SURVEYING

Fourth edition

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PREFACE

This book was originally written with the needs of students reading for the following examinations in mind: Engineering Degrees, Ordinary and Higher National Diplomas in Building, and Higher National Certificates in Structural Engineering, Civil Engineering and Building. It is also intended to cater for the needs of those studying for the examinations of the Council of Engineering Institutions. During the successive revisions which we have made over the years, we have been mindful of the syllabuses of the new MSc courses in Highway Engineering, and we have, in particular, continued to bear in mind the needs of newly-qualified Engineers and Builders as they take up appointments on site and in the drawing office.

An appreciable amount of research has been devoted to Surveying and a large number of new developments have taken place since the end of the Second World War. It was the excellent papers and articles by A. Stephenson, O.B.E., M.A., F.R.I.C.S. and J. Glendinning, O.B.E., B.Sc.Eng., M.I.C.E. on recent trends in surveying which, inter alia, inspired us to write this book in the first place, as we were then, and still are, firmly convinced that in the education of technologists, accent should be placed, where possible, on the latest developments after fundamental principles have been absorbed. In the field of practical surveying this implies the use of modern equipment and techniques where possible.

The competing demands for time by other disciplines in already crowded undergraduate syllabuses has meant, unfortunately, over the past twenty years that the constructional engineer has tended to receive less formal training and tuition in Surveying. This has enhanced the demand for a concise modern text-book giving not only the elements of surveying but also reasonable coverage of surveying instruments likely to be met with in current practice. In an effort to achieve this we are indebted to those professional engineers and academics who have passed on to us their views on, and experience with, previous editions. It is only by feedback of this nature that we can hope to monitor the needs of a relatively rapidly changing professional practice.

We have struck what we believe to be a reasonable balance between scientific principles on the one hand and techniques on the other, and although the numerous developments in the subject have entailed some increase in size of the book, it is still concise enough for field use. We have included the salient features of the more important new techniques and instruments as well as retaining traditional ones. In this context we have borne in mind that students do not always have access to instruction manuals nor, all too often due to losses on site, do engineers.

In this current edition some sections have been combined to allow the introduction of a new chapter on electronic and electro-optical distance measurement, which has certainly been a major 'growth' area of surveying. We have also revised the chapter on photogrammetry to emphasize possible direct applications of this branch of surveying to the student and, in particular, to the engineer. Compared with the previous edition, Additional Exercises no longer figures in the present one, many of the exercises having been absorbed in their respective chapters to supplement the existing exercises: some new exercises have also been added. Consideration was given to the inclusion of computer techniques, but since most students nowadays are taught the principles of computational analysis, it was decided to minimize references thereto.

Acknowledgement is hereby made and our thanks rendered to the following firms, bodies and persons who have supplied material for, or who have granted permission for the use of material in this book: Cambridge University Press: Technical Press Ltd: Controller of HMSO: Royal Geographical Society: Rank Precision Industries Ltd: Vickers Instruments Ltd: W. A. Stanley & Co Ltd: Wild Heerbrugg (UK) Ltd: Kern Co: Survey and General Instrument Co Ltd: Zeiss Co: Carl Degenhardt Ltd: C. Z. Scientific Instruments Ltd: Kelvin Hughes Ltd: Decca Ltd: Holmes Bros (Leyton) Ltd: Short and Mason Ltd: R. W. Munro Ltd: British Transport Commission: C. F. Casella Ltd: Steinheil-Lear Siegler AG (Otto Fennel GmbH): Tellurometer (UK) Ltd: Parker P R Associates Ltd: Valeport (Developments) Ltd: Plessey Ltd: A. Clarkson Ltd: Cartographic Engineering Ltd: Rabone Chesterman Ltd: Lomas and Baynes Ltd: AGA (UK) Ltd: Siemens AG (Askania GmbH): Hansa Luftbild: Williamson Manufacturing Co Ltd: Institution of Civil Engineers: Institution of Structural Engineers: University of London.

Finally our thanks are due to Dr J. H. Horlock, F.R.S., Vice-Chancellor, Professor T. Constantine, Chairman of the Department of Civil Engineering, and the Senate of the University of Salford for their help and encouragement.

A. Bannister
S. Raymond

CONTENTS

1 INTRODUCTORY

DEFINITIONS

Surveying may be defined as the art of making measurements of the relative positions of natural and man-made features on the earth's surface, and the plotting of these measurements to some suitable scale to form a map, plan or section.

In practice, however, the term 'surveying' is often used in the particular sense of meaning those operations which deal with the making of plans, i.e. working in the two dimensions which form the horizontal plane, and the term 'levelling' covers work in the third dimension, namely the dimension normal to the horizontal. Thus we have:

Surveying: operations connected with representation of ground features in plan.

Levelling: operations connected with the representation of relative difference in altitude between various points on the earth's surface

Surveying is divided primarily into: (i) geodetic surveying, (ii) plane surveying.

(i) In geodetic surveying the curvature of the earth is taken into account so that a knowledge of spherical geometry is required. All surveys of countries, such as the Ordnance Survey of Great Britain, are geodetic surveys.

(ii) In plane surveying the area under consideration is taken to be a horizontal plane, and the measurements plotted will represent the projection on the horizontal plane of the actual field measurements. For example, if the distance between two points A and B on a hillside is l, the distance to be plotted will be $l \cos \alpha$, where α is the angle line AB makes with the horizontal, assuming a uniform slope.

A horizontal plane is one which is normal to the direction of gravity, as defined by a plumb bob at a point, but owing to the curvature of the earth such a plane will in fact be tangential to the earth's surface at the point. Thus, if a large enough area is considered on this basis, a discrepancy will become apparent between the area of the horizontal plane and the actual curved area of the earth's surface.

It can be shown that for surveys up to 250 km^2 in area this discrepancy is not serious, and it is obvious therefore that plane surveying will be adequate for all but the very largest surveys. However, precautions are required when connecting such surveys to control points established and co-ordinated by geodetic surveys.

USES OF PLANE SURVEYING

The uses of plane surveying include:

(*a*) the measurement of areas;
(*b*) the making of plans in connexion with legal documents (including land transfer), Parliamentary Bills, etc.;
(*c*) the making of plans in connexion with the work of the civil engineer, architect, builder, structural engineer and town planner; and the reverse process—working from the plan back to the site—involved in setting out works;
(*d*) the making of maps and plans for military, geographical, geological, and other purposes.

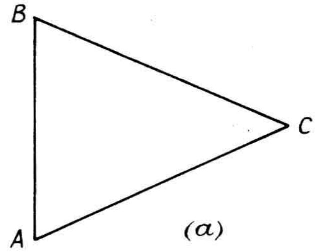
There are many other lesser uses too numerous to mention, and the importance of plane surveying, particularly to those connected with constructional work in some form or other, is readily seen.

BASIC PRINCIPLES OF SURVEYING

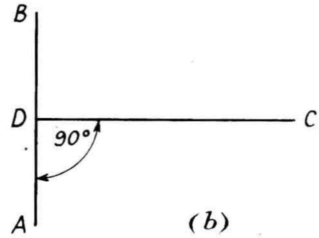
One might truthfully say that surveying as a subject is not difficult, though at the advanced stages of some branches of the art a fair demand is made on mathematical knowledge. In this respect, surveying is similar to other subjects, such as the theory of structures, in that as well as common sense and a feeling for the subject, the possession of a mathematical background is an advantage. The fundamental principles of surveying, however, are few and simple in concept.

On any area of land to be measured, it will always be possible to choose two points and to measure the distance between them. This line *AB* can be drawn to scale on paper. Other points can be located relative to the line by taking *two* other measurements which can of course be similarly drawn to scale on the paper, and in this way a map is constructed. The two measurements can consist of two measured lines, one line and an angle, or two angles. The principles are illustrated in Fig. 1.1, *A* and *B* representing in each case the two original points, and *C* a point to be located.

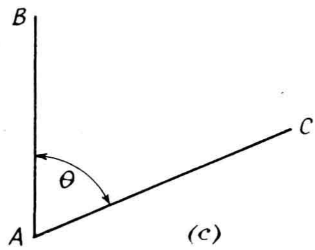
Method	*Use*
Measure AC, BC	Chain Surveys, Ties



Measure CD at right angles to AB AD is known	Offsets



Measure AC, θ	Traverse Surveys



Measure θ_1, θ_2	Intersection

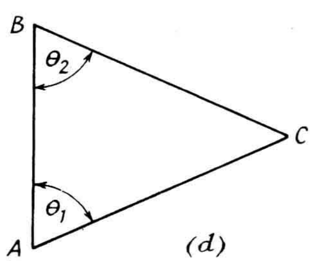


FIG. 1.1

CHECKING MEASUREMENTS

It is appropriate to say a word here on the prevention of mistakes and the elimination of errors in surveying. There is no such thing as an absolutely exact measurement, and the precision (itself a relative term) achieved depends on the instruments used in making the measurement, the care taken, and the ability of the surveyor to guarantee that his work is free from mistakes. It is axiomatic that surveying work should be self-checking where possible, and in practice some of the measurements given in the previous section, representing as they do theoretical minimum requirements, would require to be supplemented by check measurements. For example, in chain surveying, if only the lines joining the three points of a triangle were measured (Fig. 1.1*a*), it would still be possible to plot the triangle even though a mistake had been made in the measurement of one of the lines. By chaining one more line, for instance one running from one corner of the triangle to the opposite side, the error would be revealed for, except in the improbable event of two self-compensating errors, it would not be possible to plot the check line. Also, in Fig. 1.1*d*, although with absolutely exact and mistake-free measurement it is sufficient to measure angles θ_1 and θ_2 alone, in practice the angle θ_3 at C would be measured, so that, by applying the test that $\theta_1 + \theta_2 + \theta_3$ should equal 180°, a check may be made on mistakes and a distribution made of other errors. (Note that this relationship applies only in plane surveying; in geodetic surveying the laws of spherical trigonometry apply.)

2 CHAIN SURVEYING

This branch of surveying derives its name from the fact that the principal item of equipment used is the measuring chain. Notwithstanding that this and the allied items of equipment are simple in construction, work of a sufficiently high order of accuracy to cover the requirements of much ordinary engineering work is possible, especially when large-scale plans of relatively small areas are required. Also, in addition to being a complete method of surveying, some of the operations of chain surveying occur in other branches (notably traverse surveying, where the chain and tape are often used to survey detail). A good knowledge of chain surveying is therefore essential to a proper knowledge of surveying as a whole.

Historical Note The use of chain surveying dates back to the earliest times even though the records are scanty compared with those on other subjects. Only a brief reference to some of them is possible here. The most definite mention of chaining comes from drawings on the walls of some Egyptian tombs showing the 'cordmen' stretching their measuring cords of plaited palm strip. The precision with which the pyramids and, later, the Greek cities, were set out, indicates that the ancient civilizations had, even by present standards, good surveying technique. Probably the best record of the first thousand years BC is that due to Heron, a Greek who lived in Alexandria in about the first century AD. He provided the first serious account of surveying techniques, and from this it is clear that the work of Euclid and the other geometers was used in measuring up and setting out. Many of the methods and much of the equipment described by Heron were in fact too complicated for the Romans who, like present-day engineers, preferred simple methods where possible. As the Roman Empire became stabilized, great use was made of chain surveying in the fixing of boundaries, setting out new cities, aqueducts, roads, etc. The work was carried out by a trained body of men known as the 'agrimensores', and many examples survive to show the skill of these Roman surveyors. From Roman times until the present day, the main improvement has been in equipment, e.g. the link chain of wrought iron introduced in the seventeenth century, and the optical squares and steel tapes, etc. introduced in the past century.

EQUIPMENT USED IN CHAIN SURVEYING

The items of equipment required fall under three broad headings: those used for linear measurement, those used for measuring right angles, and other items.

1. Equipment for the Measurement of Lines

THE CHAIN Chains manufactured according to British Standard 4484: Part 1 : 1969 are to be 20 m long, but it is also possible to obtain chains 30 m long. They are made of tempered steel wire, 8 or 10 SWG, and are made up of links which measure 200 mm from centre to centre of each middle connecting ring. Swivelling brass handles are fitted at each end and the total length is measured over the handles. On the 20 m chain, tally markers, made of plastic, are attached at every whole metre position, and those giving 5 m positions are of a different colour. The 30 m chains may have brass tallies marking every tenth link.

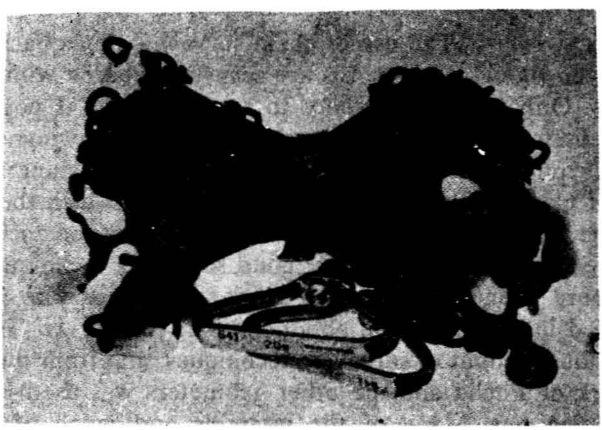


FIG. 2.1 Land Measuring Chain

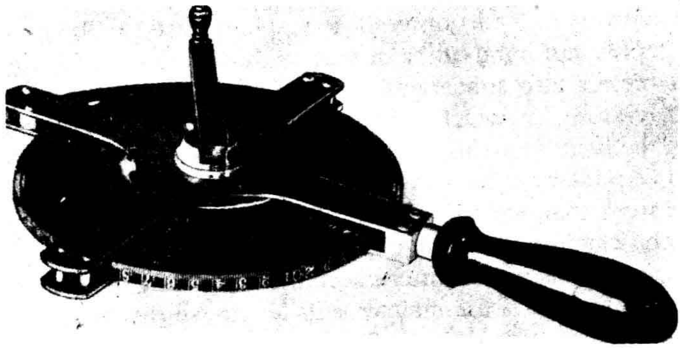


FIG. 2.2*a* Surveyor's Band (*Courtesy of Rabone Chesterman Ltd*)

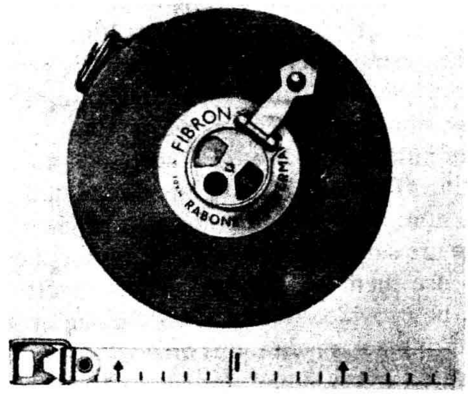


FIG. 2.2*b* Typical Measuring Tape (*Courtesy of Rabone Chesterman Ltd*)

The chain is robust, easily read, and easily repaired in the field if broken. It is liable to vary somewhat in length, however, owing to wear on the metal-to-metal surfaces, bending of the links, mud between the bearing surfaces, etc. Also its weight is a disadvantage when the chain has to be suspended.

THE SURVEYOR'S BAND (OR DRAG TAPE) This is made of steel strip, some six millimetres in width, and is carried on a four-arm open frame winder. A handle is fitted for returning the band into its frame after use, and this also provides a locking device for retaining the band. Rawhide thongs are supplied for attaching to the small loops at the extremities of the bands to allow them to be pulled or straightened. Alternatively handles, similar to those of the chain, can be fitted: lengths of 30 m or 50 m are normal but

100 m bands may be encountered. B.S. 4484: Part 1 : 1969 requires that metres, tenths and hundredths of metres should be marked, with the first and last metres also subdivided into millimetres. The operating tension and temperature for which it was graduated should preferably be indicated on the band in addition. Other types, made of special steel and used with supplementary equipment to apply a constant pull, are used for more accurate work than we are considering here, and these will be dealt with later in the chapter on Triangulation Surveys.

The steel band is a much more accurate measuring instrument than the chain, and with careful use maintains its length, so that it can be used as a standard measure. Its main disadvantages are its lack of robustness and the difficulty in doing field repairs.

TAPES These may be made of synthetic material, glass fibre being typical, or coated steel or plain steel. B.S. 4484: Part 1 suggests 10 m, 20 m or 30 m as the desirable lengths, and these are generally available.

For the synthetic types the British Standard requires major graduations at whole metre positions and tenths, with minor graduations at hundredths, and 50 mm intervals indicated. Those manufactured of glass fibre have a PVC coating (Fig. 2.2*b*). They are graduated every 10 mm and figured every 100 mm; whole metre figures are shown in red at every metre. These tapes are said to have good length-keeping properties, but it is conventional to use them for relatively short measurements.

Steel tapes may be provided with a vinyl coating or may be plain. The former type has sharp black graduations on a white background. They can be obtained graduated every 5 mm and figured every 100 mm; the first and last metre lengths are also graduated in millimetres. Whole metre figures are again shown in red at every metre.

The latter type have graduations and figures etched on to the steel and they present the same subdivisions as the vinyl-covered types. However, they are generally wider and are contained in a leather case rather than a plastic one.

2. Equipment for Measuring Right Angles

THE CROSS STAFF A typical cross staff is shown in Fig. 2.3*a*, and consists essentially of an octagonal brass box with slits cut in each face so that opposite pairs form sight lines. The instrument may be mounted on a short ranging rod and, to set out a right angle, sights are taken through any two pairs of slits whose axes are perpendicular. The other two pairs then enable angles of 45° and 135° to be set out. An alternative type of cross staff is shown in Fig. 2.3*b*.

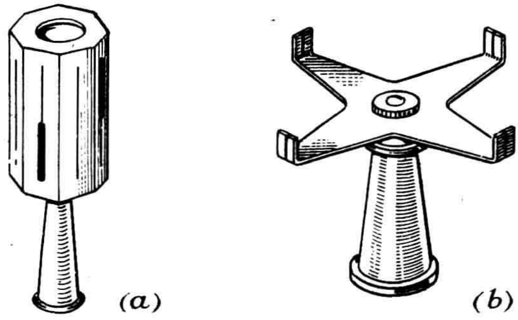


FIG. 2.3 Cross Staves

THE OPTICAL SQUARE There are two types of optical square, one using two mirrors and the other a prism. The instrument is compact, rarely measuring more than 75 mm in diameter by about 20 mm thick, and is more accurate than the cross staff.

The mirror type makes use of the fact that a ray of light reflected from two mirrors is turned through twice the angle between the mirrors, which in turn is easily derived using the principles of reflection of light. Fig. 2.4 shows the mounting. Mirror A is completely silvered, while mirror B is silvered to half its depth, the other half being left plain. Thus, the eye looking through the small eye-hole will be able to see half an object at O_1. An object at O_2 is visible in the upper (silvered) half of mirror B, and when $O_1\hat{X}O_2$ is a right angle (where X is the centre of the instrument), the image of O_2 is in line with the bottom half of O_1 seen direct through the plain glass.

The surveyor stands at X, sights O_1, and directs his assistant to move O_2 until the field of view is as shown above. Then $O_1\hat{X}O_2$ is a right angle for, considering any ray from O_2 incident on mirror A at angle α to the normal, it will emerge at the same angle to the normal.

Therefore $$X\hat{A}B = 2\alpha$$

and, from a consideration of the angles,

$$X\hat{B}A = 90° - 2\alpha$$

$$\therefore \quad A\hat{X}B = O_1\hat{X}O_2$$

$$= 90°$$

i.e. the result is independent of α.

The prismatic type of optical square employs a pentagonal-shaped prism, cut so that two faces contain an angle of exactly 45°. It is used in the same way as the mirror square, but is rather more accurate.

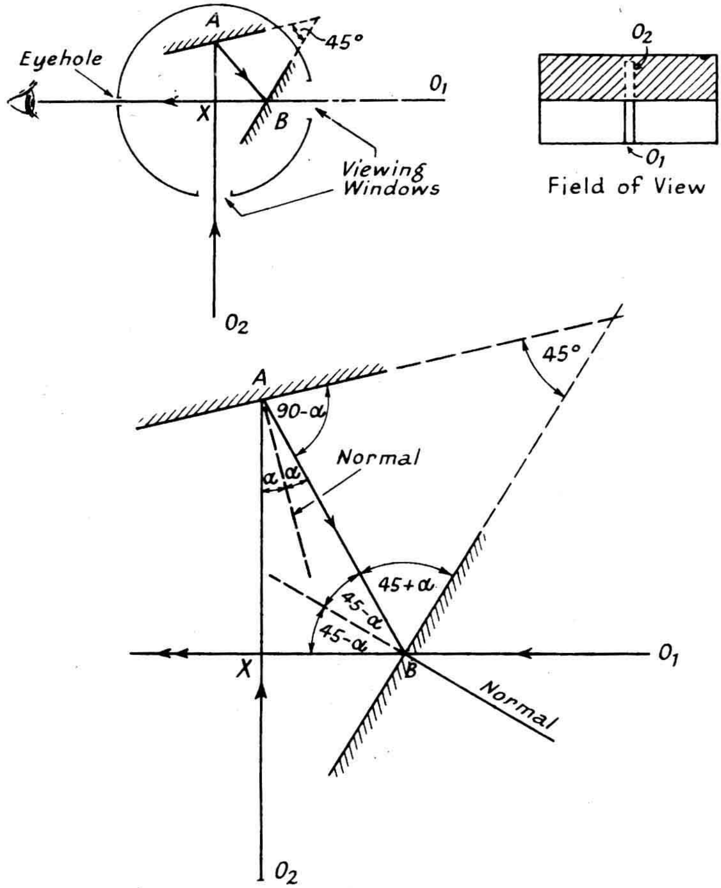


FIG. 2.4

The model shown in Fig. 2.5 (introduced by Watts) has two such prisms, and for setting out right angles the top one only is used. By using both of them, it is possible to set out two points O_1 and O_2 such that $O_1\hat{X}O_2$ is 180°.

SITESQUARE Another optical device for setting out right angles is the Watts Sitesquare which consists basically of two telescopes, one mounted above the other, with their lines of sight at 90° to each other. The Sitesquare is supported on a tripod which can be set up over a mark or nail in a peg. The lower telescope is directed to a site mark positioned on one arm of the right angle to be established by moving it (i) in the vertical plane, and (ii) laterally by means of a fine setting screw. The line of sight