SURVEYING USING A LEVEL INSTRUMENT

AN INSTRUCTION MANUAL FOR SURVEYOR'S COURSE IN JAMAMA DISTRICT LOWER JUBA, SOMALIA

Agrosphere
April 2004

FOREWARD

This manual is produced to assist the surveyor trainees understand the basics of surveying using a level instrument particularly the dumpy level. This is the 2nd course held at Agrosphere project base Jamama and is expected to take a duration of two months from mid march to mid My 2004. It is a continuation of the first course held in the same place for one month from 8th October to 8th November 2003.

At the end of the curse the surveyor trainees are expected through practical experience be able to:

- Take levels and book them in a survey record book.
- Place temporary and permanent bench marks.
- Take chainages along canals.
- Reduce and compute levels using both height of collimation and Rise and Fall methods.
- Take flying back levels for survey checks.
- Take levels along canal beds and embankments.
- Take levels and chainages along drainage and feeder roads.
- Take detailed survey on localized areas and site plans.
- Understand the various scales used in drawings.
- Draw site plans, profiles and cross section.

John Ndungu
Agrosphere
April, 2004

CONTENTS

FIGURES

1. INTRODUCTION

Small, "localized" survey work can easily and quickly be done using a level instrument.

Potential weir sites, locations where road crossings, division boxes, etc. have to be built, can be mapped by taking a few cross sections in the field and working it out in the office.

Although a theodolite, tachymeter or plane may be more suitable for this purpose, they are not always available and a certain routine is required to use them efficiently and correctly.

If a survey job is only done once in a while, the handling of a level instrument is less complicated and acquaintance with the instrument is quickly made.

In this manual different types of leveling instruments are discussed. The procedure for execution of a site survey and the way of recording and calculation of the data are shown.

2. TYPES OF LEVEL INSTRUMENTS

The level is an instrument with a telescope and bubble tube which is used for measuring differences in elevation between various points. The horizontal distances are usually measured with a measuring tape or chain.

There are three basic types of level instruments, namely:

1) Dumpy Levels
2) Engineers' Tilting Levels
3) Automatic Levels

The first two are both spirit bubble levels. The dumpy level is a very simple basic instrument, while the tilting level has certain modifications, which give greater convenience of operation and a possibility of greater precision.

The often used "quickset" level is a tilting level without foot-screws.

The automatic level, which gives a horizontal line of sight automatically, is the most convenient to use. It is however, the most vulnerable of the three and relatively expensive.

2.1 Dumpy level

a) Main characteristics

The telescope of the dumpy level is rigidly attached to the vertical spindle, the leveling of the instrument is done by means of three foot screws separating two plates. The upper plate with the vertical spindle on which the telescope and bubble tube are mounted has to be leveled (=set horizontal) with the foot screws.

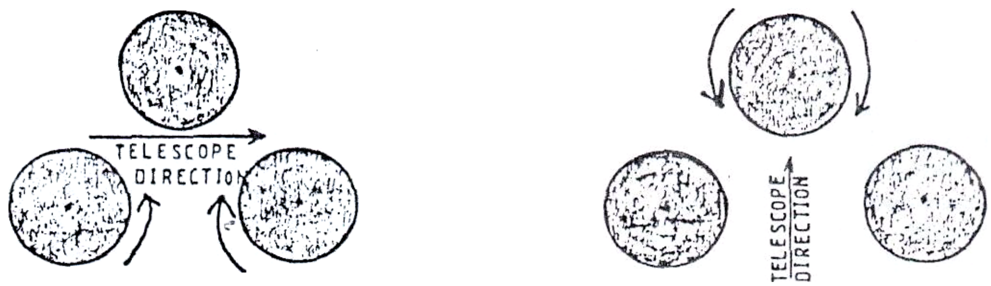
b) Setting up

After ensuring that the instrument is firmly secured to the legs of the tripod and that the legs and fittings are not loose, set up the instrument by spreading the legs evenly at a comfortable and safe angle, thrusting two legs firmly home in the ground.

Take the third leg and move it with the foot on the ground, until the instrument is as level as possible. Slide the leg in towards the instrument (5 – 10 cm) and press the third leg hard into the ground.

c) Leveling up

Commencing with the telescope and bubble parallel with one pair of screws, bring the bubble to the centre of its run by equal opposite and simultaneous movement of both screws, as shown in Figure la.



a: " Position 1" **b: " Position 2"**

Figure 1 - Leveling of the instrument with the adjustment screws

Turn the telescope through 90° to position 2, and centre the bubble using only the one screw beneath the telescope, see Figure Ib.

Repeat this process, with the telescope pointing in the same direction for the same position, until no further adjustment is required.

Before using an "unknown" instrument, some checks should be made to ensure that it is "road worthy":

d) Parallax

The first adjustment required is that of eliminating parallax. This adjustment is to ensure that the images of the sighted object and the centre cross hair are focused in the same place. It is carried out as follows:

1) Focus at infinity.

2) Position an object (level book cover, back of hand, box of Matches etc.) a few centimeters in front of the objective lens in order to give a bright plain view to contrast the cross hairs. Bring the cross hairs to their sharpest image by rotating the eye piece,

3) Sight to the staff and focus the telescope until the staff is at its sharpest definition. The parallax error should now be eliminated. To check if this is so, move the eye slightly up and down, and note if there is any relative movement between staff image and cross hairs. If there is, then the adjustment has not been carried out critically enough. Repeat until corrected.

e} Vertical axis adjustment

The second adjustment is to make the vertical axis of the instrument truly vertical when the bubble is in the centre of its run, usually spoken of as making the level "traverse". Level up the instrument as described and when the bubble is over two screws needing no adjustment, turn the telescope through 180°. If the bubble remains central, then the instrument is in adjustment. If not, bring the bubble half-way back with the bubble adjusting nuts connecting the bubble tube to the telescope. Level up with the foot screws and repeat until no adjustment is required.

It is essential to perform a collimation adjustment after this procedure has been carried out.

f) Collimation adjustment

This is commonly known as the "TWO PEG ADJUSTMENT". Its purpose is to make the line of collimation" (line of sight) horizontal when the bubble is central.
This adjustment is of prime importance, as this condition is the basis of all spirit leveling.-
Two dumpies A & B are placed about 100 *m* apart OD fairly level ground, and the instrument set midway between them at X and leveled up (see Figure 2).

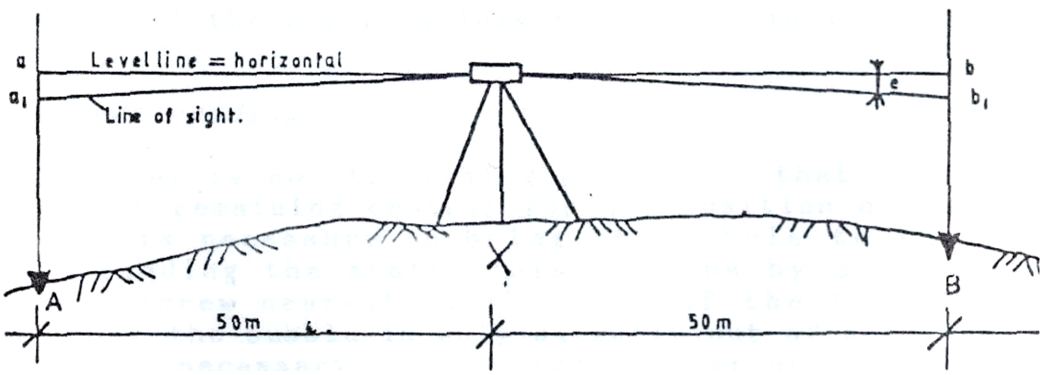


Figure 2 - Collimation test (first stage)
Readings are taken to a staff at each dumpy, ensuring that the bubble is central for each reading. As the angle of error (e) will be constant for both readings, and the distances equal, the error in reading aa_1 will be equal to the error bb_1 ($aa_1 = bb_1$) . Therefore, the difference in staff readings will be the true difference in level between the dumpies.

The instrument is then transferred to position Z, in line with both dumpies and about 3 meters beyond one of them, and leveled up (see Figure 3).

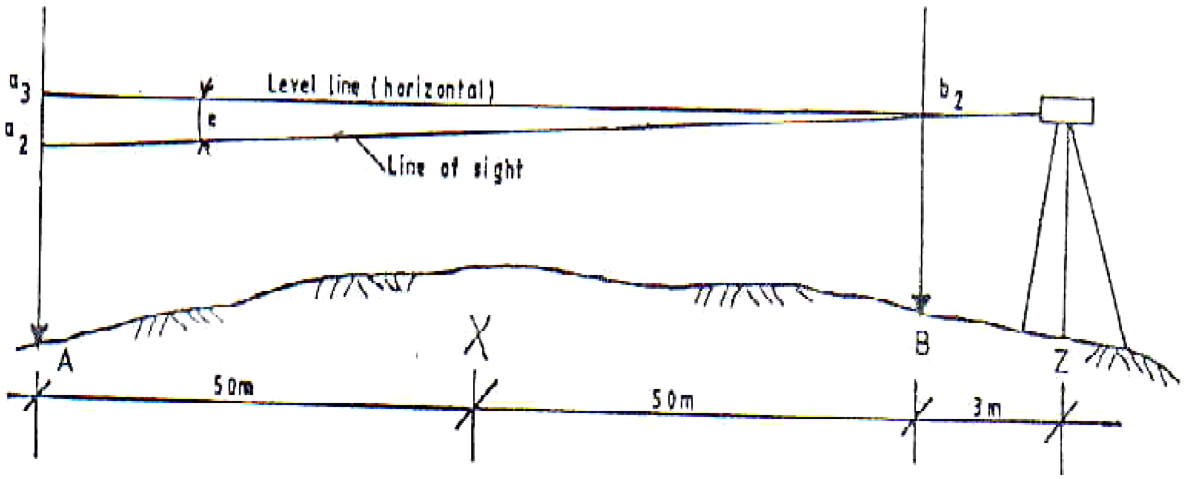


Figure 3 - Collimation test (second stage)

Staff readings are then taken to a_2 and b_2 and hence calculated.

If this agrees with the true difference, as before, then the instrument is in adjustment. If not, the total error must now be in the reading a_2 as distance to b_2 will give a negligible error. Using reading b_2, apply the known true difference to this to give the true reading as at A and move the cross hair diaphragm with the adjusting screws to give the required reading. Repeat until the error is less than 0.005 in 100 *m.*

g) Staff reading

If the level is not traversing perfectly, that is, the bubble is not remaining central for any position of the telescope, it is necessary to bring the bubble to the centre before reading the staff. This is done by adjusting the leveling screw nearest to the line of the telescope and staff. If the bubble to only slightly out of position, this may not be necessary for intermediate ground shots, but it is essential to have the bubble centered before reading change points, Bench Marks, or any other definite points.

2.2. The (Engineer's) Tilting Level

a) Main characteristics

The Tilting: Level has a telescope which is not rigidly fixed to the vertical spindle. Instead, the telescope is capable to tilt slightly in the vertical plane about a point just below the telescope. This vertical movement of the telescope is made by rotating a tilting screw below the eyepiece.

A tilting level has two bubbles:

- A circular bubble on the upper plate to achieve approximate leveling by means of the three foot screws;
- A telescope bubble (tube bubble) to be leveled for each sighting by the tilting screw only.

A special type of tilting level is the “quickest” level, often used in the P.I.U's. Contrary to the "normal" tilting level the "quickset" level does not have foot screws in the leveling head. A ball-and-socket joint is provided to level the instrument quickly, but only approximately. Accurate leveling of the instrument must be completed with the tilting screw for each sighting.

b) Setting up

Set up the tilting level in the same way as the dumpy level

See section 2.1 b).

c) Leveling Up

Using the foot screws or ball-and-socket joint bring the circular bubble into the centre of its ring. Centre the telescope bubble with the tilting screw for each staff reading.

d) Parallax

As described for the dumpy level.

e) Vertical axis adjustment

As the telescope bubble of the tilting level is never fixed permanently at right-angles to the vertical axis the bubble tube adjustment as described for the dumpy level does not apply to the tilting level.

f) Collimation adjustment

Perform the "two peg adjustment" exercise exactly as described for the dumpy level. Instead of adjusting the diaphragm, the tilting level requires to adjust the telescope bubble.

Once the true reading at A has been calculated (see page 5), the tilting screw is adjusted to move the line of sight on to this reading required. This movement will cause the bubble to move from its central position, but the line of sight will then be horizontal and the bubble should be central. Therefore adjust the bubble by its adjusting screws to bring it back to the central position.

g) Staff Reading

As described for the dumpy level

2.3 The Automatic Level

The automatic level has either foot screws or a ball-and-socket joint. Once the level has been approximately leveled, it gives automatically a horizontal line of sight without a (telescope) bubble having to be accurately set.

As the automatic level does not have a telescope bubble there is no need for the telescope to be capable of tilting, therefore, there is no tilting screw either.

Setting up and approximate leveling is done with the circular bubble in the same way as for a tilting level. The adjustment of parallax must be carried out as described for the dumpy level.
Using the automatic level the line of sight should be horizontal once the instrument has been approximately leveled using the circular bubble only. To check this, the "two-peg adjustment" test is carried out as before (see section 2.1 f). For most automatic levels the adjustment is done by moving the diaphragm, as is done for the dumpy level. Never touch the stabilizing unit of the automatic level but return the instrument to the supplier for repairs.

2.4 Leveling staff

There are several types of graduated staffs available (telescopic, folding). Readings are always in the metric system to the nearest millimeter. An example is given in Figure 4. Always study the leveling staff you will be working with before you use it in the field.

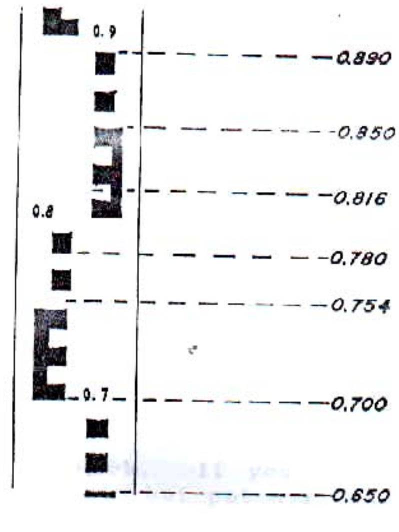


Figure 4 - Detail of Leveling Staff

3. LEVELING PROCEDURES AND FIELD BOOKS

The levels are recorded in a field book; this field book must always show the following:

- The date and year on each page;
- Name of surveyor;
- The job description (name of canal, site, grid survey etc);
- Serial number and type of the survey instrument used;
- Page number.

You may also use your field book to note field decisions made, instructions received from visiting engineers, hours worked etc. In other words your field book is a complete daily record of your work in the field. It is recommended to use a ball-point- pen to enter your measurements. The entries should be clear and neat, any other person should be able to use the field book for future reference. First of all, the draughtsman should be able to use it for plotting and mapping work. If you make a mistake, don't make the figure invisible but put a line through the error.

Draw small diagrams where necessary, always show with an arrow the direction of flow in a waterway. If indicating the right and left bank, always name them when looking in down stream direction.

There are two methods of recording, the Collimation Method and the Rise and Fall method.

3.1. Collimation method

Level at B = height of collimation - reading at B

Level at D = height of collimation - reading at D

The collimation method is also known as the "height of instrument" method. Throughout the field work the instrument height is always known by *taking* the *first sight on a. paint* of known (or assumed) level. At anytime therefore, the level of a point can be quickly worked out by subtracting its staff reading from the level of the instrument (instrument height). The method is convenient for obtaining the levels of many points from one set-up.

Thus the first point of reading should always be of known level, preferably a Bench Mark. The reading of the B.M is booked on the first line in the back sight column as this

is the point of known level, see Figure 5.

Surface shots are booked each on a separate line in the intermediate column, at the same time the distance is booked in the distance column, (see Figure 5). Figure 6 shows the positions of the instrument and change points.

DATE: 25-3-2004 **LEVELS TAKEN FOR**: IRRIGATION CANAL Bode B **FROM**: CH. 0 m **TO**: CH. 275 m **SURVEYOR**: M. B. Aden							
BACK SIGHT	**INTER-MEDIATE SIGHT**	**FORE SIGHT**	**RISE**	**FALL**	**REDUCED LEVEL**	**DIS-STANCE**	**REMARKS**
1.510					106.390		BM NO. 4
1.212		2.943		1.433	104.957	0	C P 1 (Inv. Intake)
	1.291			0.079	104.878	25	BED LEVEL
	1.404			0.113	104.795	50	BED LEVEL
	1.346		0.058		104.823	75	BED LEVEL
	1.370			0.024	104.799	100	BED LEVEL
	1.308		0.062		104.861	125	BED LEVEL
	1.294		0.014		104.875	150	
1.285		1.228	0.066		104.941		C P 2
	1.363			0.078	104.863	175	BED LEVEL
	1.582			0.219	104.644	182	
	1.347		0.235		104.879	200	BED LEVEL
	1.530			0.183	104.696	225	BED LEVEL
	1.502		0.028		104.724	250	BED LEVEL
	1.564			0.062	104.662	275	BED LEVEL
1.825		1.286	0.278		104.940		C P 3
1.691		1.540	0.285		105.225		C P 4
		0.532	1.159		106.384		BM NO. 4
7.523		7.529	2.185	2.191	106.390		
7.529			2.191				
					-0.006		
-0.006			-0.006				

Figure 5 – Collimation method (recording)

The final reading on a change point is booked in the foresight column. Make sure your staff man uses good change points or change plates. Now the instrument can be moved to the next point, leveled up again and the same change point is read again and booked in the back sight column and you can carry on taking intermediate levels. To be able to check for errors you must end your survey at the benchmark you started from or at another benchmark with known elevation so that you can check for misclosure.

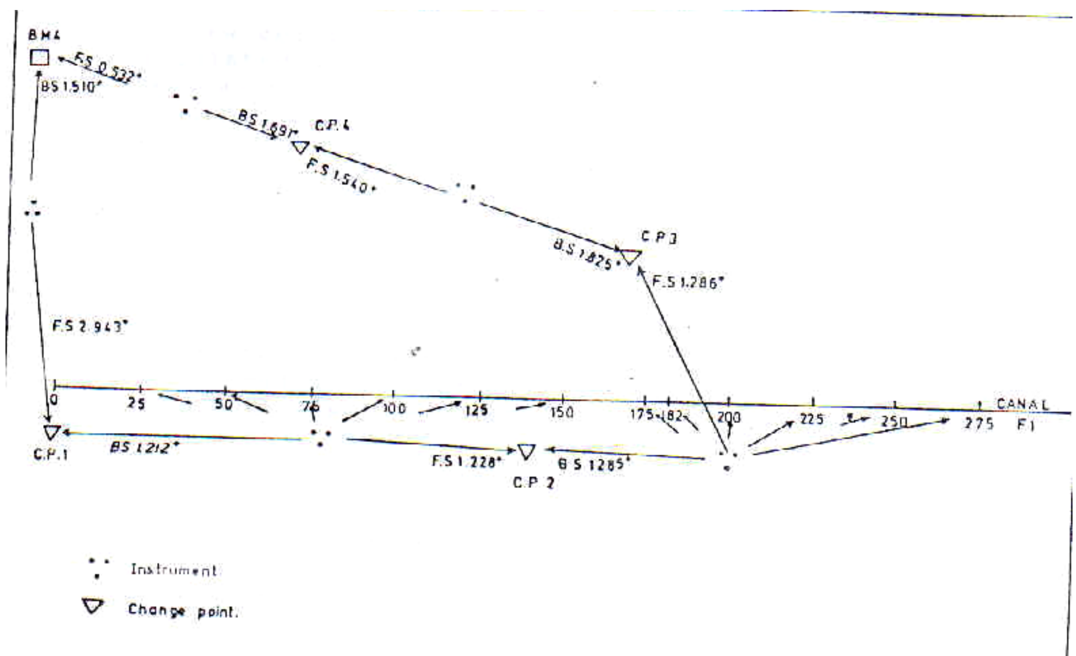


Figure 6 - Positions of instrument and change points

In Figure 5 the known value (level of bench mark No. 4) is printed thick, the measured values (staff readings and distances) are printed thin, while the calculated values are printed in Italics.

The reducing is done as follows:

1) Write the value of the known bench nark in the reduced level column on the first line and the number of the bench Mark under remarks.

2) Add to this value the value of the back sight and you obtain the collimation level. This value will remain the sane for all the intermediate points up to the next change point.

3) The reduced levels (elevations) of the intermediate points are calculated by subtracting the intermediate value from the collimation level and are booked in the column for the reduced levels.

4) The reduced level of the change point can be calculated by subtracting the fore sight value from the collimation level.

5) The new collimation level after the change point is calculated by subtracting the fore sight from the previous collimation and then by adding the back sight value. This new value is booked in the collimation column etc.

Having completed the levels from one known elevation (B.M.) to another, a check is needed on the closure of levels. The last calculated reduced level must be compared with the known value of the benchmark and the observed difference is the misclosure.
A second method to check the arithmetic of the reduced levels is to add up all the back sight readings, then to add up all the fore sight readings. The difference between the first and last reduced levels must be equal to the difference between the sum of the back sight and the sum of the fore sight readings.

Thus: BS - FS Last R.L First R.L

For the example of Figure 5:

Back Sights	Fore Sights
1.510	2.943
1.212	1.228
1.285	1.286
1.825	1.540
1.691	0.532

BS = 7.523 FS = 7.529 BS – FS = -0.006

Last R.L – First R. L = 106.384 – 106.390 = -0.006

Finally a third method to check the arithmetic can be mentioned; it requires a lot of calculation and is therefore (?) seldom used.

"The sum of all reduced levels except the first should equal: (Each instrument height) x (Number of I.S and F.S observations made from it) - (Total sum of the I.S and F.S readings)."

Taking the figures from Figure 5:

1783.916 = (107.900 x 1) + (106.169 x 7) + (106.226 x 7) +
+ (100.765 x 1) + (106.916 x 1) - (16.901 +7.529)

Or 1783.916 = 1783.916 thus arithmetic's in Fig. 5 are O.K.

3.2 Rise and Fall Method

For the same survey exercise as in section 3.1 the rise and fall method is illustrated in figure 7.

DATE: 25-3-2004 **LEVELS TAKEN FOR**: IRRIGATION CANAL Bode B **FROM**: CH. 0 m **TO**: CH. 275 m **SURVEYOR**: M. B. Aden							
BACK SIGHT	**INTER-MEDIATE SIGHT**	**FORE SIGHT**	**RISE**	**FALL**	**REDUCED LEVEL**	**DIS-STANCE**	**REMARKS**
1.510					106.390		BM NO. 4
1.212		2.943		1.433	104.957	0	C P 1 (Inv. Intake)
	1.291			0.079	104.878	25	BED LEVEL
	1.404			0.113	104.795	50	BED LEVEL
	1.346		0.058		104.823	75	BED LEVEL
	1.370			0.024	104.799	100	BED LEVEL
	1.308		0.062		104.861	125	BED LEVEL
	1.294		0.014		104.875	150	
1.285		1.228	0.066		104.941		C P 2
	1.363			0.078	104.863	175	BED LEVEL
	1.582			0.219	104.644	182	
	1.347		0.235		104.879	200	BED LEVEL
	1.530			0.183	104.696	225	BED LEVEL
	1.502		0.028		104.724	250	BED LEVEL
	1.564			0.062	104.662	275	BED LEVEL
1.825		1.286	0.278		104.940		C P 3
1.691		1.540	0.285		105.225		C P 4
		0.532	1.159		106.384		BM NO. 4
7.523		7.529	2.185	2.191	106.390		
7.529			2.191				
					-0.006		
-0.006			-0.006				

Figure 7 – Rise and fall method (recording)

Instead of calculating the collimation (height of instrument), the rise or fall from one staff position to the next is calculated by subtracting the second reading from the first:

B.S (or I.S)		F.S (or I.S)		
1.510	-	2.943	=	-1.433 (fall)
1.212	-	1.291	=	-0.079 (fall)
1.291	-	1.404	=	-0.113 (fall)
1.404	-	1.346	=	+0.058 (rise)

Note that, to obtain the rises and falls, you always have to subtract from the figures in the B.S or I.S columns the figures immediately below or one line down to the right. Once a fore sight has been subtracted, start again with the back sight on the same line, subtracting the I.S or the F.S, which ever may be on the next line down.

Having obtained all falls and rises; the total rise or fall can be calculated by taking the difference between the sum of each column. This must agree exactly with the difference between the sum of B.S. and F.S.

The reduced level of each point is obtained by adding the rise or fall of the next station to the reduced level of the one preceding it.

The final observed reduced level should be compared with the first (given) one and should agree with the calculated rise or fall between the two stations concerned.

3.3 Which method to use?

Preference of the individual should lead to the selection of the recording method used.

The height of instrument (collimation) method has the advantage that the reduced levels of the stations are obtained quicker, whereas the (mathematical) checking for the rise and fall method is clearer in arrangement.

3.4 Accuracy of recording and closure errors

All the measurements are done in metric and the value of the staff readings are rounded off to the nearest millimeter for ordinary site surveys discussed in this manual.

The maximum permissible error for such a survey is normally taken as 20   K mm, where K is the total distance leveled over in kilometers.

For instance, if the known difference in level between a B.M. No 1 and a B.M. No 2 is 2.876 m and the observed level difference from a level run with a length of 1.6 kilometers is 2.869 TO, the error is 2.876 - 2.869 = 0.007 m or 7 mm.

The permissible error is calculated with 20   K = 20   1.6 = 25 mm, and the conclusion is that the error Bade during the leveling is acceptable as it is smaller than 25 mm.

If we look at our example (see Fig. 6) we can estimate the length of the round trip at 100 + 200 + 235 = 535 m, say 550 m. The permissible error becomes 20   0.55 = 14.8 mm. Therefore the actual error of 6 mm is acceptable.

4. APPLICATIONS

4.1 Preparations

Make sure you take the following equipment to the field:

1) Dumpy level, titling level or even an automatic level instrument, provided with a horizontal circle;

2) The tripod belonging to the level instrument;

3) Measuring tape (30 m);

4) At least 3 ranging rods;

5) Sufficient pegs and prefab concrete benchmarks;

6) The level book and ball point;

7) Preferably 2 leveling staffs;

8) A change plate;

9) A panga and a spade.

When starting a survey, keep the following rules in mind, it will help you to reduce the chance on errors:

1) Do a collimation test (check) before you commence, it takes only 5 minutes and could save you day or more of releveling.

2) Make sure your staff man holds the staff vertical. This can be done with the aid of a vertical bubble fixed to the staff or by means of moving the staff very slowly forward and backward over its vertical position. In latter case the surveyor should read the lowest value in sight, see Figure 8.

3) Make sure your staff man uses fixed change points or a change plate.

4) Try to keep your back sights and fore sights of roughly equal length.

5) Always finish your survey at the starting point or at another known bench mark.

6) Try to keep your field book readable, note as many details as possible, this will simplify the plotting.

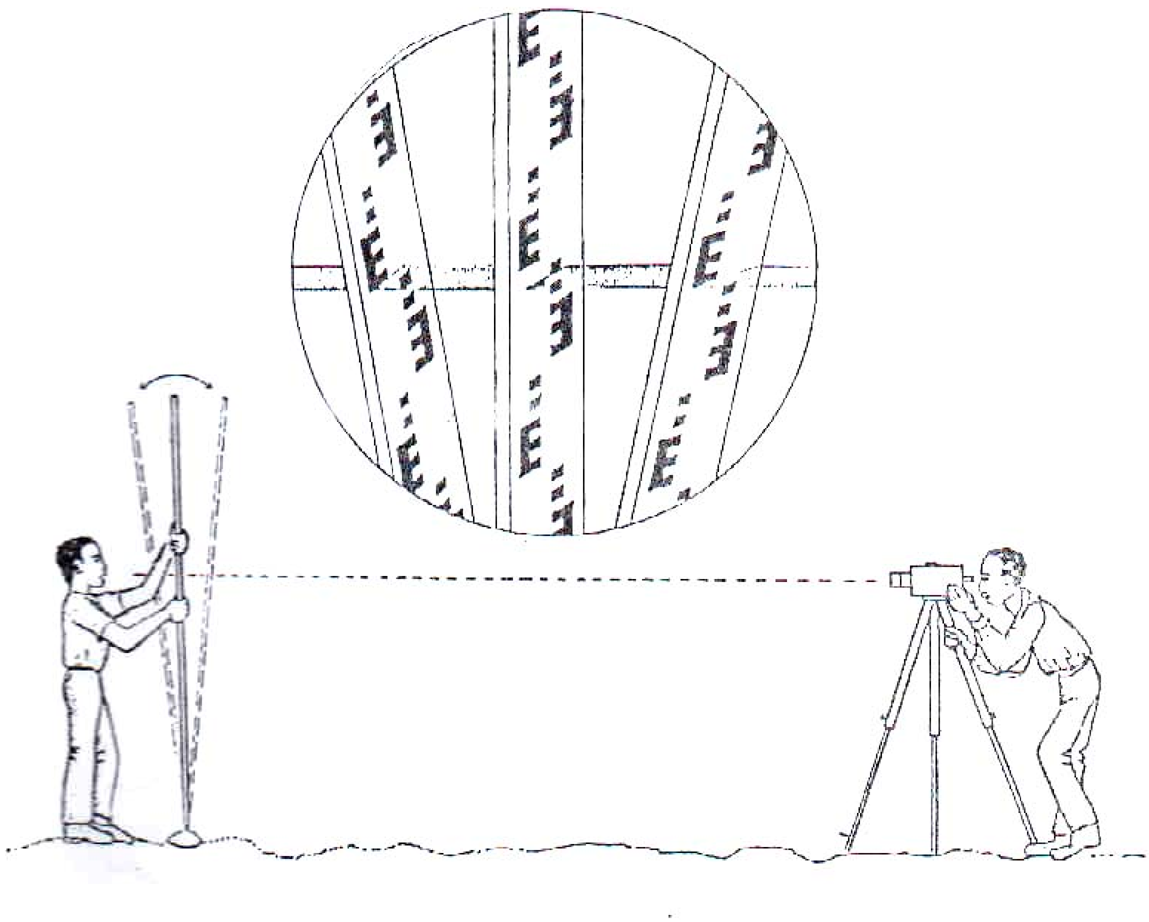


Figure 8 - Readings when staff is in vertical position!

4.2. Working procedure for a (small) weir site

Suppose that somewhere along the river stretch shown in Figure 9 a weir should be constructed. Cross sections and a plan with contours (25 cm intervals) are needed to decide on the precise location of the diversion weir and to prepare the weir design.

In Figure 9 and 10 a baseline and cross sections are indicated. The indicated cross sections are shown only to illustrate the way cross sections should be set out. Actually the cross sections should stretch to approximately 20 m on both sides of the river banks and at least cover the in Figure 9 indicated road!

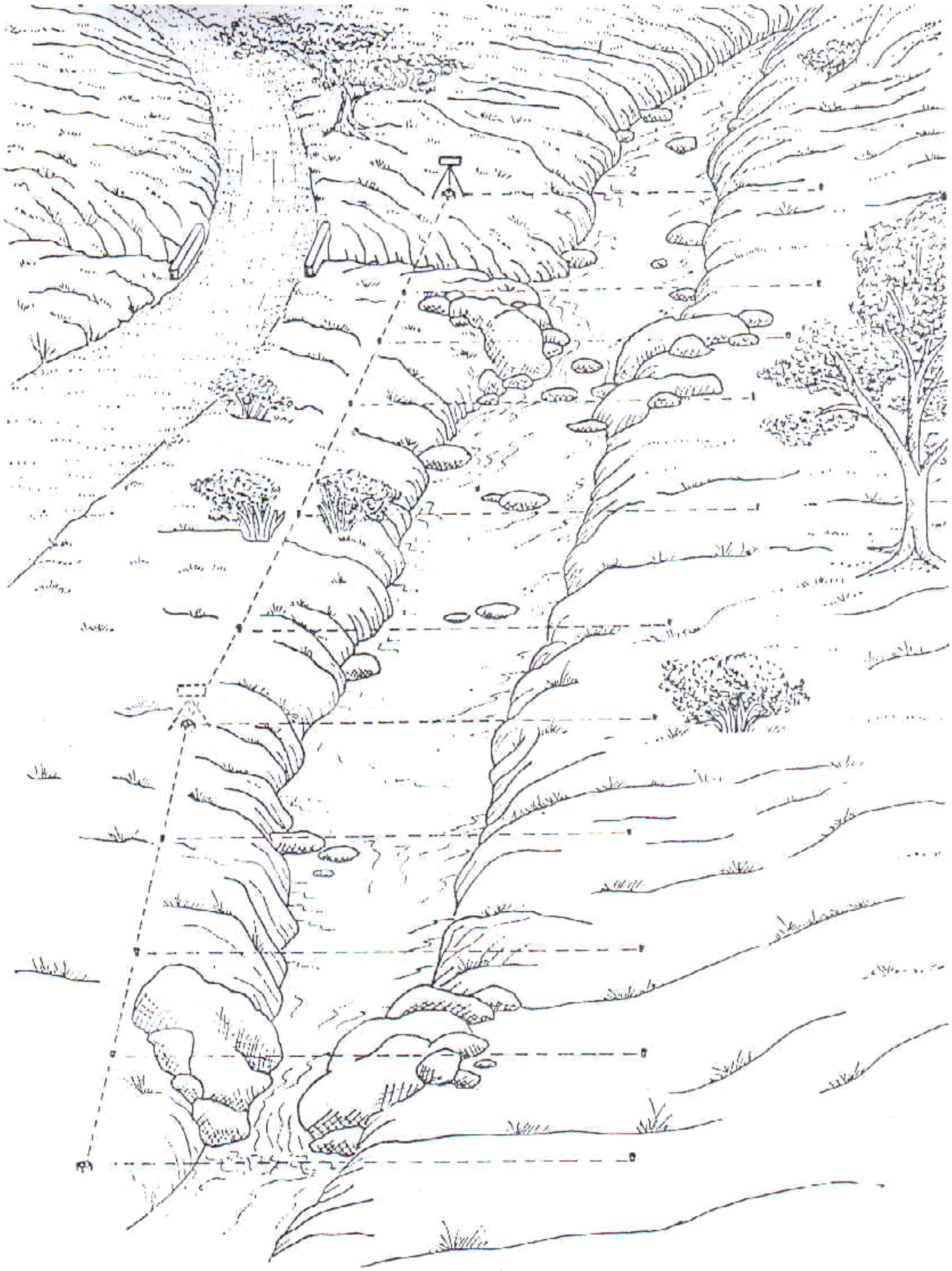


Figure 9 - Survey of weir site

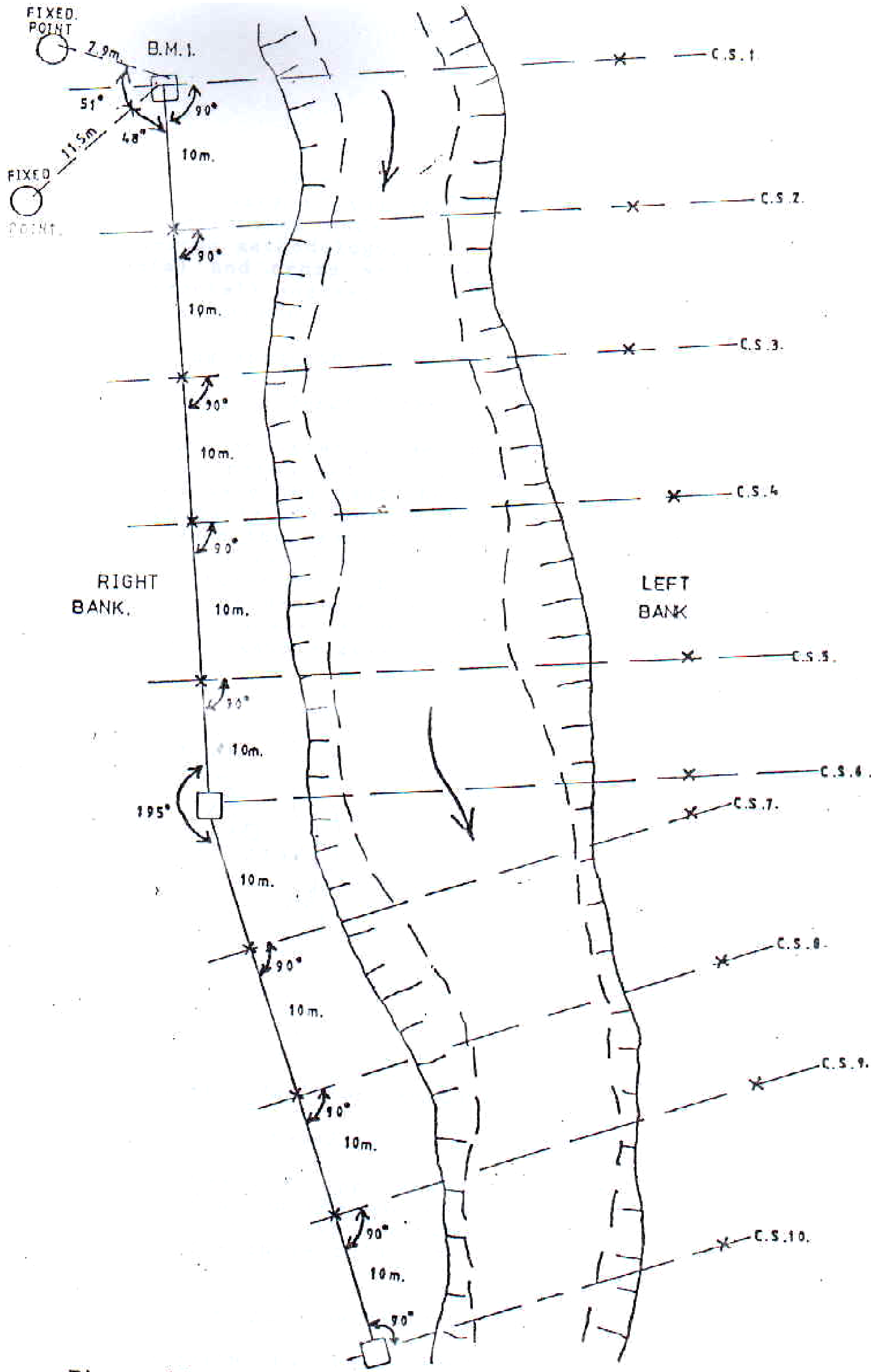


Figure 10 - Survey plan of weir site

Although your survey for the river stretch as shown in Figure 9 may vary in the smaller details from the proposed bribed here below, you are advised to follow Methodology, i.e. firstly stake and *peg* out the baseline(s) and cross sectional lines and measure lengths and (horizontal) angles, only thereafter the actual leveling exercise

The following sequence of activities can be listed.

Step 1: Establish Beach Marks

If there are no existing bench marks, start with fixing at least one permanent bench mark at a convenient spot. Bench Marks have the nasty habit to get completely removed, completely buried or partly destroyed. Retracing is very difficult when the exact position is not known. By relating a bench a ark to two fixed points in its vicinity (big trees, rocks, structures etc) and noting these particulars in the field book, the bench marks may be found again after some months or even years. A position sketch for a Bench Mark may look like the example given in Figure 11.

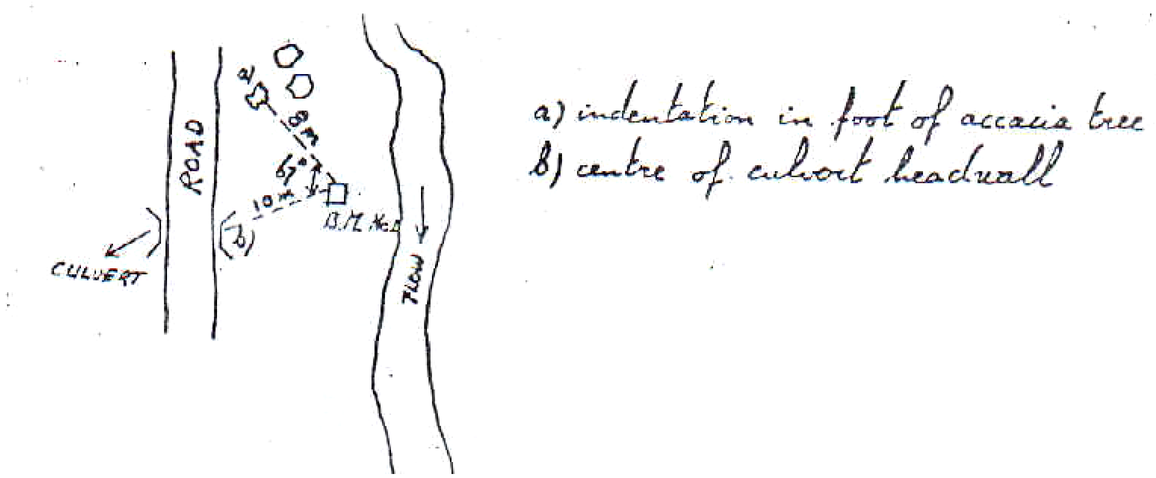


Figure 11 - Position sketch of Bench Mark

Step 2: Establish baseline

Establish a baseline approximately parallel to the **river** axis. Depending on the curvature of the river one angles might have to be included in the baseline. Provide bench marks for these points as well as for the baseline.

Step 3: Set out the required cross sections

Once the baseline has been fixed the cross sections should be staked out. Depending on the features of the river section to be surveyed a proper intermediate distance should be chosen to *get* sufficient information for the plan. In Figure 10 intervals of 10 metres have been applied while the cross sections are perpendicular to the baseline. When required varying intervals may be used. However it is strongly recommended to stick to cross sections taken perpendicular on the baseline (which should run more or less parallel to the river axis), as it greatly facilitates the later plotting and reduces the possibility of errors. Pegs are used to indicate the cross sectional lines.
To get the cross sections perpendicular on the baseline, a prism may be used which should be sighted in on 2 rods on the baseline after which the 3rd rod can be sighted in on a perpendicular line, see Figure 12.

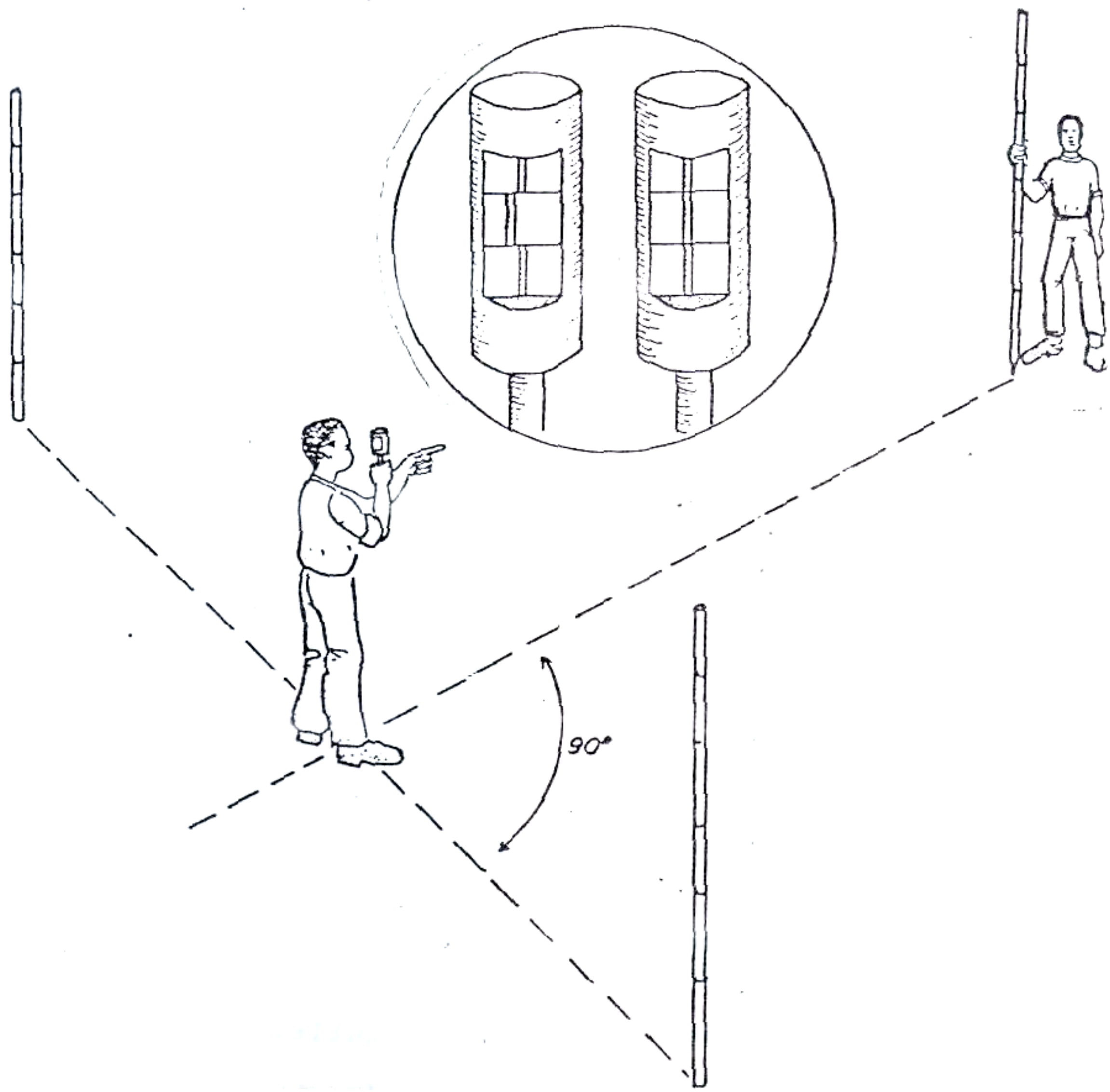


Figure 12 - Setting out perpendicular lines with a prism

If no prism is available a practical way is to stand on the baseline where a perpendicular has to be set out, point both arms to two rods on the baseline and then slowly move both arms together (forward). The third rod should be brought in line with the direction your arms are pointing in, see Figure 13. Another way is of course to use the horizontal angle of the leveling instrument. However this is time consuming as it requires the instrument to be set up at many locations.

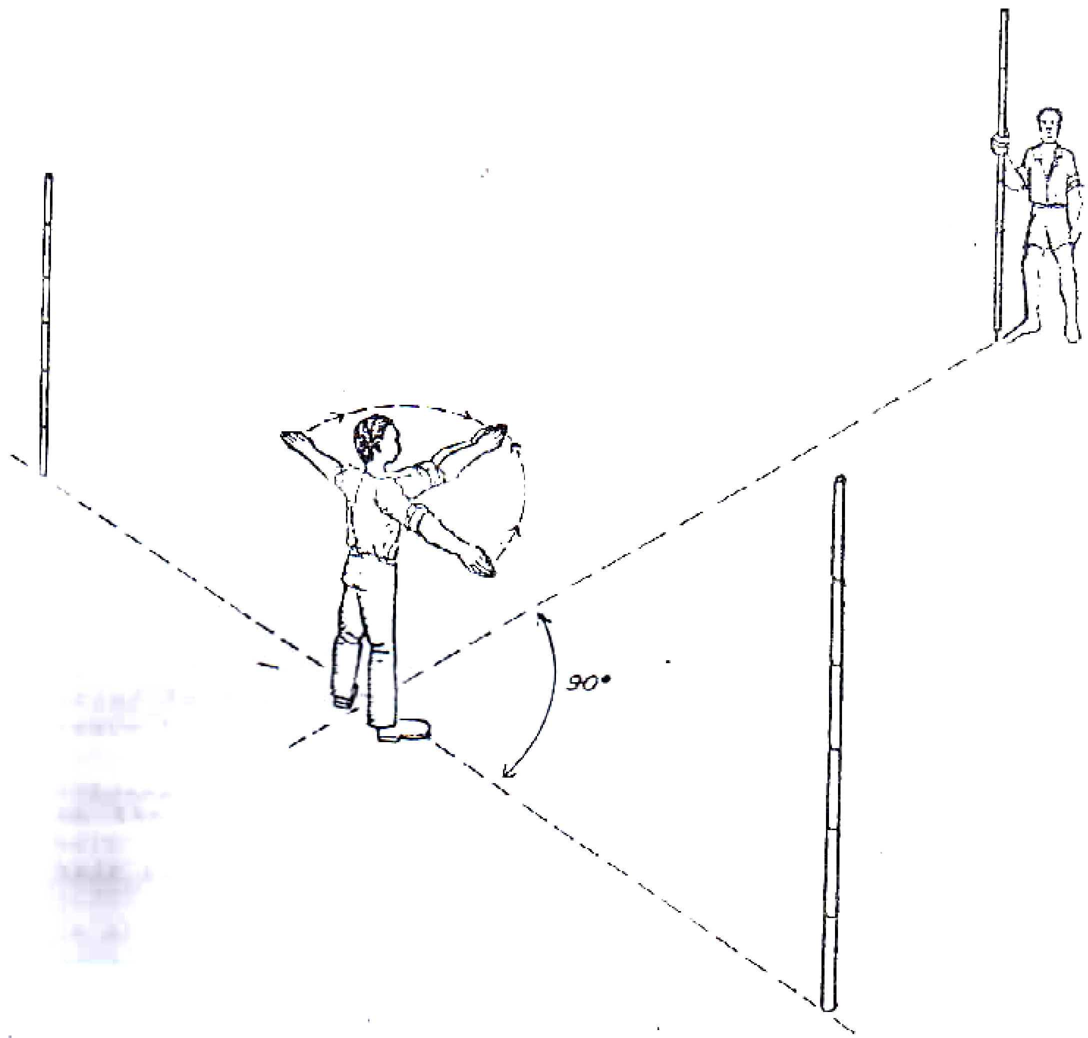


Figure 13 – Practical way for establishing perpendicular lines when no prism is available.

Step 4: Start leveling and distance measurement.

Only now the actual taking of levels with the level instrument should start; although it has already been used to measure the angles. (Don't forget to measure the angle between the baseline and at least one of the fixed points at B.M, 1 (see Figure 11). This information will enable you to reconstruct the complete baseline if the benchmarks have disappeared.

Using either “collimation" or "rise and fall" method, the cross-sections can be leveled, It is obvious that, to obtain sufficient information not only the level of a point of a cross-section should be known but also its distance to the baseline. Points in the cross section should be taken at any change of the ground slope but not more than 5 m apart.

It is recommended to fix the measuring tape (use the ranging rods) across the river, for each position of the leveling staff its distance from the baseline can then quickly be read. Keep in mind that for accurate distance measuring the tape should to kept horizontal.

If it is physically not possible to use the measuring tape, the distance can also be measured by the leveling instrument by reading the upper and lower cross hairs. The difference of the two readings multiplied by 100, gives the distance from the instrument to the staff position in meters.

For example:	reading upper hair	-	1.946 m		
	Reading lower hair	-	1.732 m		
			0.214 m		
	hence the distance	=	0.214 x 100	=	21.4 m.

it is clear that this method is not very accurate as 1 mm error in the reading gives already 10 cm error in the distance.

Reading the upper and lower cross hairs also gives a check on the correct reading of the centre cross hair as (upper hair reading + lower hair reading) divide by 2 = centre hair reading.

In above example: (1.946 + 1.732)/2 = 1.839 which should be equal to the centre cross hair reading. If it is not, the reading should be repeated.

REFERENCES

LAND SURVEYING
Ramsay J. P. Wilson, Mac Donald and Evans Ltd. 1983
ISBN 0-721-2705-4

WATER TECHNICAL PAPER NO. 7
H. Ritsema
Assistance to irrigated agriculture in Turkana/Pokot