CHAPTER 10

MOVEMENT BY HAND AND SIMPLE MECHANICAL AIDS

SECTION 1

MOVEMENT BY HAND

GENERAL

1. The most common way of moving loads over a short distance during the completion of field engineering tasks is by lifting and carrying, either as an individual or as a group. Back injuries can occur when individuals lift heavy weights incorrectly and carrying parties risk accidents unless properly controlled. It is essential that personnel be made aware of the correct procedures for lifting and carrying loads detailed herein.

2. This chapter also describes some improvised mechanical aids, and outlines the safety precautions that must be observed.

INDIVIDUAL EFFORT

3. A human physical effort can be applied in four different ways: pulling, pushing, towing and lifting. In all cases, the maximum effect is obtained with the least risk of injuries when the back is kept straight and the legs do as much work as possible. For example, when picking up a filled sandbag, stand close to it with the feet about shoulder width apart. Then bend the knees, while at the same time letting the body incline slightly forward from the hips, grasp the bag, and raise it by steadily straightening the knees.

4. If a sandbag has to be carried an appreciable distance, it is best to carry it on a shoulder. Here again the legs can help the arms. Initial upward movement is given to the load by gently bending the knees and straightening them sharply, the arms are used to guide the load into position. Remember to always keep the back straight.

5. A filled sandbag weighs 20 to 22 kg. With a little practice, the average person should have no difficulty in picking up and carrying away a conveniently shaped weight of up to 30 kg. Given assistance in getting the

load onto his shoulders, he should be able to carry 40 kg, for example, a bag of cement.

CARRYING PARTIES

6. Where the load is either too heavy or too bulky to be carried by one person, a carrying party should be organized and a leader detailed to supervise the work. For a long load, such as a spar or length of pipe that can be easily grasped, the party should be lined up on one side of the load and the load carried on the shoulders.

7. If the load is too heavy for the number of personnel that can get a good grip on it or it is so awkwardly shaped that a firm hold is impossible, carrying bars should be inserted under, or through the load, or through slings supporting it. For instance, a roll of concertina, although only 13 kg, is an awkward one-man load, yet two rolls can be easily carried by two soldiers walking one behind the other, with the load on two steel pickets.

CARRYING PARTY PROCEDURES

8. Before a carrying task commences, the group must understand that they must concentrate on the job so that each individual reacts promptly to every word of command. Only then will the load be evenly distributed and carried with the minimum of effort and risk.

9. **Preliminary Procedures.** A leader is detailed for each task and is not to take part in the lift if the number of carriers exceeds eight. The leader, having ascertained what the load is, where it has to be taken, and any restrictions on the route, is responsible for:

a. making sure that there are sufficient personnel to carry the load;

b. obtaining carrying bars, slings, improvised shoulder pads, gloves or improvised hand protection as necessary;

c. reconnoitering the route and selecting the best path in order to avoid sudden changes in slope, sharp corners and projections which might catch the load;

d. sizing the party and dividing it evenly around the load (smaller personnel in front); and

e. thoroughly briefing the carrying party.

10. **Lifting the Load.** The commands are "HANDS ON", "PREPARE TO LIFT" and "LIFT". On the command "HANDS ON" the carriers bend down and take a firm hold on the load or the carrying bar. On the command "PREPARE TO LIFT" the carriers take up a proper lifting position. On the command "LIFT", they straighten up, steadily lifting the load. Lifting the load onto the shoulders should be done in three stages: to arm's length, to the chest and finally onto the shoulders. For the first two stages, the carrying party face inwards while during the third they turn to face forward.

11. **Lowering.** The commands are "PREPARE TO LOWER", and "LOWER". Lowering from the shoulders should be done in two stages. On the command "LOWER", the weight is taken from the shoulders and held in the hands at shoulder level. It is then lowered to the ground. All movements are carried out smoothly and gently. If the load is being moved, the first word of command is "CHECK", so that all members of the carrying party stop at the same time before preparing to lower.

12. **Resting.** During long carrying tasks, rest may be required. The position of carriers may be changed during rest periods to reduce fatigue.

13. **Towing and Hauling.** For larger or more awkward loads, it maybe more convenient for the party to haul the loads using cordage. For efficient work the following points shall be observed:

a. a thick rope is better than a thin one. A 32 mm diameter rope is best and a 16 mm rope is about the smallest that the average person can get a firm grip on;

b. the party shall be spaced equally along the rope on alternate sides, with the shorter carriers nearer to the load;

c. to optimize their tractive (pulling) forces, soldiers are to keep their legs, body and head in one straight line, letting their legs do the work using their arms simply as links between their body and the rope; and

d. the party must work and move together on the commands of the leader.

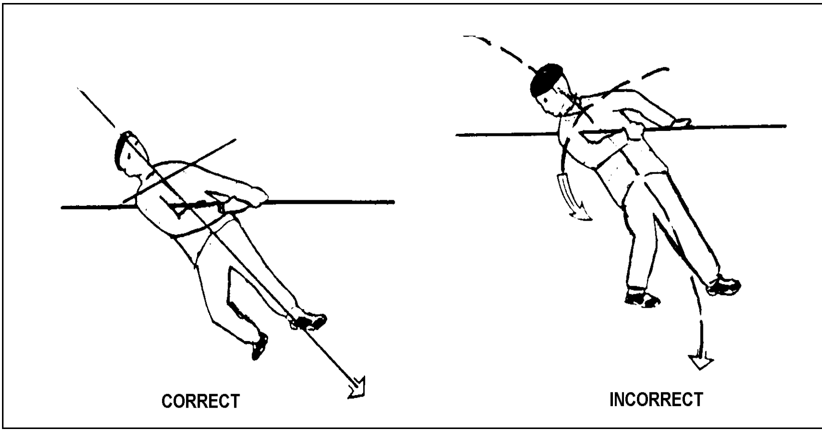

Fig 10-1-1 Right and Wrong Way of Heaving on a Rope

LABOUR CONSTANTS

14. If the ground surface is reasonably good and soldiers can exert their full power on the load, the number of soldiers required to lift or move a weight can be estimated using the following guide:

a. in small parties up to four, each can, for short periods only:

(1) push or pull horizontally with a force of 35 kg;

(2) pull downwards on rope (maximum three persons) with a force of 45 kg;

(3) lift 55 kg; and

(4) lift and carry 45 kg;

b. in large parties, there are factors which reduce the work that each individual can do. Each soldier can:

(1) lift and carry 25 to 40 kg;

(2) apply a tractive force of 20 to 25 kg on a tow rope; or

(3) exert continuous pressure of 7 to 10 kg on the bar of a capstan or handle of a winch.

SECTION 2

SIMPLE MECHANICAL AIDS

GENERAL

1. Humans have always used their intelligence to invent mechanical aids to increase their strength. This section describes several simple aids which can be easily improvised and outlines the safety precautions that shall be observed when using them.

SAFETY PRECAUTIONS

2. The biggest danger in moving heavy weights with mechanical aids is that the load may get out of control. The following precautions shall be observed:

a. the working party shall always be on the safe side of the load when working on a slope. Loads are hauled, not pushed, uphill;

b. be careful not to trip over the projecting rollers;

c. remove as many lashings or projections as possible;

d. on gentle slopes have two personnel with chocks walk on both sides ready to wedge if necessary; and

e. use preventer tackles on steep slopes, the running end of the hauling rope shall be taken twice around a holdfast picket. Should the load start to get out of control, the rope can be pulled tight to stop or slow the load.

LEVERS

3. The lever is a simple mechanical aid which is used to gain mechanical advantage when lifting (levering) objects. The point about which the lever rotates is called the fulcrum. The distance from the fulcrum to the points of application of the power and the weight are called the lever and counter-lever respectively. A lever may be used in one of three ways:

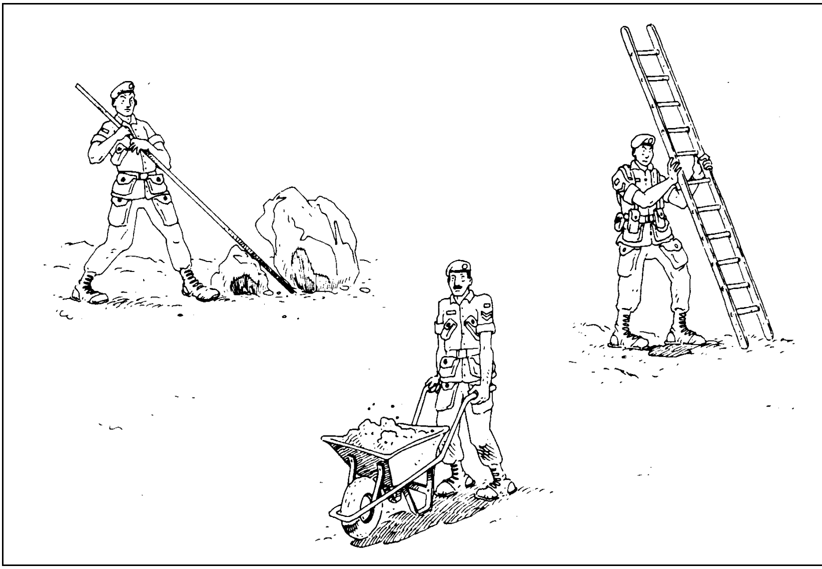

Fig 10-2-1 Examples of Levers

a. with the fulcrum between the weight and the power, as in the case of levering a rock;

b. with the weight between the fulcrum and the power, as in the case of a wheel barrow; and

c. with the power between the fulcrum and the weight, as in raising a ladder or scaffolding pipe.

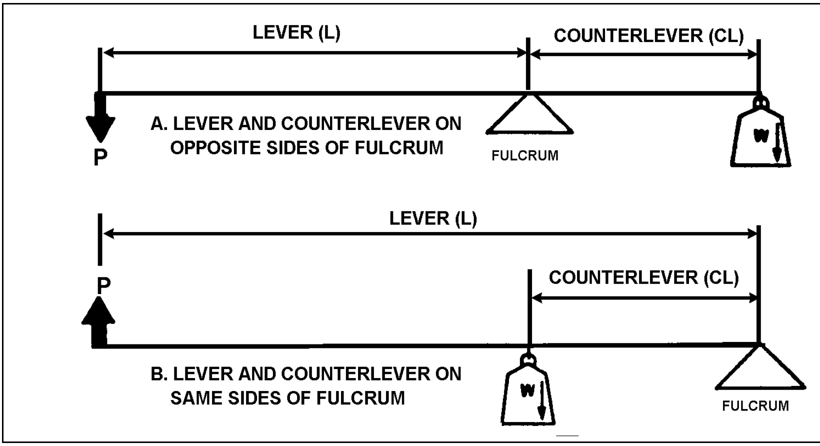

Fig 10-2-2 Levers

4. The crowbar is a commonly used lever and the carpenter's hammer employs the principle of a lever to draw nails. The cant hook (Peavy) (Chapter 3) is a special lever for rolling and turning logs.

5. The mechanical advantage of any lever is determined by the formula:

Mechanical advantage = $\frac{L}{C}$	Where L = the length of the lever, and C = the length of the counter lever

6. The power required to lift a given load is determined by the formula:

$P = \frac{W \times C}{L}$	Where P = power required W = weight C = length of the counter lever L = length of the lever

ROLLERS

7. Rollers can be used as an aid to moving heavy weights in a horizontal direction, or up and down slight slopes. They give no mechanical

advantage, but reduce the resistance to motion (friction). Rollers can be fixed or moveable.

8. **Moveable Rollers.** Moveable rollers are mainly used for moving heavy and bulky loads over fairly level ground. They may be improvised from steel bar, piping or hardwood logs. Provided that there is no slipping, the load travels twice as fast as the rollers over the ground and in the same direction, that is, at right angles to the axis of the rollers. If the load is required to travel in a curve, the rollers are laid out as shown in Fig 10-2-3. If the ground is soft, it may be necessary to lay down a plank path. Plenty of spare rollers should be available to feed in front of the load. Care is required to ensure that rollers projecting outside the edges of the load do not trip the working party.

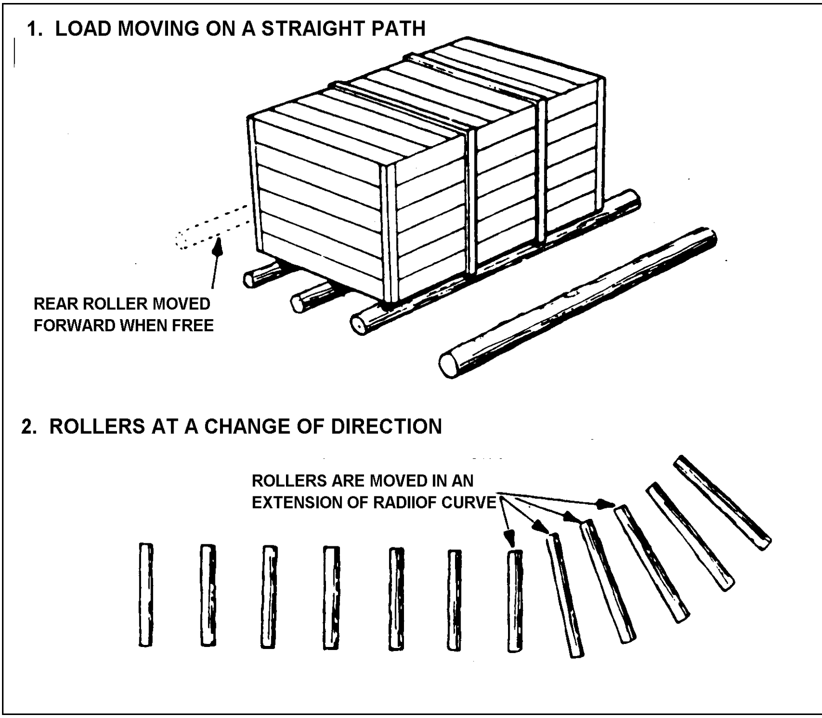

Fig 10-2-3 Movable Rollers

9. **Fixed Rollers.** Fixed rollers are special equipment such as those used in bridging operations.

PARBUCKLING AND WINDLASSING

10. **Parbuckling.** Parbuckling is a method of hauling a load up a steep slope such as a river bank. It can only be used on loads with a shape that will rotate fairly easily. The slope has to be free of prominent projections. If it is very rough an artificial slope can be made, for example, of two planks.

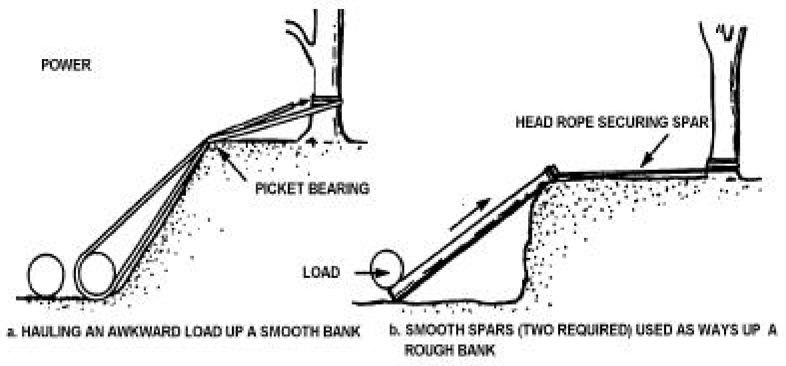

Fig 10-2-4 Parbuckling

11. **Spanish Windlass.** The spanish windlass can be used to move heavy loads over short distances (Fig 10-2-5). A rope is fastened to the weight to be moved and to an anchorage, and the windlass is erected on the line of the rope. The windlass consists of a vertical and horizontal spar with a bight of the rope taken around the horizontal spar. The weight is moved by rotating the windlass and the tow of the vertical spar moves towards the anchorage as the weight is pulled in. Care is required to ensure that:

a. the rope on both sides comes away from the vertical spar at the same level;

b. the windlass is set up exactly in line with the weight and anchorage; and

c. the vertical spar has a blunt end that will not dig in the ground.

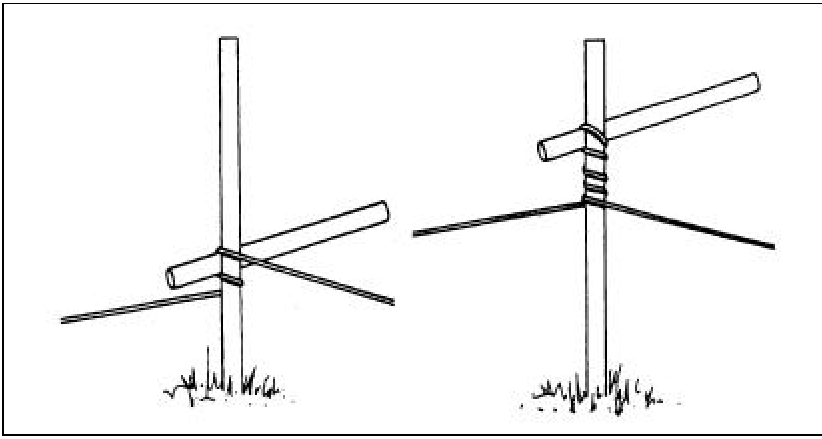

Fig 10-2-5   Spanish Windlass

CHAPTER 11

FIELD SURVEYING

SECTION 1

LEVELING

GENERAL

1. Before most tasks are started there is a requirement for dimensions of one type or another. Field surveying covers the various methods and equipment used to attain these measurements.

2. The basis of most field survey is geometry. Topics covered in this chapter are field leveling, measurement and geometry and their application to field engineering tasks.

LEVELLING

3. A line or a surface is said to be level when it is horizontal. Many field engineering tasks require surfaces that are more or less level and uprights that are roughly vertical.

4. **Principles**. There are two basic principles that allow horizontal and vertical lines to be established. First, a plumb-bob is drawn towards the centre of the earth by gravity, this gives a vertical line. Second, liquid will flow under the force of gravity until its surface is level, thus causing a horizontal line. These two principles form the basis of most levelling instruments, and govern their improvised construction. Field engineer levelling equipment ranges from boning rods to sophisticated optical devices.

NON-OPTICAL LEVELLING EQUIPMENT

5. The line level, and spirit level or carpenter level make use of the principle that the undisturbed surface of a liquid is level. If a bubble of air is placed in an enclosed glass container filled with liquid and the surface of the glass is parallel to the straight edge supporting it, the straight edge will be level when the bubble appears in the centre of the glass. The carpenter's level works on this principle.

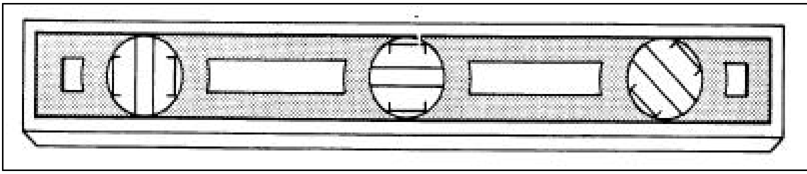

Fig 11-1-1 Carpenter’s Level

6. **Field Level**. (Fig 11-1-2). The field level is a simple piece of equipment used by Field Engineers.

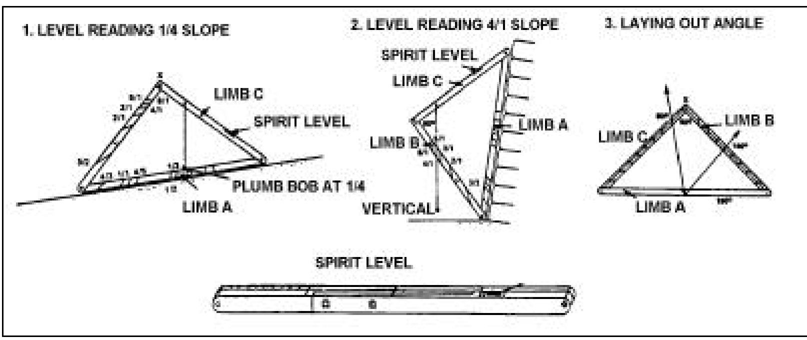

Fig 11-1-2 Field Levels

a. to measure a slope or gradient, fix the level with limb A along the slope or gradient and read off the figure cut by the plumb-bob line as shown in Fig 11-1-2 a and b.

b. to measure an angle, use as shown in Fig 11-1-2 c.

7. **Boning Rods**. (Fig 11-1-3). Boning rods are formed in the shape of a capital T. They are generally made of softwood 75 mm wide, 15 mm thick, and 900 mm high. Each consists of a long upright with a head fixed at right angles to the top. They come in sets of threes and of the same size. They are used in the following manner:

a. two pegs are driven flush with the surface on the line to be surveyed, as far apart as possible and made level with a straight edge or spirit level;

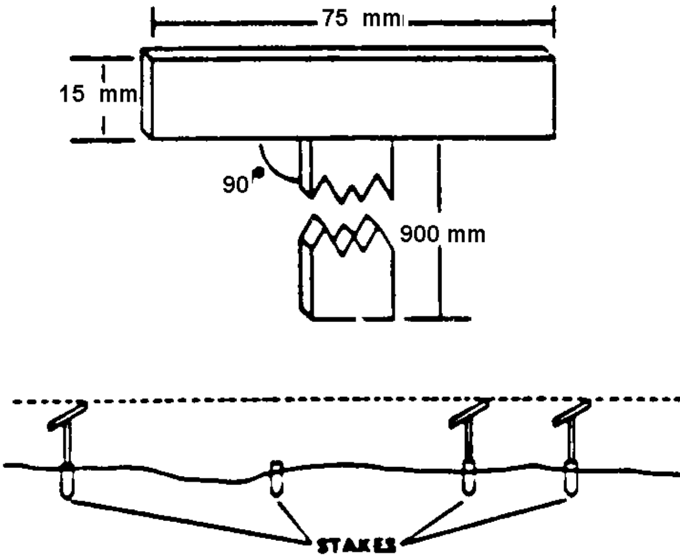

Fig 11-1-3 Boning Rods

b. a boning rod is then placed on each of the two pegs. Since the boning rods are identical in height, the line of site across the top edge of one to the top of the other will be level; and

c. at points farther along the line drive in other pegs. The third boning rod is held on each peg in turn and the difference in level is checked by sighting along the top of all three.

IMPROVISED LEVELLING DEVICES

8. A flat sided bottle filled with water, oil or some other liquid can be used as a level (Fig 11-1-4 a). To make a level, place a short length of tape about 5 mm across the end of the bottle as shown below, mark the tape with horizontal lines about 5 mm apart. Half fill the bottle with liquid and lay it on a roughly level surface, mark the liquid level on the line on the tape. Rotate the bottle 180 degrees and mark the liquid on the tape again, if the

mark is the same, the mark is the true horizontal position, if not the mid-point between the two marks is true horizontal. Clearly mark this point and you are ready to work.

9. **Length of Flexible Tubing**. A length of flexible tubing nearly filled with water can be used to level two points; for example batter boards on a construction site (Fig 11-1-4b). One end of the tubing is placed against the point from which the level is to be taken. Water is slowly trickled in, the other end of the tube is raised or lowered until the water stands to the brim at both ends. The two points are then level.

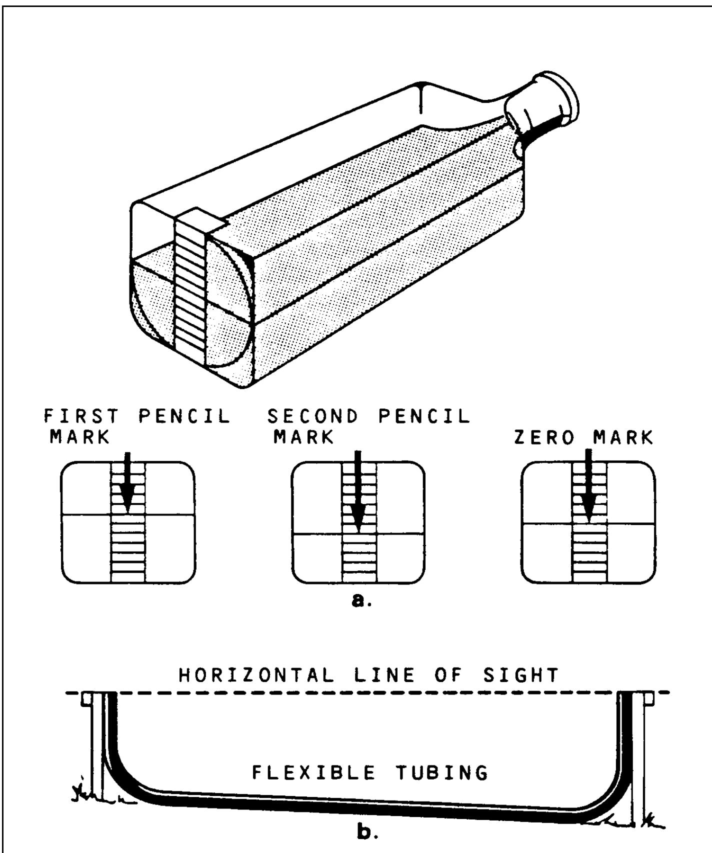

Fig 11-1-4 Improvised Levelling Devices

BATTER BOARDS

10. Batter boards are set up around building layout stakes and are located three or more metres outside the building lines. This enables form work or excavation to be done without disturbing the geometrical design. The boards are made of 50 mm x 100 mm stakes and 250 mm x 150 mm or wider ledgers. The ledgers are nailed to the stakes in a level position at a convenient working height above the foundation. The batter boards shall be approximately level with each other and the ledger boards must be large enough to extend well past each corner

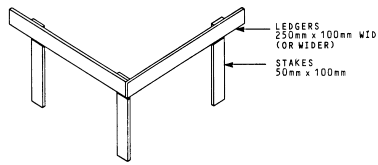

Fig 11-1-5 Batter Boards

11. Using lines and a plumb-bob, string the lines so that they pass directly over the layout stakes, this may be determined by using the plumb-bob. Mark the top of the ledger boards where the lines cross and make a shallow saw cut, pull the lines tight and fasten them to nails driven into the back of the ledger.

ABNEY HAND LEVEL

12. The abney hand level is a convenient pocket level used for measuring slopes either in gradients from 1:1 to 1:10 or in angles from 0 to 60 degrees. It is also used in cross ht. sections in road design, and determining heig

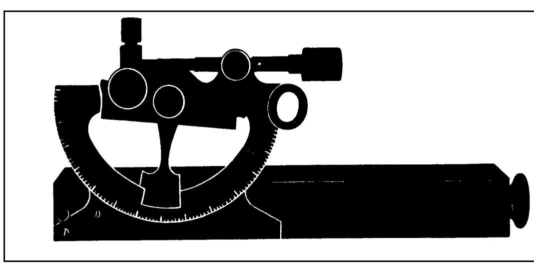

Fig 11-1-6 Abney Hand Level

13. Description. The level consists of a box with a slide, a sloping mirror and a horizontal wire. The slide must be fully extended before any readings can be taken.

a. **Mirror.** The mirror is a highly polished piece of steel, at an angle of 45° to the box, engraved with a horizontal line at its centre. This line and horizontal wire must lie on the line of sight through the axis of the level when measuring a slope. The function of the mirror is to reflect the image of the bubble to the observer's eye, through a hole in the top of the body.

b. **Vertical Arc**. On the side of the body is a vertical arc graduated in gradients and degrees on either side of a zero mark. Both depressions and elevations may be read to an accuracy of 10 minutes of a degree (3 mils).

c. **Bubble Tube**. The bubble tube is tilted about the centre of the vertical arc by a milled nut. The vernier arm is attached to the bubble tube axis and moves with the tube. To check the level, the index must be at 0° when the level is on a true horizontal surface. The bubble is bisected by the engraved line on the mirror. If any adjustments are required they are made by altering the capstan nuts at each end of the bubble tube.

14. **Method of Operation.**

a. The telescope is focused on the object so that it is intersected by the horizontal hair. The bubble image is then moved by adjusting the milled nut until it is intersected by the horizontal engraved line at the same time as the object is intersected by the horizontal hair. The required angle or gradient is then read off on the vertical arc against the index of the vernier arm.

b. To lay out a slope this procedure is reversed. The gradient or angle is set on the vertical arc and the level is tilted until the bubble is intersected by the line of the mirror. At this point the horizontal hair will be intersecting a point at the required gradient as measured from the observer's eye. The range pole has a sight vane on it at the same height as the observer's eye.

ENGINEER LEVELS

15. Where more precise levelling is required an engineers level is used. The levels in current use in the service today are Fuji, Geo Tech, and Nikon and Wild. These are capable of resolving differences in height and can also be used to measure horizontal distances. Each type of level comes with its own user handbook.

SECTION 2

MEASUREMENT

LINEAR MEASUREMENTS

1. **Length**. Standard metric units of linear measurement are millimetre (mm) or 1/1000 of a metre, metre (m) which is equivalent to 100 centimetres or 1/1000 of a kilometre, and kilometre (km) 1000 metres. Volume and area are derived from these linear units.

2. **Area**. Area is measured as length X width and is expressed as units squared: square millimetre (mm^2), square metre (m^2), square kilometre (km^2) or hectares (ha) (10,000 m^2).

3. **Volume**. Volume is measured as length X width X height and is expressed in cubic measurement: cubic metres (m^3), millilitres (ml), cubic centimeters (cc) and litres (l).

MEASURING SLOPES

4. Slope is defined as the measurement of the inclination of a surface in terms of rise over run. It can be expressed in degrees, or as a percentage or ratio. For example, a rise of one metre in ten metres could be written as ratio of 1 to 10 (1:10), or a percentage 10% or in degrees 6°.

5. Slopes can be measured by using a field level, boning rods, or an Abney hand level. Two types of slopes are shown in Fig 11-2-1 and Fig 11-2-2.

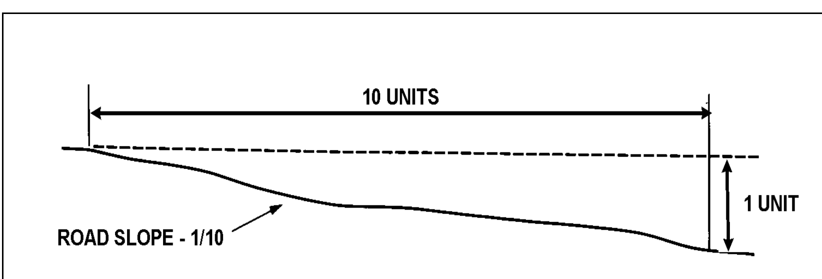

Fig 11-2-1 Gradient on a Road

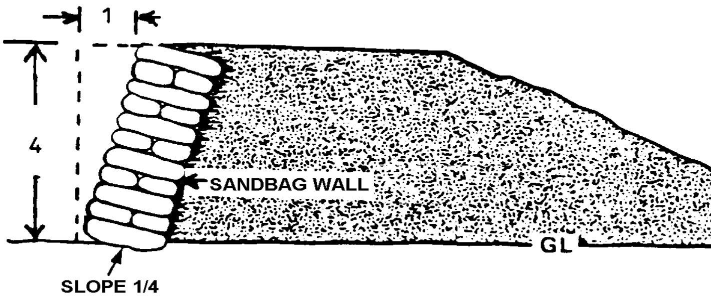

Fig 11-2-2 Slope of a Sand Bag Wall

6. **Field Level**. For short slopes where the surface is uneven the method shown in Figure 11-2-3 is suitable. The level is 1.2 m long and can be used in the folded position with the spirit level up.

Average slope = 1 : $\frac{1.2}{h}$	where:	h is the height from the ground to the level.

The same procedure can be used with the line level and a measured piece of string.

7. **Using Boning Rods**. For a long slope, where an average figure is required, boning rods can be used as shown in Fig 11-2-3:

a. set out two boning rods on the slope, with the distance between them determined by the ability to site over both;

b. hold the center or intermediate rod closest to whichever rod is convenient and where a straight sight can be made over all three rods;

c. place a straight edge on the intermediate rod and the next closest; and

d. read the slope with a field level and plumb-bob positioned on the straight edge resting on pegs that supported the boning rods.

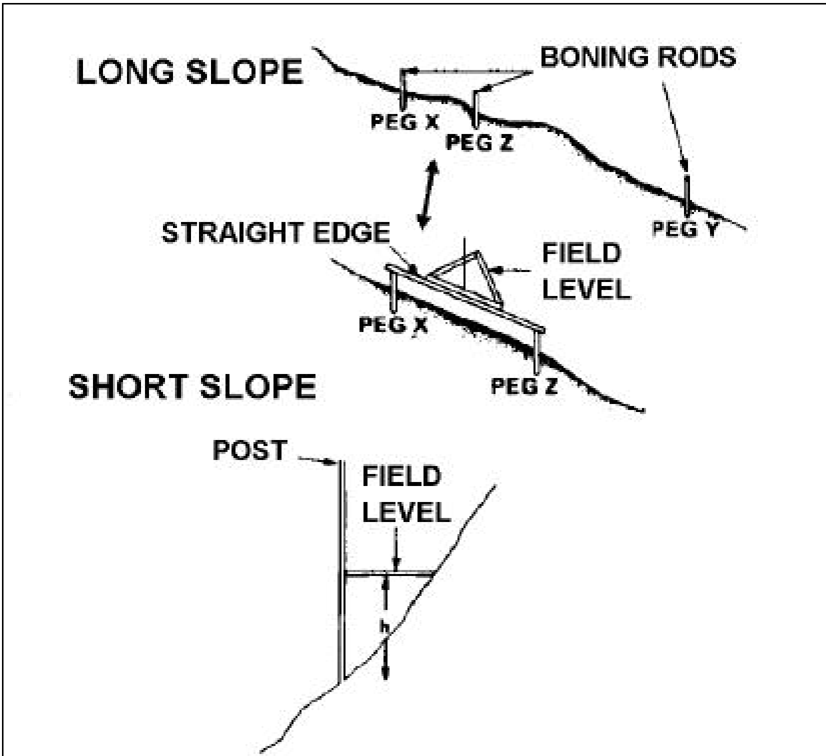

Fig 11-2-3 Measuring Slopes

SECTION 3

GEOMETRY

GEOMETRIC FIGURES

1. **Angles**. Angles are commonly used in field engineering for mine warfare, road survey, bridging and a number of other tasks. Angles are measured in degrees or mils, there being 360 degrees or 6400 mils in a complete circle.

2. **Triangles**. A triangle is an enclosed three-sided figure where the sum of the three interior angles equals 180 degrees (3200 mils). The area of a triangle is determined by multiplying the length of the base by the height and dividing by two (Fig 11-3-1).

$$A = \frac{b \times h}{2}$$

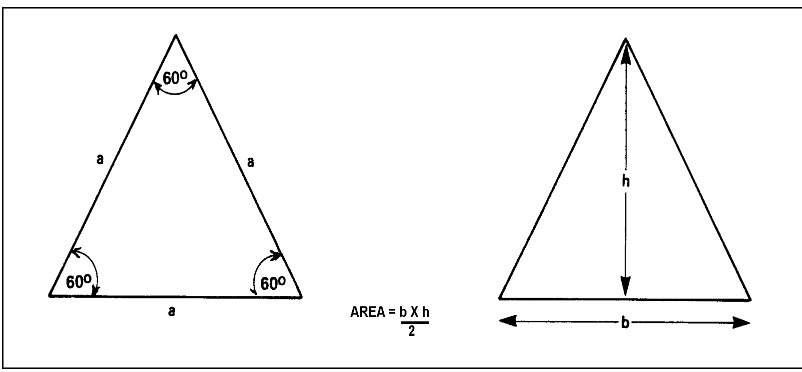

Fig 11-3-1 Triangles

3. **Parallelograms**. Parallelograms are four-sided figures in which the opposite sides are parallel. Rectangles and squares are also parallelograms. The area of a parallelogram is found by multiplying the length of one side by the perpendicular height of the other side. They have the following characteristics:

a. opposite sides are of equal length;

b. the four angles total 360 degrees (6400 mils); and

c. opposite angles are equal.

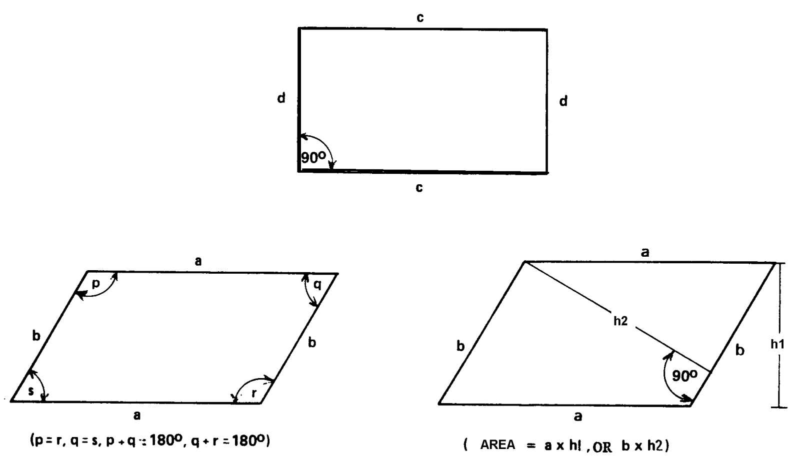

Fig 11-3-2 Parallelograms

4. **Trapezoids**. Trapezoids (Fig 11-3-3) are four-sided figures with one pair, but not both pairs of sides parallel. They have the following characteristics:

a. one pair of sides do not have equal angles;

b. all sides are not of equal length; and

c. the area of a trapezoid is found by multiplying the height by the average of the two parallel sides.

$$A = h \times \frac{(b1 + b2)}{2}$$

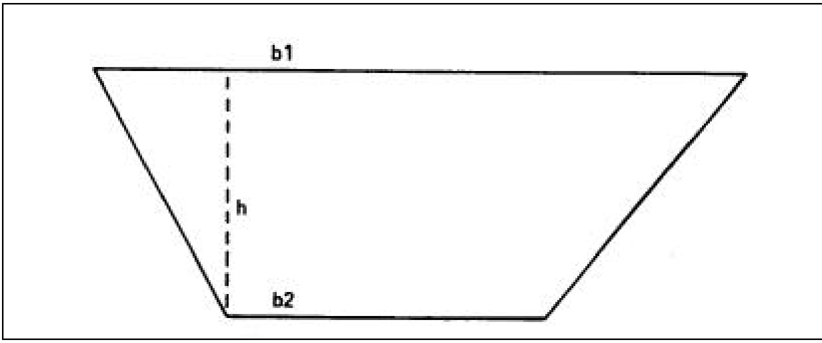

Fig 11-3-3 Trapezoid

5. **Circles**. A circle is bounded by a single line in which every point on the line is the same distance from the center. The length of this line is known as the circumference (c). The distance from the centre to the line is called the radius (r). A straight line drawn from one point on the line through the centre to a point opposite is called the diameter (d).   is a value that represents the numerical relation between the circle's circumference and it's diameter; that value is 3.1416.

a. circumference (c).

$$c = 2 r = \pi d$$

b. area (A).

$$A = r^2 = \frac{\pi d^2}{4} = \frac{c^2}{4\pi}$$

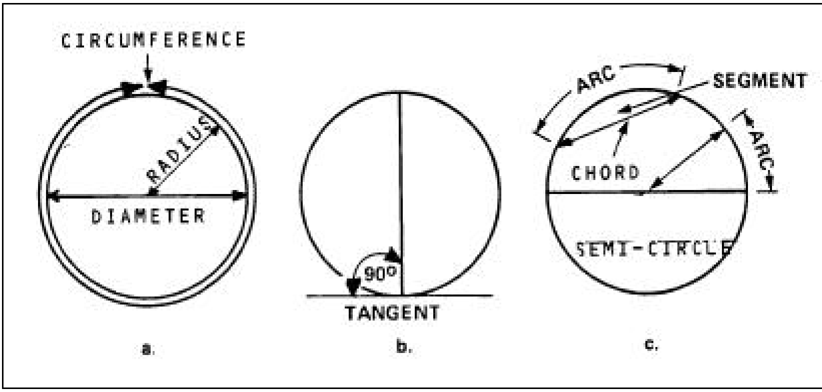

Fig 11-3-4 Parts of a Circle

c. **Example Problem**. Find the circumference and area of a circle with a +diameter of 15 mm.

(1) circumference. $c = \pi\ d = 3.1416 \times 15 = 47.124$ mm

(2) area. $A = \frac{c^2}{4\pi} = \frac{(47.124)^2}{4 \times 3.1416} = 176.72\ mm^2$

FIELD GEOMETRY

6. Field geometry is the application of the basic geometry discussed in the previous section. The equipment required is: a tape or string, wooden stakes and a hammer.

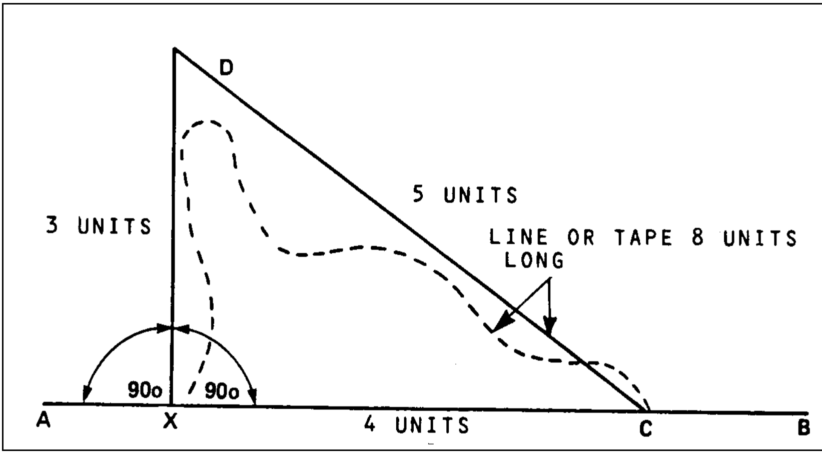

Fig 11-3-5 Setting Out a Right Angle

7. **To Set Out a Right Angle**:

a. lay out base tape AB and drive stake at point X;

b. mark a tape or string in three lengths: one of three units, one of four units and one of five units; and

c. place the ends of the string on the stake at X, run the tape four units along the base AB to establish point C. Loop the string over a stake at C. Pull the string taut and establish point D so that XD is three units and DC is five units long. The angle formed at X is a 90° angle.

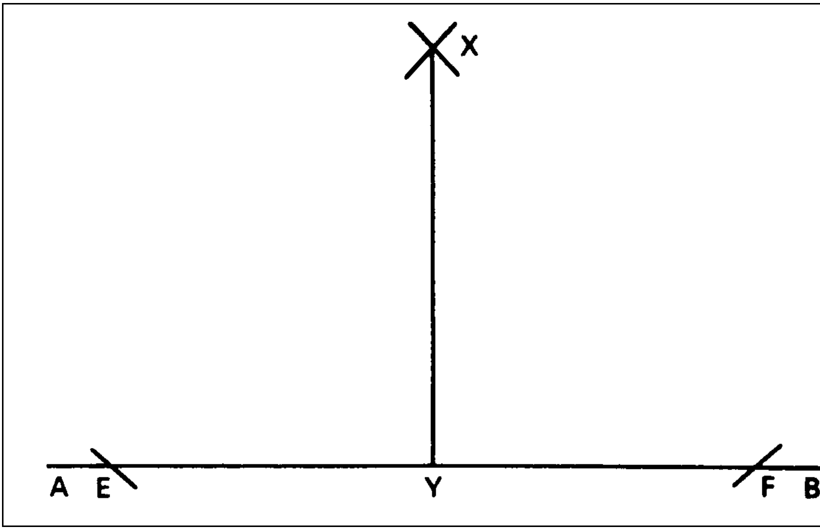

Fig 11-3-6 Setting Out a Right Angle Away from a Line

8. **To Set Out a Right Angle Away From a Line** (Fig 11-3-6), when AB is the given line and Y is the given point that the right angle to AB is required:

a. establish points E and F equal distances from Y along line AB;

b. take a string longer than line EF and find it's mid-point;

c. from points E and F extend the string so that mid-point X is established; and

d. angle XYB is a right angle.

9. **To Set Out 30° and 60° Angles to a Given Line** (Fig 11-3-7):

a. drive a peg at point X on line AB and at any convenient point along AB place a second peg C;

b. to pegs X and C attach the ends of a string which is twice the length of XC;

c. grip the centre point of the string, draw it taut and peg it at point D;

d. the angles at DXC, XCD and XDC will be 60°; and

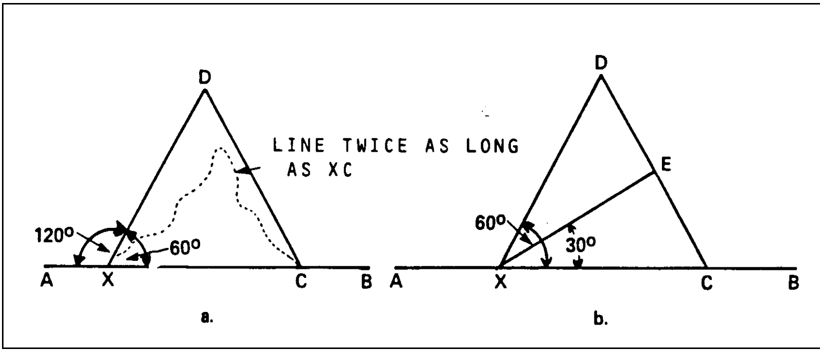

Fig 11-3-7 Constructing an Angle of 60°

e. by finding the centre along line DC, point E, and drawing line between X and E, a 30° angle is formed at angle EXC.

10. A **45° Angle** is normally found by bisecting an angle of 90°:

a. form a 90° angle DXC along line AB;

b. shorten the base by one unit. Draw a line from D to the shortened point on AB, point E. Connect D and E with a tape; and

c. find the centre point F of line DE and connect X and F. The angles formed at X to D and F, and X to F and E are 45° angles.

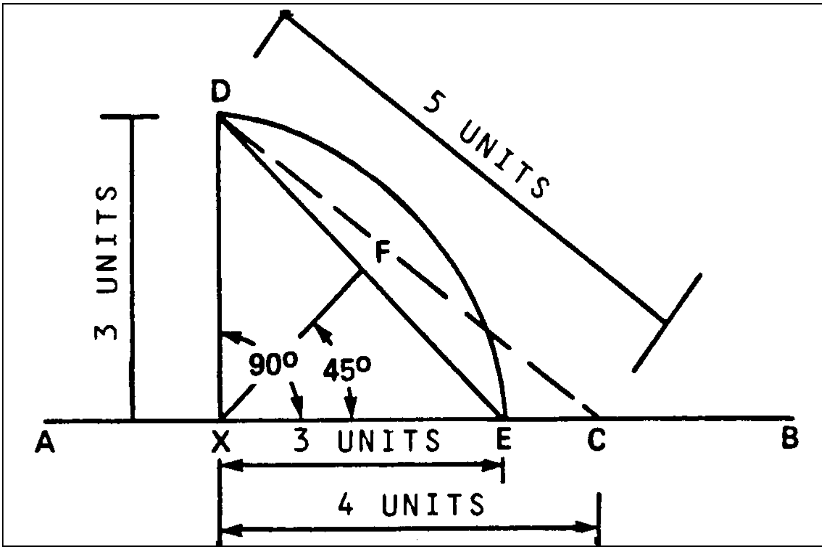

Fig 11-3-8 Constructing an Angle of 45°

11. **Bisecting Angles** (Fig 11-3-9 a):

a. hold one end of a length of string at 0 and mark points C and D so that lines OC and OD are equal in length and must be the same distance from OE;

b. at C and D take another length of string slightly longer then CD, scribe two arcs that intersect a point E;

c. join line OE; and

d. the triangles formed by COE and DOE will be equal, therefore angle COE equals angle DOE.

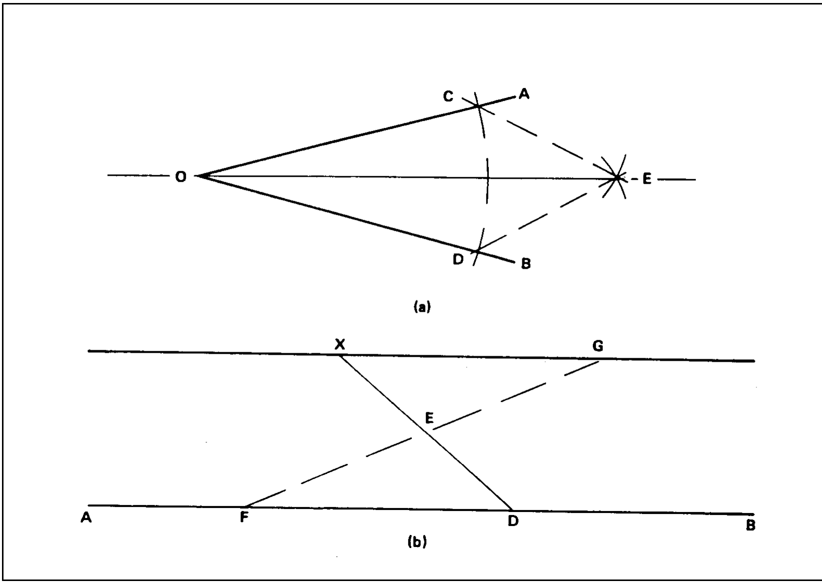

Fig 11-3-9 Bisecting Angles and Forming Parallel Lines

12. **To Form a Parallel Line** (Fig 11-3-9 b):

a. on a given line AB select a point D; run a line from point D to a point X where the parallel line is to be established (for greater accuracy the angle of ADX should be between 45 and 60^{o});

b. mark the centre of XD as point E;

c. select a second point F on AB and join F and E and extend the line to G so that EG = FE; and

d. XG will be parallel to AB.

MEASURING A GAP

13. It is often necessary to measure the distances between two points that are separated by a gap such as a river. Two methods of measuring using field geometery are described below. Stores required are string or tape, stakes and a hammer.

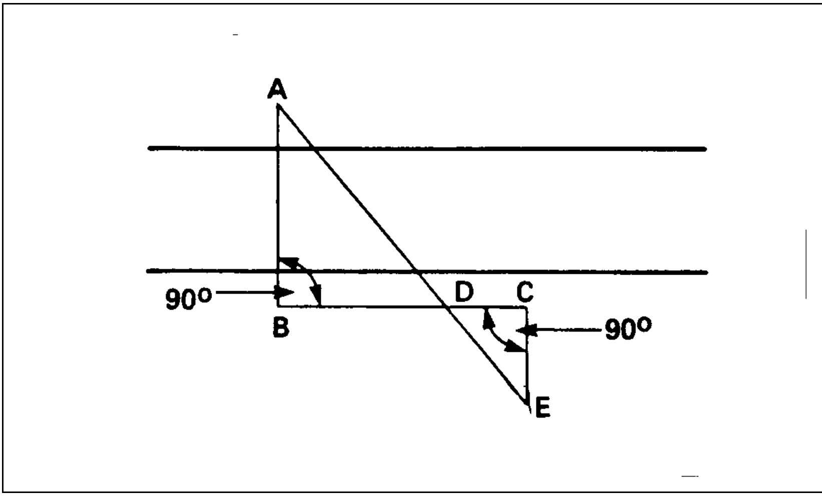

Fig 11-3-10   Measuring a Gap

14. **Method 1 - Using Proportional Right-Angled Triangles**, where AB is the distance to be measured (Fig 11-3-10):

a. place a stake at point B and, using a string, mark a line BC at right angles to line AB making line BC as long as practical;

b. choose a point D on BC so that the length of DC is a convenient proportion of the length of BD ie. 1/2, 1/3 or 1/4;

c. at C lay off CE at right angles to BC. Follow line CE to point E where A can be sited through point D, place a stake E;

d. the two triangles ABD and ECD are proportional and right angled and, because BD and DC are proportional to each other the other sides are also proportional so that AB and EC are in the same proportions; and

e. if BD is three times larger than DC then AB is three times larger than EC.

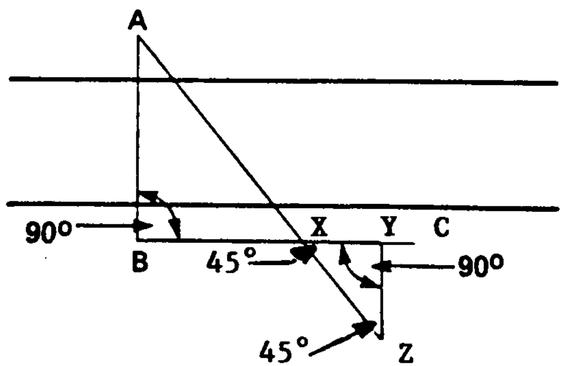

Fig 11-3-11 Measuring a Gap

15. **Method 2 - Using Proportional Right-Angled Triangles**. Where it is difficult to get a clear line of vision back from the near bank this method may be used. The method is only approximate and requires three personnel (Fig 11-3-11).

a. lay down a base tape BC at right angles to AB;

b. using the method illustrated in Fig 11-2-8 lay out triangle XYZ with the base XY parallel to the gap. The sides XY and YZ should be equal and as long as possible;

c. have one person hold the corners of the triangle XYZ keeping it taut. Persons X and Y walk down the base tape BC until person Z is able to line up X and A then halt is called; and

d. the angle formed by AXB will then be 45° degrees and BX will be equal to AB.

SECTION 4

HEIGHT, AREA AND VOLUME

CALCULATING HEIGHT

1. **Using a Known Reference**. The height of an object such as a tower or a cliff can be measured by using the shadows formed by the cliff and any convenient pole that can be measured. The ratio of the length of the cliff shadow to the pole shadow gives the ratio of the cliff height to the pole height.

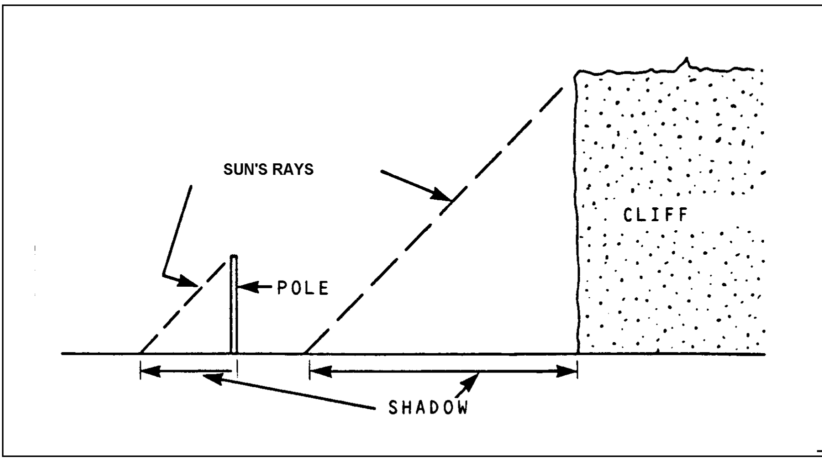

Fig 11-4-1 Establishing Height

2. **Using the Abney Hand Level**. The angle or gradient read on the Abney Hand Level can be correlated with the tables at Fig 11-4-2 and Fig 11-4-3 to produce the height of an object. Fig 11-4-2 lists gradients corresponding to applicable angles which would otherwise have to be interpolated from the vertical arc. Fig 11-4-3 gives values for vertical rise or fall per unit traversed horizontally. (Note: These two tables are designed for use with right-angled triangles).

Degrees	One in	Degrees	One in	Degrees	One in
1	57,0	10	5,6	26	2,0
2	28,6	12	4,7	28	1,88
3	19,0	14	4,0	30	1,73
4	14,3	16	3,4	32	1,6
5	11,4	18	3,0	34	1,43
6	9,5	20	2,7	36	1,37
7	8,1	22	2,4	38	1,23
8	7,1	24	2,2	45	1,00
9	6,3				

Fig 11-4-2 Gradients and Vertical Change of Certain Angles

Angle º	Rise or Fall	Angle º	Rise or Fall	Angle º	Rise or Fall
1	0,0175	16	0,2867	31	0,6009
2	0,0349	17	0,3057	32	0,6249
3	0,0524	18	0,3249	33	0,6494
4	0,0699	19	0,3443	34	0,6745
5	0,0875	20	0,3640	35	0,7002
6	0,1051	21	0,3839	36	0,7265
7	0,1228	22	0,4040	37	0,7536
8	0,1405	23	0,4245	38	0,7813
9	0,1584	24	0,4452	39	0,8098
10	0,1763	25	0,4663	40	0,8391
11	0,1944	26	0,4877	41	0,8693
12	0,2126	27	0,5095	42	0,9004
13	0,2309	28	0,5317	43	0,9325
14	0,2493	29	0,5543	44	0,9657
15	0,2679	30	0,5774	45	1,0

Fig 11-4-3   Gradients and Vertical Change of Certain Angles (Tangent Law)

3. It is essential that the horizontal distance from the observer to the object be measured or estimated. The height of the object above the observer's station = (angle to top of object) x (horizontal distance) + (height of observer's eye) (Method 1). When a building or object has sloping

ground from the observer to the foot of the building or object, an allowance must be made, (See Method 2).

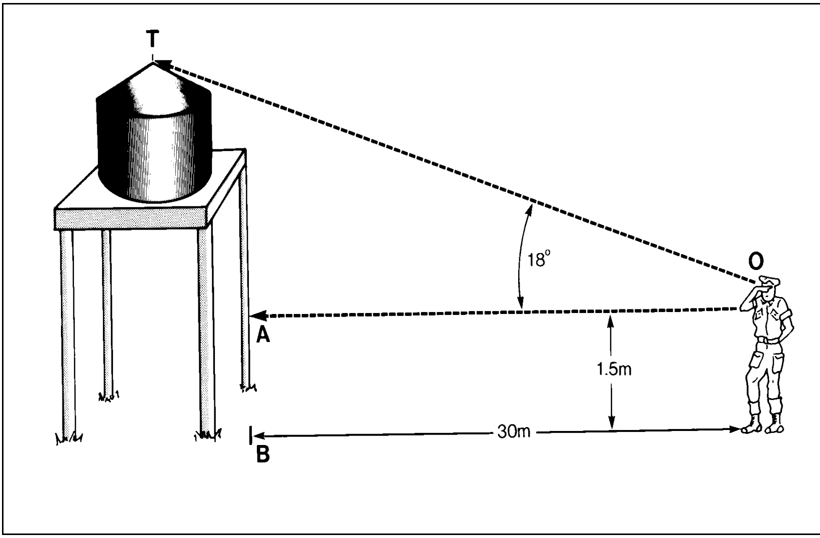

Fig 11-4-4 Finding Height of an Object (Method 1)

a. **Method 1.** The angle to top of tower is 18°, the height of the observer AB is 1.5 m and the distance from the observer O to the tower is 30 m.

(1) 18° expressed as a gradient (Fig 11-4-2) = 1 in 3 or 1/3 approximately or expressed as a decimal (Fig 11-4-3) = 0.3249.

(2) tower height TB = 1/3 x 30 + 1.5 m = 11.50 m; or TB = 30 x 0.3249 + 1.5 = 11.25 m.

b. **Method 2.** (Fig 11-4-5) The angle to the tower base is 10° above the observer's line of sight and to the top of the tower 36°. The distance from the observer to the tower base is 150 m.

(1) from Fig 11-4-2, angle to base (AB) = 0.1763 and angle to top (AT) = 0.7265.

(2) the distance (AB) from the observer's line of sight to the base = 0.1763 x 150 = 26.45 m.

(3) the distance (AT) from the observer to the tower top = 0.7265 x 150 m = 108.98 m.

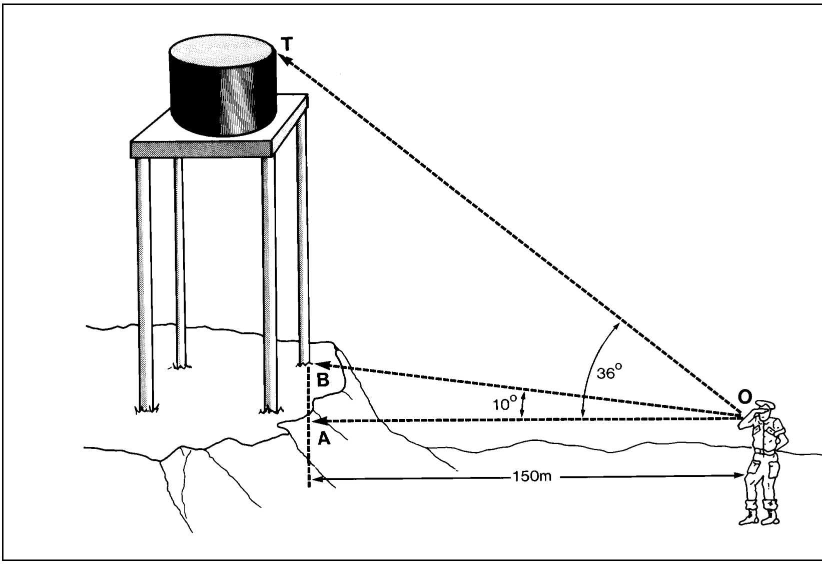

Fig 11-4-5 Finding Height of an Object (Method 2)

(4) height of tower = AT-AB=108.98m-26.45m= 82.53

c. In the case of small buildings on level ground, height may be obtained quickly as follows:

(1) set index to 45° elevation, or 1 in 1,

(2) stand back,

(3) look through telescope and put horizontal line on top of building,

(4) by moving towards and away from the building the engraved line will bisect the bubble, and

(5) measure distance from feet of observer to base of building and add observer's height to obtain the height of the building.

AREA OF IRREGULAR FIGURES

4. **Calculating the Area of Parts of a Circle**. Calculating the area of parts of a circle is generally obtained through a process of subtraction, for example:

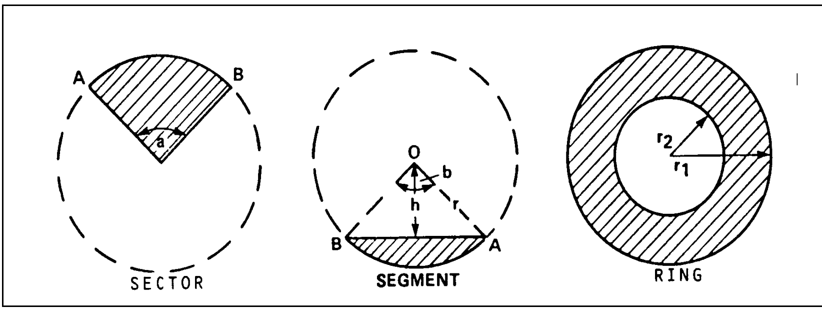

Fig 11-4-6 Areas of Parts of Circles

a. **Area of a Sector** subtending an angle "a" at the center. The area is proportional to the whole circle as angle "a" is to 360°.

$$A = \pi r^2 \times \frac{a}{360}$$

b. **Area of a Segment.** The area of a segment is the area of the sector OAB obtained above, less the area of the triangle AOB.

$$A = \pi r^2 \times \frac{a}{360} - \frac{AB \times h}{2}$$

c. **Area of Ring.** The area of a ring, for example the cross section of a pipe, can be calculated as the area of the outer circle minus the area of the inner circle.

$$A = \pi (R_1)^2 - \pi (R_2)^2 \quad \text{or } \pi (R_1^{\,2} - R_2^{\,2})$$

5. **Calculating the Area of a Polygon**. To calculate the area of an irregular figure bounded by a number of straight lines. Divide the figure, area ABCDE in Fig 11-4-7, into a series of triangles, and use the formula for calculating the area of triangles as described in Section 3.

6. When there are no clear lines of site across the figure, the answer can be obtained by calculating the area of the containing rectangle, AOPQ in Fig 11-4-7, and subtracting the unwanted areas.

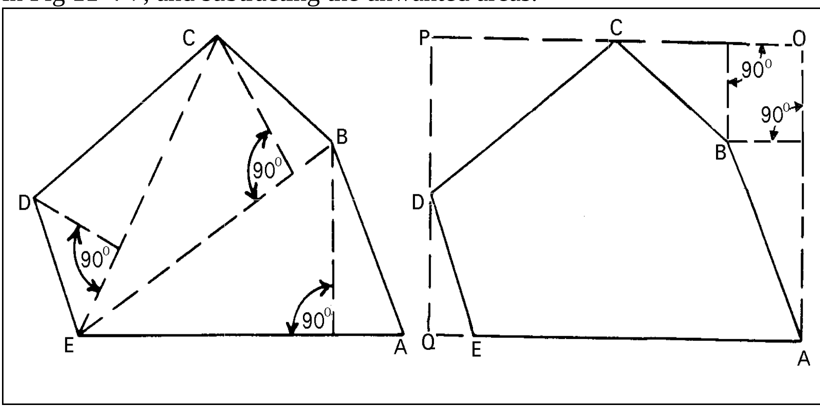

Fig 11-4-7 Calculating the Area of an Irregular Figure

7. Calculating the Volume of a Regular Solid.

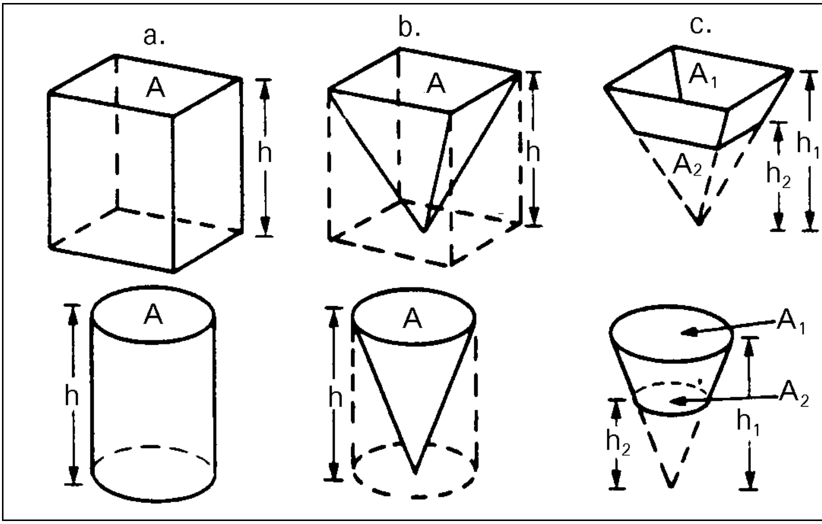

Fig 11-4-8 Volume of Regular Solids

a. The volume of a prism or cylinder is the area of the base X the height (h). (Fig 11-4-8a)

$$\text{Volume} = \pi r^2 \times h$$

b. The volume of a pyramid or cone is the area of the base multiplied by the height (h) then divided by three. (Fig 11-4-8b)

$$\text{Volume} = \frac{\pi r^2 \times h}{3}$$

c. To find the volume of a reservoir with sloping sides, the volume is that of the larger figure less the volume of the smaller (see Fig 11-4-8c).

$$\text{Volume} = \frac{(A_1 \times h_1)}{3} - \frac{(A_2 \times h_2)}{3}$$

NOTE: The values of h_1 and h_2 are calculated from the depth of the reservoir and the slope of the sides (Fig 11-4-8c).

ESTIMATING DISTANCE, AREA AND VOLUME

8. **Distance.** Each engineer shall be familiar with the following normal personal measurements:

a. the normal length of a pace is about 750 mm;

b. hand span is about 225 mm (small finger tip to thumb tip);

c. palm width is about 100 mm (across the knuckles); and

d. boot length is about 300 mm.

9. **Area.** Area can be judged by relating to familiar objects, ie:

a. a soccer field is 1.8 ha; and

b. a tennis court is 260 m^2.

10. **Volume.** Volume is more difficult to estimate:

a. a 45 gallon drum holds 200 litres; and

b. a one cubic metre tank holds 1000 litres.