Topic 2: LEVELLING

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PREVIEW

Introduction

Levelling is, for engineers, the most frequently used survey skill. The process is simple, and the chances of making mistakes are great.

This topic deals with the use and application of the optical level in engineering.

Objectives

After completing this topic you should be able to :

- set up and adjust a level for use
- check that a level is in proper adjustment
- apply procedures to isolate gross errors before they become part of your results
- apply procedures to minimise the incidence of systematic and random errors
- reduce your field observations and apply checks to your work.

Readings

Read Muskett Chapter 2

REQUIRED

SKILLS

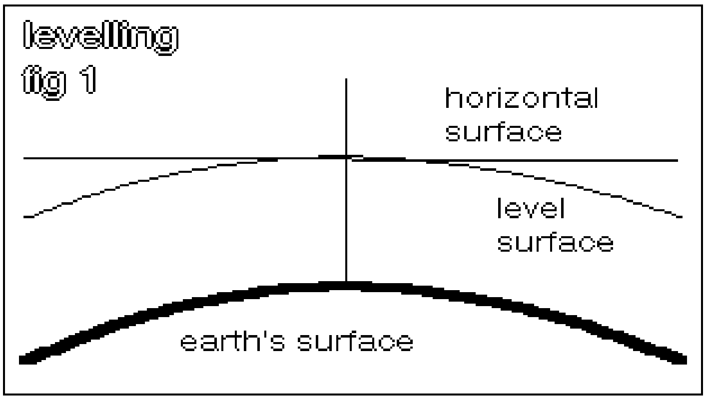
The most important skill to learn in this chapter is how to do a **levelling traverse**. You will need to understand how a level works, how to set it up (and minimise errors), how to book the data, and adjust it for errors (as long as the misclosure is acceptable!).

Once you have these skills, you can tackle **applications** of levelling such as taking levels along a longitudinal section, including cross-sections, and collecting data for contouring.

DEFINITIONS

Levelling is involved with the use of a (usually) optical level to determine **elevations**. We do this by starting from a point of known elevation (a **benchmark**), and proceeding to calculate **differences in elevation**, until we get to another point of known elevation (often the original benchmark). We can then calculate whether any errors (**misclosure**) exists in our measurements. If the misclosure is small, we can distribute the error over all our measurements.

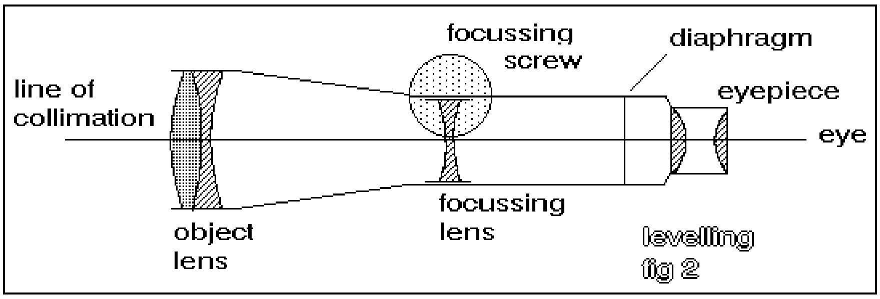
A level (instrument) establishes a **horizontal plane** at each set up point.



A **level surface** is a surface on which gravity is constant. A level surface approximates with a horizontal surface over short distances.

A **horizontal surface** is normal to the direction of gravity at the instrument point.

TELESCOPE



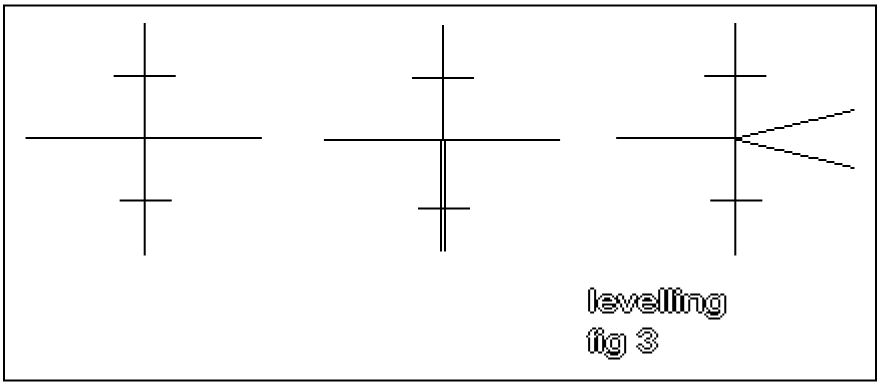
The external image is focussed onto the plane of the diaphragm, using the focussing screw which moves the focussing lens along the axis of the telescope.

The axis of the telescope is defined by the centre of the objective lens and the centre of the cross hairs (diaphragm). It is also known as the **line of collimation**.

The eyepiece is focussed to adjust the focal point of its lens system onto the **diaphragm** or cross hairs.

CROSS HAIRS

The cross hairs usually resemble one of these:



SETTING UP A LEVEL

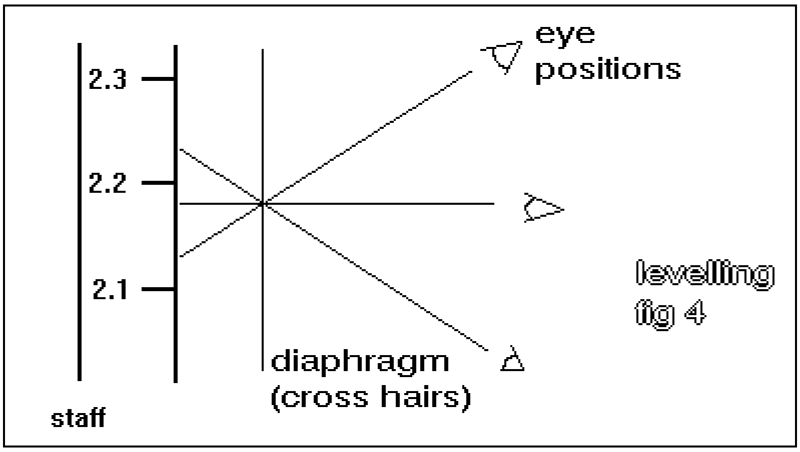
1. Remove parallax

It is essential that :

1. the image is focussed to fall in the plane of the diaphragm, and

2. the eyepiece is adjusted so that its focal point is also in the plane of the diaphragm

If this doesn't occur, then moving the eye with respect to the eyepiece, will move the object relative to the cross-hairs. This is parallax, and it will result in an incorrect staff reading, as shown in this Diagram...



The cure: hold a field card in front of the telescope so as to direct light into the telescope and adjust the eyepiece until the cross hairs are fine and dark. This is a personal setting and should remain constant for any one person, regardless of the distance sighted.

Focus the telescope on the staff using the focussing screw or knob, usually placed halfway along the telescope.

Check for parallax by moving your eye slightly. The image should remain stationary with respect to the cross hairs. If it is not refine the telescope focussing.

2. Level the instrument

Turn two footscrews in opposite senses until the pill bubble is centred along the line between the two footscrews. The bubble will move in the direction of your left thumb. Centre the bubble in the direction perpendicular to this using the third footscrew alone. You may have to repeat this process two or three times to get the bubble properly centred.

Modern (automatic) levels use a pill bubble which makes the instrument approximately level. That is all that is required with an automatic level. The automatic compensator then levels the line of sight to about 0^{o} 0' 01"

Typical levels

Automatic level

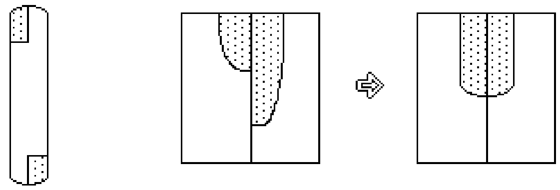
Almost universal now. It uses a compensating system of prisms suspended in the telescope to ensure that the line of collimation is horizontal. Simply centre the pill bubble as above.

Digital level

An automatic level that reads and records the staff for you (at much greater cost).

Tilting level

The telescope is hinged. An accurate bubble tube (usually with a split bubble viewer) is used for accurate levelling of each shot:



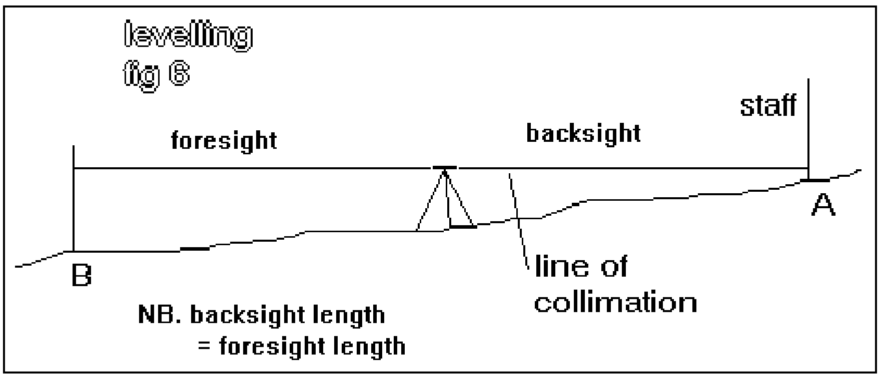
levelling
fig 5

The Tilting level replaced the Dumpy level which required 3 footscrews to be adjusted for each shot.

A LEVELLING TRAVERSE

OVERVIEW

A levelling traverse is based on **differential levelling**, which uses the difference in level (elevation) between points A and B. If we start from a point of known elevation (a **benchmark**, then we can calculate the level of each point in the traverse.



eg. if the staff reading at A is 1.64 m and at B is 3.74 m, then B is 2.10 m **lower** than A (ie the **fall = backsight - foresight)**.

We can make a series of such measurements as follows. Start at A, a benchmark, so the first measurement is a backsight to A, and the second is a foresight to B. (B is known as a **Change Point**, or C/P). **The staff remains at B**, while the instrument moves. Note that the instrument is set up approximately halfway between the points we want to level, **never over them.**

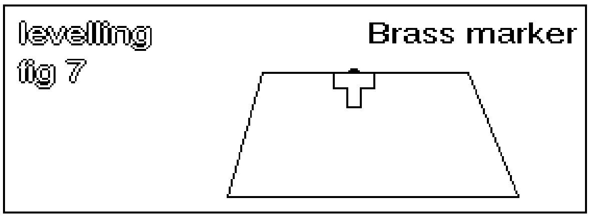
Move the instrument. Take a backsight to B. Move staff to C. (C is another Change Point). Foresight to C, and so on.

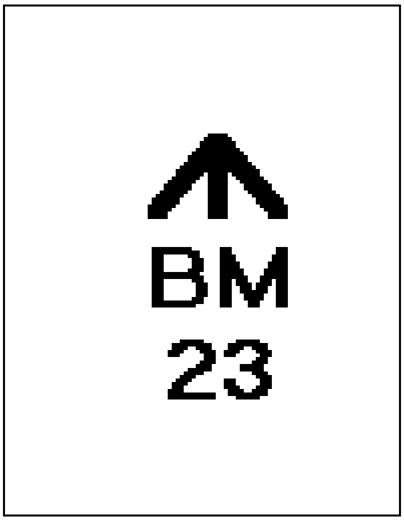
Eventually, a backsight to Z, and a foresight to A.

The traverse is then **CLOSED**. This allows a **check** on the levels, since the sum of all the changes in level should be zero. A level traverse may also be closed between two different points of known height, in which case the sum of all the changes in level should equal the difference in level given for these points.

In a levelling traverse, the temporary points between bench marks are known as change points (or C/P). A change point allows us to move the instrument forward.

A Bench Mark (BM) is a point of known elevation, and may appears as:



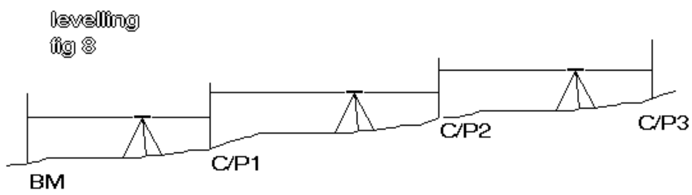


Registered Bench Marks are also called PSMs (Permanent Survey Marks).

Australian Height Datum (AHD) is the absolute reference for levels in Australia. It approximately coincides with Mean Sea Level. A State Datum may also exist.

Levels are usually referred to as **reduced levels (RL's).** You often see on plans: **"Datum of Levels - AHD".**

BASIC BOOKING



The Rise and Fall Method

BS = Backsight
FS = Foresight
IS = Intermediate Sight
RL = Reduced Level

BS	IS	FS	Rise	Fall	RL	Remarks
1.672		-------			93.827	BM
0.837		1.245	0.427		94.254	C/P 1
1.895		1.526		0.689	93.565	C/P 2
1.296		1.176	0.719		94.284	C/P 3
		1.750		0.454	93.830	BM
5.700		5.697	1/146	1/143		
	0.003		0.003		0.003	

Note that this is a **closed traverse** (it starts at the BM and ends at the same BM).

Note that both readings (BS and FS) for each staff point go on one line - **one point, one line**, and that **the first line has no foresight** (since we always start with a backsight to our benchmark). The position of the level instrument is not recorded in the level book, and is relatively unimportant.

There is a misclosure of 0.003 m (3 mm), which can be distributed over the preceding points as follows:

RL	Remark	n times 0.75 mm has been
94.253	C/P 1	deducted from each point
93.563	C/P 2	
94.282	C/P 3	

This type of correction is almost always necessary.

Check on booking (and calculations)

$\sum$(BS) - $\sum$(FS) = RL(end BM) - RL(start BM). This checks your survey accuracy, and should be within tolerances given below or suitable for your project. This check should be applied before you leave the job.

The following check the arithmetic of your level reductions and must be exact:

- $\sum$(BS) - $\sum$(FS) = $\sum$(Rise) - $\sum$(Fall)
- $\sum$(BS) - $\sum$(FS) = RL(last BM) - RL(start BM)

  In this check RL (last BM) is the value you work out reducing your levels, not the control value used for RL (end BM).

Apply the checks progressively during reduction. When you have calculated the rises and falls, apply the check before calculating the RL's. This may save you having to work the RL's twice.

Always calculate the RL's by mental arithmetic without using a calculator, otherwise the check will not work. It will not reveal and error made in copying from calculator to level book. You may think that you will not make such an error, but it is common. Everything checks out, but one level is out by a whole metre - potential disaster!!!

Distribute error evenly over all calculated levels as shown. (There are also other methods of doing this, to be discussed later).

Misclosure should be 12.$\sqrt{K}$ mm where K is the length of the traverse in km (for 1 km, 12 mm error is acceptable). This assumes sightings of maximum 60m, and reading staff to the nearest mm (not the nearest 5 mm!).

Another formula is **misclosure < 5$\sqrt{N}$** where N is the number of stations in the traverse.

If the error is acceptable, distribute it over all change points.

Check on Adjustment of a Level (Two Peg Test)

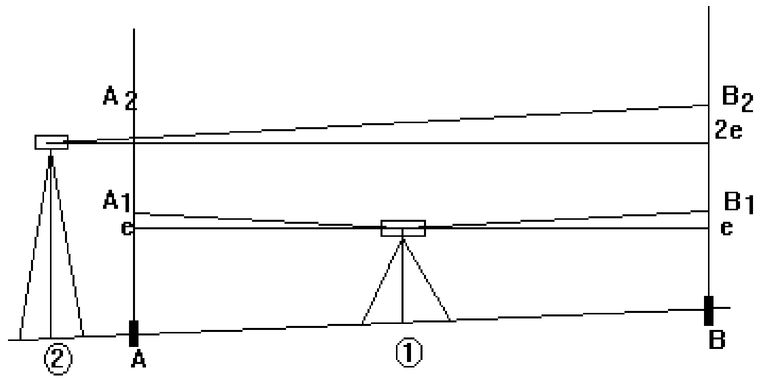
Aim
To check that the levelling instrument is free of collimation error. That is, to check that the level produces a truly level line of sight when the main level vial is properly centered, or in the case of an automatic level, when the compensator is controlling the line of sight.

Theory
If the level is set up midway between two points, the difference in level observed will be the true difference in level, as whatever instrumental error may be present will affect equally both observations and so cancel out.

If the level is then set close to one of the points and the difference in level is measured again, the error to the far point will be double that of the first observations, and will not be cancelled out.
If the level is in adjustment, the difference in level measured from the centre and from one end will be the same. If the instrument is out of adjustment, it will be revealed by this test.

Method
Select two points 50 to 80 metres apart. They should have a height difference of 0.3 to 0.4 metres, and be marked with nails or pegs with a domed top so that the staff can be placed at exactly the same height each time it is held at the point.

Measure out the mid point between the two pegs using a fibre tape, and set up the level at this mid point (position 1). It is **not** necessary to use a plumbob to set exactly over the point



Take staff readings at points A and B and calculate the true difference in height:

$$dH_{true} = A_1 - B_1$$

Move the instrument to point 2, at minimum focussing distance and read the staff at A and B again. Calculate the observed difference in height:

$$dH_{obs} = A_2 - B_2$$

The collimation error of the instrument at say 60 metres is:

$$E = dH_{true} - dH_{obs}$$

The magnitude of E should not be greater than 0.003 m, and preferably less.

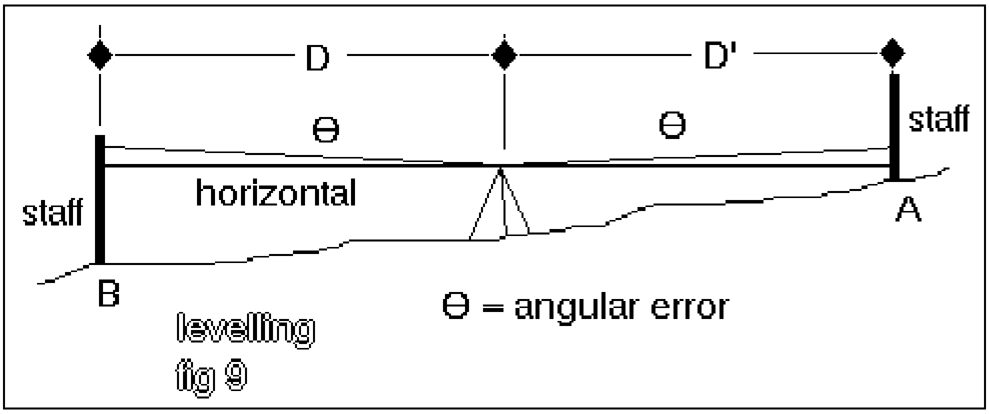
If you have the handbook for the level and some experience in the process, you can adjust the level to remove the error, by calculating the correct staff reading B_2

$$B_2 = A_2 + B_1 - A_1$$

After making the adjustment in accordance with the maker's instructions, **the whole test must be repeated to ensure that the adjustment has been made correctly.**

Precautions

You must keep length of foresight equal to length of backsight to eliminate effect of error in instrument, ie. D = D'.



MORE ON BOOKING

Intermediate Sights

BS	IS	FS	Rise	Fall	RL	Remarks
4.320			---------		34.600	BM, AHD
	1.726		2.594		37.194	Road C/L
	2.017			0.291	36.903	Top Kerb
2.275		1.475	0.542		37.445	C/P
						and so on

Intermediate sights are used where we want to collect many points, but where we don't want to make every one a change point (since this is very time consuming because the instrument **must** be moved for each one). An example would be where we were doing a traverse along a road centreline. We would take cross-section levels as intermediate sights.

Intermediate sights are **not** change points, and so are **not** checked.

The levels for any critical points, such as temporary bench marks (TBM's), inverts of pipes, crest of spillway, etc. **must be read as change points.**

A Rise (R_i) is defined below. A negative rise is a Fall

$R_i = BS_{(i-1)} - FS_i$ **OR**

$R_i = BS_{(i-1)} - IS_i$ **OR**

$R_i = IS_{(i-1)} - IS_i$ **OR**

$R_i = IS_{(i-1)} - FS_i$

Collimation Method

BS	IS	FS	Coll Ht	RL	Remarks
4.320		---------	38.920	34.600	BM, AHD
	1.726			37.194	Road C/L
	2.017			36.903	Top Kerb
2.275		1.475	39.720	37.445	C/P
					and so on

The **Collimation method** is most useful when many intermediate sights must be taken (eg. centreline surveys and grids).

It is useful if a point of known height is to be found (eg. a **contour line**) because the required staff reading is easily determined

It **doesn't allow for any easy check** on booking, so the Rise and Fall Method is preferred for Levelling Traverses.

Again, there are **no** checks on the Intermediate sights. A misbooking on one of these values will not be obvious. Special care is required.

LEVELLING TECHNIQUES

1. **heat shimmer** - read high on the staff
   - reduce the length of shots
   - avoid hot surfaces, eg. roads, concrete

2. **economy** of levelling (ie. don't do too much work)
   * obtain **maximum length** of shots while keeping **foresight length = backsight length**
   * on a hill, this may result in a zig zag pattern, if moving the maximum height of the staff each time
3. **try not to read the very top or very bottom** of staff
4. **any critical point whose level must be established, must be a change point** (this allows the level of that point to be checked after closing).
5. keep **backsight length = foresight length**
6. **it is not necessary to move in a straight line**
7. It is quicker to read an extra change point than to spend much time trying to get the maximum elevation difference, or with much difficulty, find an instrument position where you can see your last change point and the next required point, or try to see through trees.

INSTRUMENT CONSIDERATIONS

1. **bubble** must be sensitive (tilting level only)
2. **telescope** must have clear optics
3. check **stability** of the instrument, including tripod (anything loose?)
4. **stable change point** and stable setting-up point
5. level fairly low and **legs of tripod spread to half the height of the tripod** for maximum stability
   - avoid areas causing vibrations eg. roads
6. check the **staff** - clear markings. To improve accuracy, improve staff and/or level.

If greater accuracy is required, use a more sophisticated level and a more accurately graduated staff.

APPLICATIONS OF LEVELLING

ELEVATIONS OF POINTS

- requires a levelling traverse
- discussed already (previous topic)

LONGITUDINAL SECTIONS

longitudinal (long) sections are often used for the design and construction of roads, pipelines, channels, dams, railways etc.

Assume that the line of the road has already been established by other means (eg. theodolite traverse)

Take levels :

(i) every 20 m (usually a peg every 20 m)
(ii) points where gradient changes
(iii) edges of natural features, eg. drain, pond, etc
(iv) if crossing another road, footpath, kerb, centreline etc.

Longitudinal (long) sections are usually plotted to a **distorted scale**.

eg. 1:500 horiz, 1:100 vertically.

See text Section 2.6 for an example.

Note the numbers are written along the vertical lines which represent "**chainages**" along the longitudinal section.

For accuracy:

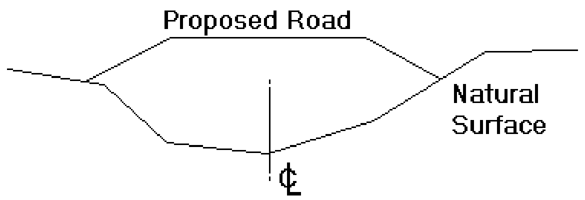
(i) level between Bench Marks or **close** the survey.

(ii) Try to **pick up other points** of known elevation along the way (can then detect an error before the job is complete).

(iii) see earlier tips on **levelling technique**

CROSS-SECTIONS

* often associated with **long sections**
* at **right angles** to long sections
* for **roads**, channels, dams, etc.
* width of x-section must match **width of works**.
* use an **optical square** to define the right angle.



X-Section @ 2120 m

* either take a level **every X metres** (eg. 5 m), or at changes of grade, or both (you must know the distance from the centreline peg to level point (eg. use a tape)).

* for **steep terrain**, more than one set up may be necessary for each x-section.

* usually plot cross-sections to **natural scale** i.e. same scale horizontal and vertical. Scale should be the same as the vertical scale of the longitudinal section.

* it may be possible to take levels on more than one x-section from a **single set up point**.

CONTOURING

* a contour joins points of **equal elevation**

* the **contour interval** is the vertical distance between contours (eg. 0.5 m).

* contours close together imply a **steep gradient**

* two contour lines of different value **never intersect**.

Uses

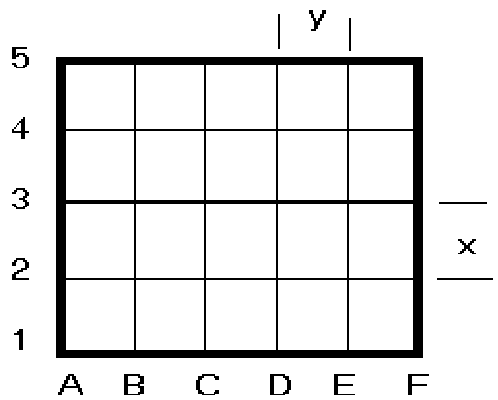
assessments of many civil engineering projects, eg.

(i) housing estates
(ii) dams, roads, reservoirs, pipelines
(iii) buildings, ...

* clearly requires levels over a large area. Contours are interpolated from the levels.

Here are some methods for collecting those levels.

Grids

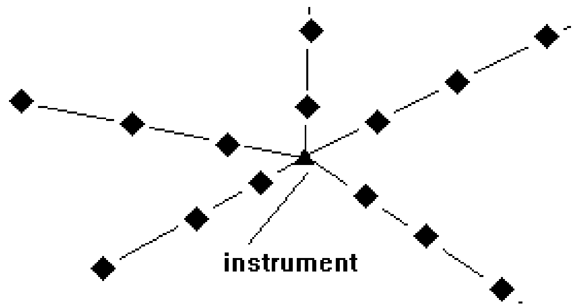


levelling
fig 11

* good for **small, fairly flat sites**
* establish grid of suitable size with **tapes**, and take level at each intersection..

Radiating lines

* from a central point



levelling
fig 12

* **directions** of lines must be known (compass may be accurate enough, but many levels have a horizontal circle for reading angles).

Direct contours

* the contour is **located on ground** and marked with pegs

* assistant moves until **appropriate reading** appears on staff.
  (Collimation Method of booking works well here)

* used for **contour ditches**, banks, etc.

* not suitable for plan production, as you must survey the position of the contour after setting it out on the ground - a lot of extra work.

> ***Activity 2.1***
>
> *Read Muskett 6.6*

SUMMARY

- The level must be adjusted to your eyes before you use it.
- Automatic levels, where the line of sight is set by prisms suspended in the telescope housing are the most commonly used type.
- Level traverses are closed to provide a check on your work. Important points are levelled as change points.
- The *rise and fall* method of reduction gives a check on your work of converting staff readings to *reduced levels.*
- Good work requires adapting to site and environmental conditions.
- Levelling can be used to obtain the elevations of points, longitudinal and cross sections for say roads, or levelling and area such as a sports field.
- Contours can be interpolated from the levels

KEY CONCEPTS AND DEFINITIONS

The optical level produces a level line of sight defined by the centre of the objective lens and the central cross hairs. This is known as the line of collimation.

Staff readings are measured downwards from the line of sight, and are intrinsically negative quantities.

The two peg test allows you to check the accuracy of an instrument, by using the instrument itself.

REVIEW QUESTIONS

Chapter 2, pp. 29-31, exercises 2.1 and 2.2, (a) and (b) [NOT (c)]

ANSWERS TO REVIEW QUESTIONS

If any student records levels in the manner shown in exercise 2.1 in my pracs, he/she will be shot immediately – no waiting for dawn!!.

Answers will be available on the subject page at an appropriate stage.