking back on "rogue" results due to transcription or punching errors.

Here again with a suitable input format it is possible to record in the field directly on to the coding sheet. From then on all the work is done by the computer until the plot of points is produced. The only thing left to do is the really interesting part of making the picture appear around the dots.

Applications.

We have employed this technique on a wide variety of sites for contouring, delineating earthworks, surveying ancient field boundaries, settlement sites, an early 17th C. iron smelting complex and other features, as follows

Bar Hill Roman Fort on the Antonine Wall.

The Dod, Roxburghshire, Iron age multi-vallate earthworks and settlement sites.

Rispain, Wigtownshire, Iron age ditch and double bank earthworks.

Kilpatrick, Arran, early field boundaries, scattered settlements and features

Cruggleton Castle, Wigtownshire, medieaval earthworks and cliff edge defences.

Smailholme Tower, Roxburghshire, medieval field boundaries, settlements, isolated farm buildings.

Glenkinglass, Argyllshire, 17th C. Iron smelting complex.

Freswick, Caithness, multi-period settlement site.

The Hirsel, contour survey of early medieval site including terraces.