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Basic concepts of surveying

The aim of this chapter is to introduce the reader to the basic concepts of surveying. It is therefore the most important chapter and worthy of careful study and consideration.

1.1 DEFINITION

Surveying may be defined as the science of determining the position, in three dimensions, of natural and man-made features on or beneath the surface of the Earth. These features may be represented in analogue form as a contoured map, plan or chart, or in digital form such as a *digital ground model* (DGM).

In engineering surveying, either or both of the above formats may be used for planning, design and construction of works, both on the surface and underground. At a later stage, surveying techniques are used for dimensional control or setting out of designed constructional elements and also for monitoring deformation movements.

In the first instance, surveying requires management and decision making in deciding the appropriate methods and instrumentation required to complete the task satisfactorily to the specified accuracy and within the time limits available. This initial process can only be properly executed after very careful and detailed reconnaissance of the area to be surveyed.

When the above logistics are complete, the field work – involving the capture and storage of field data – is carried out using instruments and techniques appropriate to the task in hand.

Processing the data is the next step in the operation. The majority, if not all, of the computation will be carried out with computing aids ranging from pocket calculator to personal computer. The methods adopted will depend upon the size and precision of the survey and the manner of its recording; whether in a field book or a data logger. Data representation in analogue or digital form may now be carried out by conventional cartographic plotting or through a totally automated computer-based system leading to a paper- or screen-based plot. In engineering, the plan or DGM is used when planning and designing a construction project. The project may be a railway, highway, dam, bridge, or even a new town complex. No matter what the work is, or how complicated, it must be set out on the ground in its correct place and to its correct dimensions, within the tolerances specified. To this end, surveying procedures and instrumentation of varying precision and complexity are used depending on the project in hand.

Surveying is indispensable to the engineer when planning, designing and constructing a project, so all engineers should have a thorough understanding of the limits of accuracy possible in the construction and manufacturing processes. This knowledge, combined with an equal understanding of the limits and capabilities of surveying instrumentation and techniques, will enable the engineer to complete the project successfully in the most economical manner and in the shortest possible time.

1.2 PRINCIPLES

Every profession must be founded upon sound practice and in this engineering surveying is no different. Practice in turn must be based upon proven principles. This section is concerned with examining the principles of survey, describing their interrelationship and showing how they may be applied in practice. Most of the principles below have an application at all stages of a survey and it is an unwise and unprofessional surveyor who does not take them into consideration when planning, executing, computing and presenting the results of the survey work. The principles described here have application across the whole spectrum of survey activity, from field work to photogrammetry, mining surveying to metrology, hydrography to cartography, and cadastral to construction surveying.

1.2.1 Control

A control network is the framework of survey stations whose coordinates have been precisely determined and are often considered definitive. The stations are the reference monuments, to which other survey work of a lesser quality is related. By its nature, a control survey needs to be precise, complete and reliable and it must be possible to show that these qualities have been achieved. This is done by using equipment of proven precision, with methods that satisfy the principles and data processing that not only computes the correct values but gives numerical measures of their precision and reliability.

Since care needs to be taken over the provision of control, then it must be planned to ensure that it achieves the numerically stated objectives of precision and reliability. It must also be complete as it will be needed for all related and dependent survey work. Other survey works that may use the control will usually be less precise but of greater quantity. Examples are setting out for earthworks on a construction site, detail surveys of a greenfield site or of an as-built development and monitoring many points on a structure suspected of undergoing deformation.

The practice of using a control framework as a basis for further survey operations is often called 'working from the whole to the part'. If it becomes necessary to work outside the control framework then it must be extended to cover the increased area of operations. Failure to do so will degrade the accuracy of later survey work even if the quality of survey observations is maintained.

For operations other than setting out, it is not strictly necessary to observe the control before other survey work. The observations may be concurrent or even consecutive. However, the control survey must be fully computed before any other work is made to depend upon it.

1.2.2 Economy of accuracy

Surveys are only ever undertaken for a specific purpose and so should be as accurate as they need to be, but not more accurate. In spite of modern equipment, automated systems, and statistical data processing the business of survey is still a manpower intensive one and needs to be kept to an economic minimum. Once the requirement for a survey or some setting out exists, then part of the specification for the work must include a statement of the relative and absolute accuracies to be achieved. From this, a specification for the control survey may be derived and once this specification has been achieved, there is no requirement for further work.

Whereas control involves working from 'the whole to the part' the specification for all survey products is achieved by working from 'the part to the whole'. The specification for the control may be derived from estimation based upon experience using knowledge of survey methods to be applied, the instruments to be used and the capabilities of the personnel involved. Such a specification defines the expected quality of the output by defining the quality of the work that goes into the survey. Alternatively a statistical analysis of the proposed control network may be used and this is the preferable approach. In practice a good specification will involve a combination of both methods, statistics tempered by experience. The accuracy

of any survey work will never be better than the control upon which it is based. You cannot set out steelwork to 5 mm if the control is only good to 2 cm.

1.2.3 Consistency

Any ‘product’ is only as good as the most poorly executed part of it. It matters not whether that ‘product’ is a washing machine or open heart surgery, a weakness or inconsistency in the endeavour could cause a catastrophic failure. The same may apply in survey, especially with control. For example, say the majority of control on a construction site is established to a certain designed precision. Later one or two further control points are less well established, but all the control is assumed to be of the same quality. When holding-down bolts for a steelwork fabrication are set out from the erroneous control it may require a good nudge from a JCB to make the later stages of the steelwork fit.

Such is the traditional view of consistency. Modern methods of survey network adjustment allow for some flexibility in the application of the principle and it is not always necessary for all of a particular stage of a survey to be of the same quality. If error statistics for the computed control are not to be made available, then quality can only be assured by consistency in observational technique and method. Such a quality assurance is therefore only second hand. With positional error statistics the quality of the control may be assessed point by point. Only least squares adjustments can ensure consistency and then only if reliability is also assured. Consistency and economy of accuracy usually go hand in hand in the production of control.

1.2.4 The Independent check

The independent check is a technique of quality assurance. It is a means of guarding against a blunder or gross error and the principle must be applied at all stages of a survey. Failure to do so will lead to the risk, if not probability, of ‘catastrophic failure’ of the survey work. If observations are made with optical or mechanical instruments, then the observations will need to be written down. A standard format should be used, with sufficient arithmetic checks upon the booking sheet to ensure that there are no computational errors. The observations should be repeated, or better, made in a different manner to ensure that they are in sympathy with each other. For example, if a rectangular building is to be set out, then once the four corners have been set out, opposite sides should be the same length and so should the diagonals. The sides and diagonals should also be related through Pythagoras’ theorem. Such checks and many others will be familiar to the practising surveyor.

Checks should be applied to ensure that stations have been properly occupied and the observations between them properly made. This may be achieved by taking extra and different measurements beyond the strict minimum required to solve the survey problem. An adjustment of these observations, especially by least squares, leads to misclosure or error statistics, which in themselves are a manifestation of the independent check.

Data abstraction, preliminary computations, data preparation and data entry are all areas where transcription errors are likely to lead to apparent blunders. Ideally all these activities should be carried out by more than one person so as to duplicate the work and with frequent cross-reference to detect errors. In short, wherever there is a human interaction with data or data collection there is scope for error.

Every human activity needs to be duplicated if it is not self-checking. Wherever there is an opportunity for an error there must be a system for checking that no error exists. If an error exists, there must be a means of finding it.

1.2.5 Safeguarding

Since survey can be an expensive process, every sensible precaution should be taken to ensure that the work is not compromised. Safeguarding is concerned with the protection of work. Observations which are

written down in the field must be in a permanent, legible, unambiguous and easily understood form so that others may make good sense of the work. Observations and other data should be duplicated at the earliest possible stage, so that if something happens to the original work the information is not lost. This may be by photocopying field sheets, or making backup copies of computer files. Whenever the data is in a unique form or where all forms of the data are held in the same place, then that data is vulnerable to accidental destruction.

In the case of a control survey, the protection of survey monuments is most important since the precise coordinates of a point which no longer exists or cannot be found are useless.

1.3 BASIC MEASUREMENTS

Surveying is concerned with the fixing of position whether it be control points or points of topographic detail and, as such, requires some form of reference system.

The physical surface of the Earth, on which the actual survey measurements are carried out, is not mathematically definable. It cannot therefore be used as a reference datum on which to compute position.

Alternatively, consider a level surface at all points normal to the direction of gravity. Such a surface would be closed and could be formed to fit the mean position of the oceans, assuming them to be free from all external forces, such as tides, currents, winds, etc. This surface is called the geoid and is defined as the equipotential surface that most closely approximates to mean sea level in the open oceans. An equipotential surface is one from which it would require the same amount of work to move a given mass to infinity no matter from which point on the surface one started. Equipotential surfaces are surfaces of equal potential; they are not surfaces of equal gravity. The most significant aspect of an equipotential surface going through an observer is that survey instruments are set up relative to it. That is, their vertical axes are in the direction of the force of gravity at that point. A level or equipotential surface through a point is normal, i.e. at right angles, to the direction of gravity. Indeed, the points surveyed on the physical surface of the Earth are frequently reduced, initially, to their equivalent position on the geoid by projection along their gravity vectors.

The reduced level or elevation of a point is its height above or below the geoid as measured in the direction of its gravity vector, or plumb line, and is most commonly referred to as its height above or below mean sea level (MSL). This assumes that the geoid passes through local MSL, which is acceptable for most practical purposes. However, due to variations in the mass distribution within the Earth, the geoid, which although very smooth is still an irregular surface and so cannot be used to locate position mathematically.

The simplest mathematically definable figure which fits the shape of the geoid best is an ellipsoid formed by rotating an ellipse about its minor axis. Where this shape is used by a country as the surface for its mapping system, it is termed the reference ellipsoid. *Figure 1.1* illustrates the relationship between these surfaces.

The majority of engineering surveys are carried out in areas of limited extent, in which case the reference surface may be taken as a tangent plane to the geoid and the principles of plane surveying applied. In other words, the curvature of the Earth is ignored and all points on the physical surface are orthogonally projected onto a flat plane as illustrated in *Figure 1.2*. For areas less than 10 km square the assumption of a flat Earth is perfectly acceptable when one considers that in a triangle of approximately 200 km², the difference between the sum of the spherical angles and the plane angles would be 1 second of arc, or that the difference in length of an arc of approximately 20 km on the Earth's surface and its equivalent chord length is a mere 8 mm.

The above assumptions of a flat Earth, while acceptable for some positional applications, are not acceptable for finding elevations, as the geoid deviates from the tangent plane by about 80 mm at 1 km or 8 m at 10 km from the point of contact. Elevations are therefore referred to the geoid, at least theoretically, but usually to MSL practically.

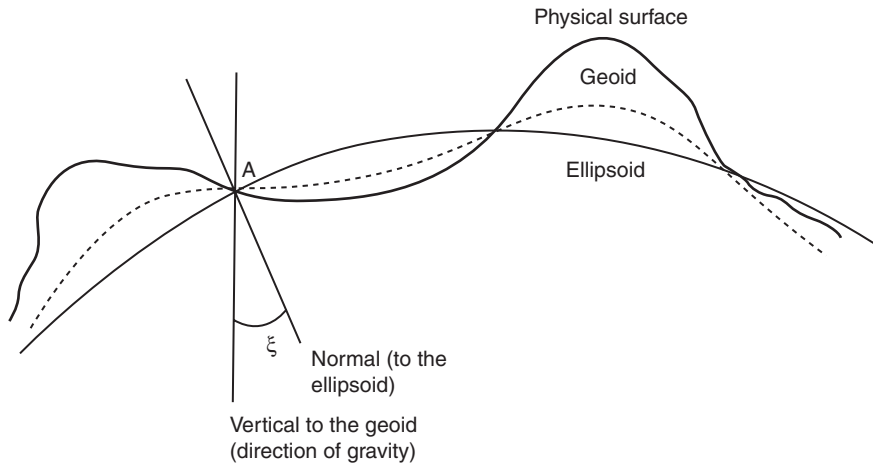


Fig. 1.1 Geoid, ellipsoid and physical surface

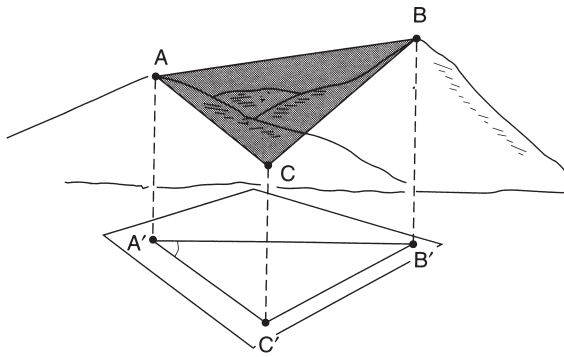


Fig. 1.2 Projection onto a plane surface

An examination of *Figure 1.2* clearly shows the basic surveying measurements needed to locate points A , B and C and plot them orthogonally as A' , B' and C' . Assuming the direction of B from A is known then the measured *slope distance* AB and the *vertical angle* to B from A will be needed to fix the position of B relative to A . The *vertical angle* to B from A is needed to reduce the slope distance AB to its equivalent horizontal distance $A'B'$ for the purposes of plotting. Whilst similar measurements will fix C relative to A , it also requires the *horizontal angle* at A measured from B to C ($B'A'C'$) to fix C relative to B . The *vertical distances* defining the relative elevation of the three points may also be obtained from the slope distance and vertical angle or by direct levelling (Chapter 3) relative to a specific reference datum. The five measurements mentioned above comprise the basis of plane surveying and are illustrated in *Figure 1.3*, i.e. AB is the slope distance, AA' the horizontal distance, $A'B$ the vertical distance, BAA' the vertical angle (α) and $A'AC$ the horizontal angle (θ).

It can be seen from the above that the only measurements needed in plane surveying are angle and distance. Nevertheless, the full impact of modern technology has been brought to bear in the acquisition and processing of this simple data. Angles may now be resolved with single-second accuracy using optical and electronic theodolites; electromagnetic distance measuring (EDM) equipment can obtain distances up

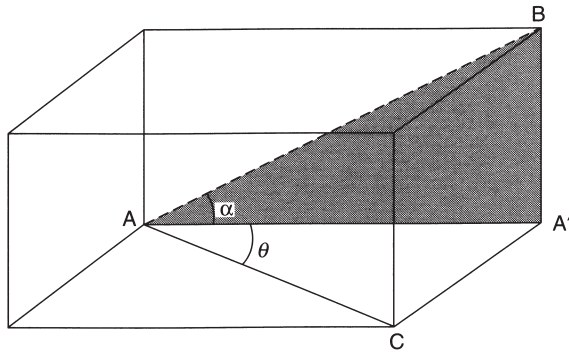


Fig. 1.3 Basic measurements

to several kilometres with millimetre precision, depending on the distance measured; lasers and north-seeking gyroscopes are virtually standard equipment for tunnel surveys; orbiting satellites are being used for position fixing offshore as well as on; continued improvement in aerial and terrestrial photogrammetric and scanning equipment makes mass data capture technology an invaluable surveying tool; finally, data loggers and computers enable the most sophisticated procedures to be adopted in the processing and automatic plotting of field data.

1.4 CONTROL NETWORKS

The establishment of two- or three-dimensional control networks is the most fundamental operation in the surveying of large or small areas of land. Control networks comprise a series of points or positions which are spatially located for the purpose of topographic surveying, for the control of supplementary points, or dimensional control on site.

The process involved in carrying out the surveying of an area, the capture and processing of the field data, and the subsequent production of a plan or map, will now be outlined briefly.

The first and obvious step is to know the purpose and nature of the project for which the surveys are required in order to assess the accuracy specifications, the type of equipment required and the surveying processes involved.

For example, a major construction project may require structures, etc., to be set out to subcentimetre accuracy, in which case the control surveys will be required to an even greater accuracy. Earthwork volumes may be estimated from the final plans, hence contours made need to be plotted at 2 m intervals or less. If a plan scale of 1/500 is adopted, then a plotting accuracy of 0.5 mm would represent 0.25 m on the ground, thus indicating the accuracy of the final process of topographic surveying from the supplementary control and implying major control to a greater accuracy. The location of topographic data may be done using total stations, GPS satellites, or, depending on the extent of the area, aerial photogrammetry. The cost of a photogrammetric survey is closely linked to the contour interval required and the extent of the area. Thus, the accuracy of the control network would define the quality of the equipment and the number of observations required.

The duration of the project will affect the design of survey stations required for the control points. A project of limited duration may only require a long, stout wooden peg, driven well into solid, reliable ground and surrounded by a small amount of concrete. A fine nail in the top defines the geometrical position to be located. A survey control point designed to be of longer duration is illustrated in Chapter 6, *Figure 6.15*.

The next stage of the process is a detailed reconnaissance of the area in order to establish the best positions for the control points.

Initially, data from all possible sources should be studied before venturing into the field. Such data would comprise existing maps and plans, aerial photographs and any previous surveying data of that area. Longitudinal sections may be drawn from the map contours to ensure that lines of sight between control points are well above ground level and so free of shimmer or refraction effects. If the surveys are to be connected into the national surveys of the country (Ordnance Survey National Grid in the UK), then the position of as many national survey points as possible, such as (in the UK) those on the GPS Active or Passive Network, should be located. These studies, very often referred to as the 'paper survey', should then be followed up with a detailed field reconnaissance.

This latter process locates all existing control in the area of interest, both local and national, and establishes the final positions for all the new control required. These final positions should be chosen to ensure clear, uninterrupted lines of sight and the best observing positions. The location of these points, and the type of terrain involved, would then influence the method of survey to be used to locate their spatial position.

Figure 1.4 indicates control points A, B, \dots, F , in the area to be surveyed. It is required to obtain the coordinate positions of each point. This could be done using any of the following methods:

- (a) Intersection or resection
- (b) Traversing
- (c) Networks
- (d) GPS satellites

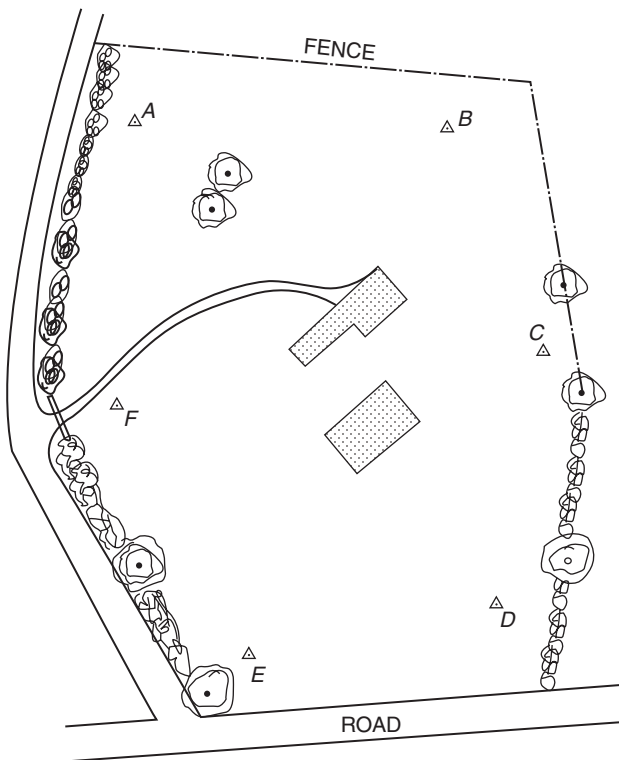


Fig. 1.4 Control points

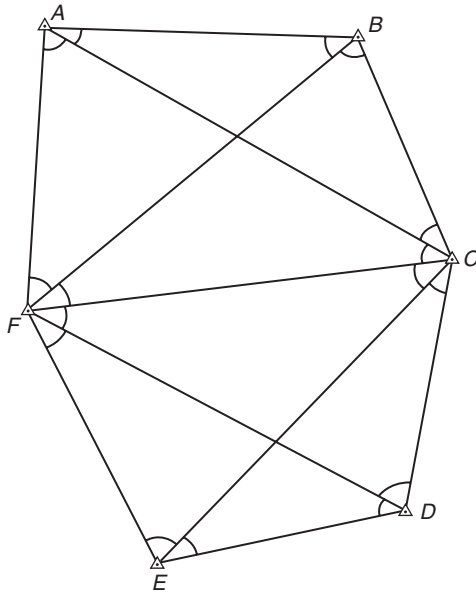


Fig. 1.5 A network

Figure 1.5 illustrates possible lines of sight. All the horizontal angles shown would be measured to the required accuracy to give the shape of the network. At least one side would need to be measured, say AB , to give the scale or size of the network. By measuring a check baseline, say ED , and comparing it with its value, computed through the network, the scale error could be assessed. This form of survey is classical triangulation and although forming the basis of the national maps of many countries, is now regarded as obsolete because of the need for lines of sight between adjacent points. Such control would now be done with GPS.

If the lengths of all the sides were measured in the same triangular configuration without the angles, this technique would be called 'trilateration'. Although giving excellent control over scale error, swing errors may occur. For local precise control surveys the modern practice therefore is to use a combination of angles and distance. Measuring every angle and every distance, including check sights wherever possible, would give a very strong network indeed. Using sophisticated least squares software it is now possible to optimize the observation process to achieve the accuracies required.

Probably the most favoured simple method of locating the relative coordinate positions of control points in engineering and construction is traversing. *Figure 1.6* illustrates the method of traversing to locate the same control points A to F . All the adjacent horizontal angles and distances are measured to the accuracies required, resulting in much less data needed to obtain coordinate accuracies comparable with the previous methods. Also illustrated are minor or supplementary control points a, b, c, d , located with lesser accuracy by means of a link traverse. The field data comprises all the angles as shown plus the horizontal distances Aa, ab, bc, cd , and dB . The rectangular coordinates of all these points would, of course, be relative to the major control.

Whilst the methods illustrated above would largely supply a two-dimensional coordinate position, GPS satellites could be used to provide a three-dimensional position.

All these methods, including the computational processes, are dealt with in later chapters of this book.

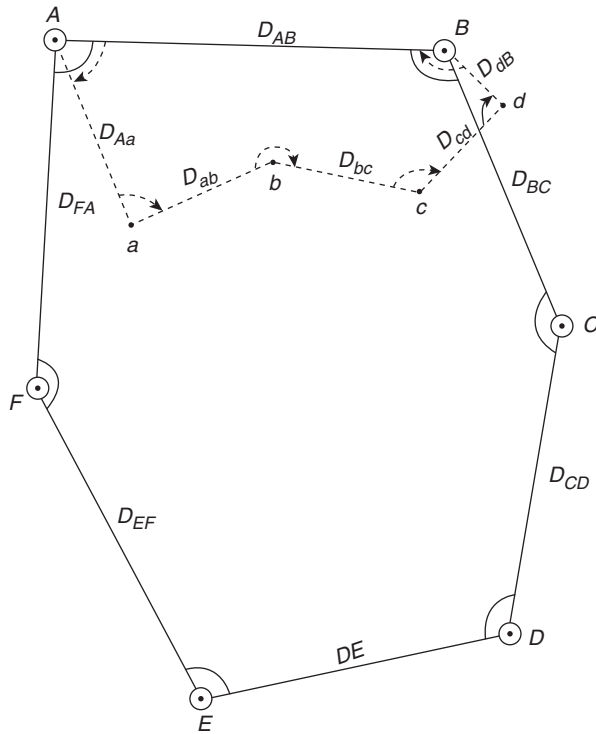


Fig. 1.6 Major traverse A to F. Minor link traverse A to B

1.5 LOCATING POSITION

Establishing control networks and their subsequent computation leads to an implied rectangular coordinate system over the area surveyed. The minor control points in particular can now be used to position topographic data and control the setting out of a construction design.

The methods of topographic survey and dimensional control will most probably be:

- (a) by polar coordinates (distance and bearing) using a total station; or
- (b) by GPS using kinematic methods.

Considering method (a), a total station would be set up over a control point whose coordinates are known as 'a', and back-sighted to another control point 'b' whose coordinates are also known. Depending on the software on board, the coordinates may be keyed into the total station. Alternatively, the bearing of the line 'ab', computed from the coordinates, may be keyed in. Assuming the topographic position of a road is required, the total station would be sighted to a corner cube prism fixed to a detail pole held vertically at (P_1), the edge of the road as shown in Figures 1.7 and 1.8. The field data would comprise the horizontal angle $baP_1(\alpha_1)$ and the horizontal distance D_1 (Figure 1.8). Depending on the software being used, the angle α_1 would be used to compute the bearing aP_1 relative to 'ab' and, with the horizontal distance D_1 , compute the rectangular coordinates of P_1 in the established coordinate system. This process is repeated for the remaining points defining the road edge and any other topographic data within range of the total station. The whole area would be surveyed in this way by occupying pairs of control points situated throughout the area.

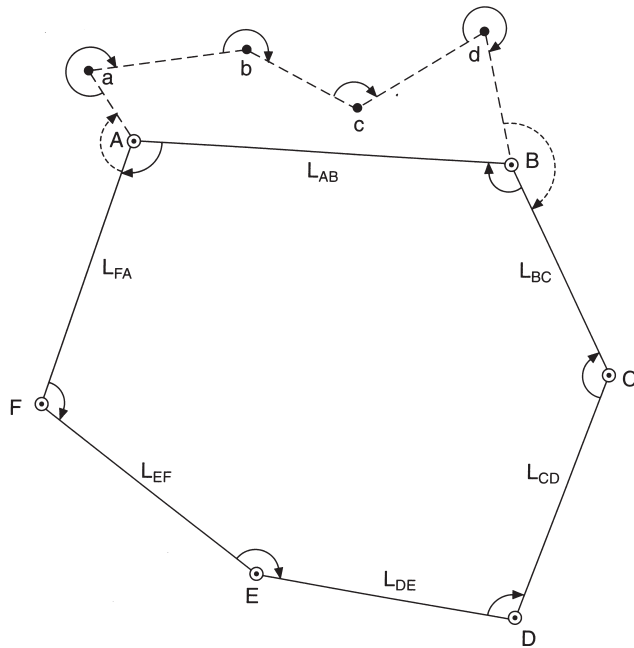


Fig. 1.7 Traverse

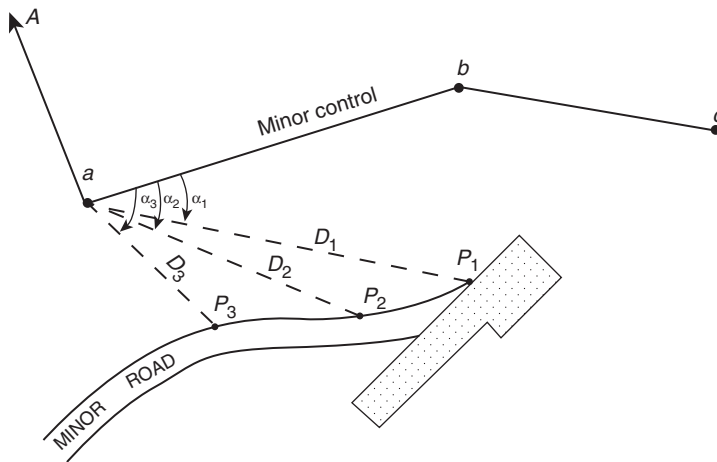


Fig. 1.8 Detailing by polar coordinates

For method (b), using GPS equipment, the methods are dealt with in detail in Chapter 9: Satellite positioning.

A further development is the integration of a total station with GPS. This instrument, produced by Leica Geosystems and called SmartStation, provides the advantages of both the systems (a) and (b).

If using existing control, the local coordinate data is copied into the SmartStation and used in the usual manner on existing pairs of control points. Where the GPS cannot be used because of excessive tree cover for instance, then the total station may be used in the usual way.

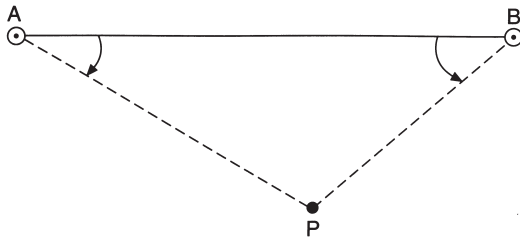


Fig. 1.9 Intersection

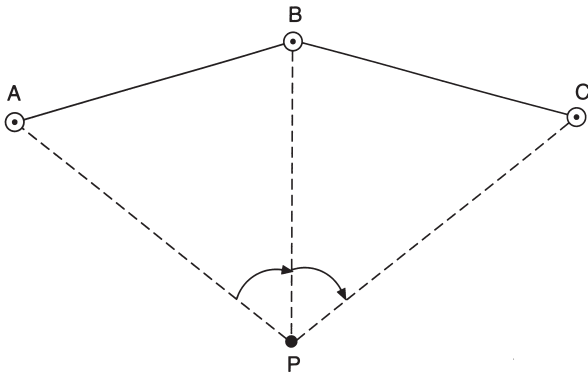


Fig. 1.10 Resection

Perhaps the most significant aspect of this instrument is that pairs of points for orientation as well as position could be established by GPS thereby eliminating the need to establish a prior control network, with great savings on time and money.

Alternative methods used very often for the location of single points are intersection, where P is fixed by measuring the horizontal angles BAP and PBA as shown in *Figure 1.9*, and resection (*Figure 1.10*). This method forms the basis of triangulation. Similarly, P could be fixed by the measurement of horizontal distances AP and BP , and forms the basis of the method of trilateration. In both these instances there is no independent check, as a position for P (not necessarily the correct one) will always be obtained. Thus at least one additional measurement is required, either by combining the angles and distances, by measuring the angle at P as a check on the angular intersection, or by producing a trisection from an extra control station.

Resection (*Figure 1.10*) is done by observing the horizontal angles at P to at least three control stations of known position. The position of P may be obtained by a mathematical solution as illustrated in Chapter 6.

It can be seen that all the above procedures simply involve the measurement of angles and distances.

1.6 PLOTTING DETAIL

In the past, detail would have been plotted on paper or a more stable medium such as plastic film. However, today all practical 'plotting' is computer based and there is now an abundance of computer plotting software

available that will not only produce a contour plot but also supply three-dimensional views, digital ground models, earthwork volumes, road design, drainage design, perspective views, etc.

1.6.1 Computer systems

To be economically viable, practically all major engineering/surveying organizations use an automated plotting system. Very often the total station and data logger are purchased along with the computer hardware and software as a total operating system. In this way interface and adaptation problems are precluded. *Figure 1.11* shows a computer driven plotter which is networked to the system and located separately.

The essential characteristics of such a system are:

- (1) Capability to accept, store, transfer, process and manage field data that is input manually or directly from an interfaced data logger (*Figure 1.12*).
- (2) Software and hardware are in modular form for easy access.
- (3) Software will use all modern facilities, such as 'windows', different colour and interactive screen graphics, to make the process user friendly.
- (4) Continuous data flow from field data to finished plan.
- (5) Appropriate database facility for the storage and management of coordinate and cartographic data necessary for the production of DGMs and land/geographic information systems.
- (6) Extensive computer storage facility.
- (7) High-speed precision flat-bed or drum plotter.

To be truly economical, the field data, including appropriate coding of the various types of detail, should be captured and stored by single-key operation, on a data logger interfaced to a total station. The computer



Fig. 1.11 *Computer driven plotter*



Fig. 1.12 Data logger

system should then permit automatic transfer of this data by direct interface between the logger and the system. The software should then: store and administer the data; carry out the mathematical processing, such as network adjustment, produce coordinates and elevations; generate data storage banks; and finally plot the data on completion of the data verification process.

Prior to plotting, the data can be viewed on the screen for editing purposes. This can be done from the keyboard or touch screen using interactive graphics routines. The plotted detail can be examined, moved, erased or changed as desired. When the examination is complete, the command to plot may then be activated. *Figure 1.13* shows an example of a computer plot.

1.6.2 Digital ground model (DGM)

A DGM is a three-dimensional, mathematical representation of the landform and all its features, stored in a computer database. Such a model is extremely useful in the design and construction process, as it permits

quick and accurate determination of the coordinates and elevation of any point. The DGM is formed by sampling points over the land surface and using appropriate algorithms to process these points to represent the surface being modelled. The methods in common use are modelling by 'strings', 'regular grids' or 'triangulated irregular networks'. Regardless of the methods used, they will all reflect the quality of the field data.

The 'regular grid' method uses appropriate algorithms to convert the sampled data to a regular grid of levels. If the field data permits, the smaller the grid interval, the more representative of landform it becomes. Although a simple technique, it only provides a very general shape of the landform, due to its tendency to ignore vertical breaks of slope. Volumes generated also tend to be rather inaccurate.

In the 'triangulated irregular networks' (TIN) method, 'best fit' triangles are formed between the points surveyed. The ground surface therefore comprises a network of triangular planes at various inclinations (*Figure 1.14(a)*). Computer shading of the model (*Figure 1.14(b)*) provides an excellent indication of the landform. In this method vertical breaks are forced to form the sides of triangles, thereby maintaining correct ground shape. Contours, sections and levels may be obtained by linear interpolation through

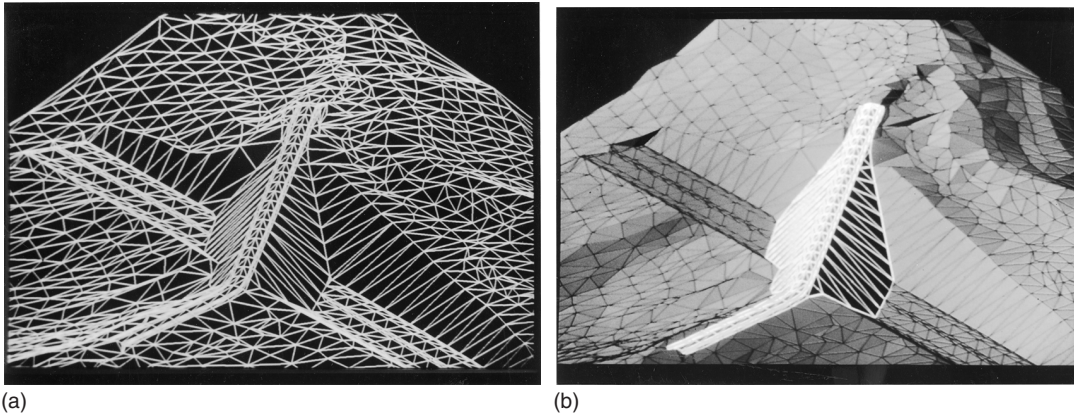


Fig. 1.14 (a) Triangular grid model, and (b) Triangular grid model with computer shading

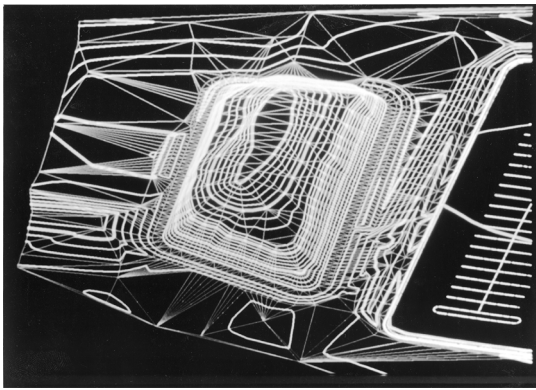


Fig. 1.15 Computer generated contour model

the triangles. It is thus ideal for contour generation (*Figure 1.15*) and computing highly accurate volumes. The volumes may be obtained by treating each triangle as a prism to the depth required; hence the smaller the triangle, the more accurate the final result.

1.6.3 Computer-aided design (CAD)

In addition to the production of DGMs and contoured plans, a computer-based surveying system permits the finished plan to be easily related to the designed structure. The three-dimensional information held in the database supplies all the ground data necessary to facilitate the finished design. *Figure 1.16* illustrates its use in road design.

The environmental impact of the design can now be more readily assessed by producing perspective views as shown in *Figure 1.17*. Environmental impact legislation makes this latter tool extremely valuable.

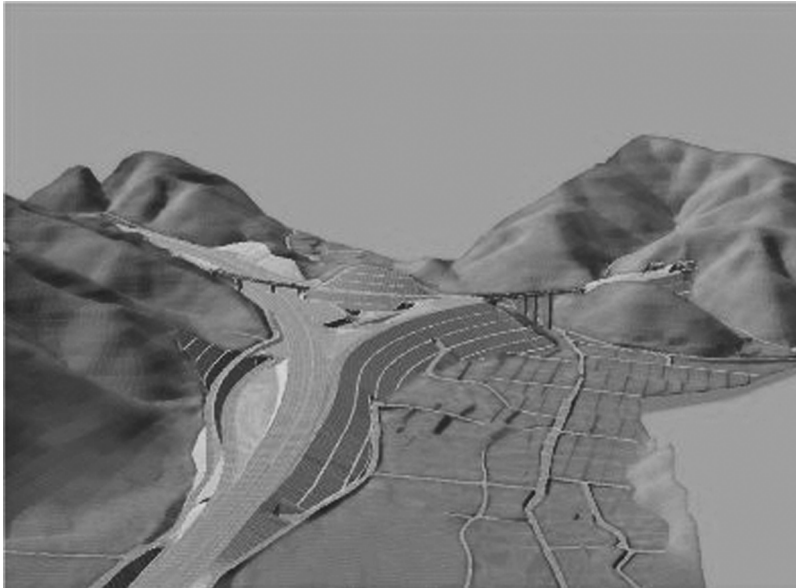


Fig. 1.16 *Computer aided road design – courtesy of ISP (Integrated Software Products)*

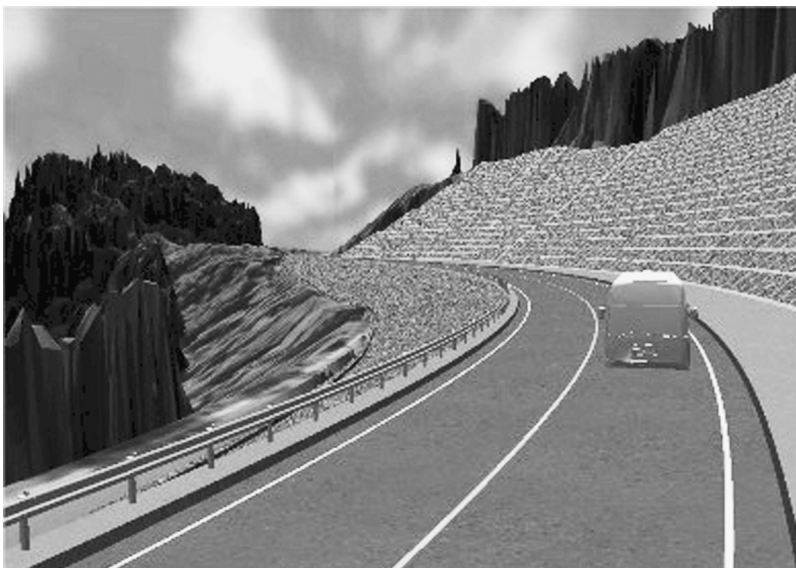


Fig. 1.17 *Perspectives with computer shading – courtesy of ISP (Integrated Software Products)*

1.7 SUMMARY

In the preceding sections the basic concepts of surveying have been outlined. Because of their importance they will now be summarized as follows:

- (1) *Reconnaissance* is the first and most important step in the surveying process. Only after a careful and detailed reconnaissance of the area can the surveyor decide upon the techniques and instrumentation required to complete the work economically and meet the accuracy specifications.
- (2) *Control networks* not only form a reference framework for locating the position of topographic detail and setting out constructions, but may also be used for establishing minor control networks containing a greater number of control stations at shorter distances apart and to a lower order of accuracy, i.e. *a, b, c, d* in *Figure 1.6*. These minor control stations may be better placed for the purpose of locating the topographic detail.

This process of establishing the major control to the highest order of accuracy, as a framework on which to connect the minor control, which is in turn used as a reference framework for detailing, is known as *working from the whole to the part* and forms the basis of all good surveying procedure.

- (3) *Errors* are contained in all measurement procedures and a constant battle must be waged by the surveyor to minimize and evaluate their effect.

It follows from this that the greater the accuracy specifications the greater the cost of the survey because it results in more observations, taken with greater care, over a longer period of time and using more precise (and therefore more expensive) equipment. It is for this reason that major control networks contain the minimum number of stations necessary and surveyors adhere to the economic principle of working to an accuracy neither greater than nor less than that required.

- (4) *Independent checks* should be introduced not only into the field work, but also into the subsequent computation and reduction of field data. In this way, errors can be quickly recognized and dealt with. Data should always be measured more than once and preferably in different ways. Examination of several measurements will generally indicate if there are blunders in the measuring process. Alternatively, close agreement of the measurements is indicative of high precision and generally acceptable field data, although, as shown later, high precision does not necessarily mean high accuracy, and further data processing may be necessary to remove any systematic error that may be present.
- (5) *Commensurate accuracy* is advised in the measuring process, i.e. the angles should be measured to the same degree of accuracy as the distances and vice versa. For guidance: 1" of arc subtends 1 mm at 200 m. This means that if distance is measured to, say, 1 in 200 000, the angles should be measured to 1" of arc, and so on.

In the majority of engineering projects, sophisticated instrumentation such as 'total stations' interfaced with electronic data recording is the norm. In some cases the recorded data can be used to produce screen plots in real time.

GPS and other satellite systems are used to fix three-dimensional position. Such is the accuracy and speed of positioning using satellites that they may be used to establish control points, fix topographic detail, set out position on site and carry out continuous deformation monitoring. However, they cannot be used to solve every positioning problem and conventional survey techniques continue to have about equal importance.

However, regardless of the technological advances in surveying, attention must always be given to instrument calibration and checking, carefully designed projects and meticulous observation. As surveying is essentially the science of measurement, it is necessary to examine the measured data in more detail, as discussed in the next chapter.