Basic Levelling

A. Filomeno

2000
Introduction to Levelling & Principles of levelling

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- The Levelling Staff

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LEVELLING – Introduction

Definitions

Level Surface: A level surface is a surface, all points of which are normal to the pull of gravity. i.e. a line at right angles to the string line on a freely suspended plumb bob. The open sea provides a good example of a level surface.

Horizontal Surface: A horizontal surface is one which passes through a point at right angles to the pull of gravity at that point.

Datum surface: The reference plane used in surveying is called a DATUM. In this country the main datum surface is the mean sea level at Newllyn in Cornwall and heights above this plane are referred to as being ABOVE ORDNANCE DATUM (AOD).

Height: The height of a point can be regarded as the distance measured vertically to that point from a level reference plane or surface.

Reduced level: The reduced level of a point is its height above a reference plane.

In basic surveying the reduced level of a point is calculated with reference to a horizontal line. For large distances the curvature of the earth would introduce errors, but for the distances involved in normal use of optical instruments the horizontal line and the level line can be considered as one and the same.
**Principles of Levelling**

All vertical height measurements from the ground or other points under consideration are referred to a plane of reference known as the HORIZONTAL PLANE of COLLIMATION. This is the line of sight through the telescope of an optical level. The difference between such measurement would indicate differences in height or level.

It can be seen in the above figure that point B is lower than point A and the difference in the measurement of 0.300m tells us the difference in level.

Mathematically we have subtracted the height at point A from the height at point B.

\[ 1.800 - 1.500 = 0.300 \]

From a Surveying point of view we have taken the level at point A, say 20.000m and added the vertical distance to the horizontal plane to give a level (or height) for the horizontal plane. We can obtain the level at point B by subtracting the vertical distance from the value of the level for the horizontal plane. The difference in levels between A and B is then apparent.
Viz.: -
Level at A = 20.000m (say)
Level of horizontal datum = 20.000 + 1.500 = 21.500m
Level at B = 21.500 - 1.800 = 19.700m
Hence
Difference in level between A and B = 20.000 – 19.700 = 0.300m

Although this sounds convoluted and lengthy, when dealing with many points reference to a horizontal reference plane avoids many mistakes and simplifies calculations.

In order to determine the level of the horizontal plane of collimation (HPC) a vertical measurement from a known (or assumed) level needs to be carried out. This is the first step in determining all other levels.

**Exercise:**

Given that a datum level exists at point Z, whose value is 20.500m;

a) Determine the levels of points A to F and state the difference in height between point G and H.

b) Calculate the gradient of the ramp between G and H.

*Hint: Assume a reference plane along plane XY*
**Equipment**

The horizontal plane referred to earlier as the HORIZONTAL PLANE of COLLIMATION (or HPC) is the line of sight through an instrument called a SURVEYORS LEVEL. These instruments consist basically of a telescope with a means of adjustment to ensure the line of sight through the telescope is truly horizontal.

The most basic type is the DUMMY LEVEL, which consists of telescope attached to a vertical spindle, which allows the telescope to rotate horizontally. To ensure the instrument can be set up horizontally a spirit level is attached to the body of the telescope and the whole assembly rests on three adjustable screws.

It is worth getting to know the technical terms associated with this instrument, as they are common with other types.
The longitudinal axis of the spirit level is factory set parallel to the line of sight. The attitude of the spirit level is adjusted by rotating the levelling screws. When the bubble of the spirit level is in the centre of its run then the line of sight through the instrument is horizontal.

Surveyors levels are used to measure the vertical distances from points to the horizontal line of sight. The line of sight is the optical centre of the instrument and is defined by lines etched on a glass graticule inside the eyepiece of the instrument. These lines are called CROSSHAIRS. There are various variations and markings but for levelling purposes only the central horizontal crosshair is used.
The vertical measurements are accomplished by using the surveys level in conjunction with a graduated LEVELLING STAFF. (see figure) This can best be described as a simplified tape measure. The markings on the staff are at 1cm interval and are colour coded and blocked out in the shape of an ‘E’ to facilitate taking readings through the telescope.

When the cross hair falls between whole centimetre markings the millimetres or third decimal place must be estimated.
The Dumpy level is little used and practically obsolete, but does form the basis of more modern instruments.

The **TILTING LEVEL** is the commonest form of level available and consists of all the components discussed above but the telescope has some movement in the vertical plane along with a secondary spirit level and adjusting screw to allow more precise setting to the horizontal. The initial adjustments are as for the Dumpy level but a circular spirit level is utilised. Prior to taking any staff reading the TILTING SCREW is adjusted until the bubble in the long spirit level is in the centre of its run.

Gaining popularity, especially amongst students is the **AUTOMATIC LEVEL**. Again the basic components reflect those of the Dumpy. The internal arrangement is vastly different though. A series of suspended glass prisms within the body of the telescope ensure that the line of sight through the telescope remains horizontal; as long as the instrument is reasonably level as indicated by the round spirit level bubble!

Instrument levelled, Horizontal ray refracted symmetrically through prisms and directed to centre of eye piece.

Instrument slightly off level, horizontal ray refracted asymmetrically to direct ray to centre of eye piece. Note: The prisms remain suspended vertically.
Although a popular and useful instrument and found on many sites it can have problems when subjected to excessive vibrations.

**Levelling Practice - flying levelling**

Flying levelling is used when the reduced level of a point is to be found from another point of known reduced level.

If we study the simplest scenario where the known reduced level and the point whose reduced level is required are intervisible from the position of the levelling instrument we can analyse the arithmetic involved in calculations.

Once the instrument is in adjustment (discussed later) and the telescope is aimed at the staff on the known point (A), the view through the eyepiece will show a reading which indicates the height of the line of sight above the known point (A). If this known point had a reduced level of (say) 21.000m and the staff reading, as seen through the eye-piece, was (say) 2.195m, then the reduced level of the line of sight will be: -

\[
21.000m + 2.195m = 23.195m
\]

This first staff reading onto a known level is termed the **BACKSIGHT (BS)** reading.

The line of sight is termed the **HORIZONTAL PLANE OF COLLIMATION (HPC)**.

Hence \[\text{HPC} = \text{Known reduced level} + \text{BS}\]
The plane of reference has now been established (HPC) and the next reading of the staff can be referred to this.

The staff is next placed at the point whose reduced level is desired (B) and the telescope of the level is rotated to target the new staff position, care being taken not to alter the adjustment of the instrument (i.e. don’t knock it).

The new staff reading is taken, 3.195m (say). This indicates that point B is 3.195m below the level of the line of sight or HPC, which was calculated to be 23.195m. The reduced level of point B is therefore:

\[
23.195m - 3.195m = 20.000
\]

This staff reading onto the point whose desired level is required is termed the **FORESIGHT** reading (FS).

Hence \( Reduced \ Level = HPC - FS \)
The staff readings and calculations are booked in a standard field book as follows:

<table>
<thead>
<tr>
<th>BACK SIGHT</th>
<th>INTER-MEDIATE</th>
<th>FORE SIGHT</th>
<th>H.P.C.</th>
<th>REDUCED LEVEL</th>
<th>DISTANCE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.195</td>
<td></td>
<td>23.195</td>
<td>21.000</td>
<td></td>
<td></td>
<td>known reduced level at A</td>
</tr>
<tr>
<td></td>
<td>3.195</td>
<td>20.000</td>
<td></td>
<td></td>
<td></td>
<td>calculated reduced level at B</td>
</tr>
</tbody>
</table>

If is required to the reduced level of a point a considerable distance from a known point, or where obstructions occur, then it is necessary to use CHANGE POINTS.

A CHANGE POINT (cp) is a position whose level is found in order for that position to become the next known reduced level when the instrument is moved to a new position. Consequently flying levelling over considerable distances becomes a series of readings between known points (or calculated) and an unknown point. In other words a series of alternate BACKSIGHT and FORESIGHT readings. It should be stressed that in levelling the position of the staff is important. The levelling instrument is merely placed where convenient.
The following example illustrates the method of calculation and booking known as the **HEIGHT OF COLLIMATION** method.

### Calculation and Booking

<table>
<thead>
<tr>
<th>BS</th>
<th>INTER</th>
<th>FORE</th>
<th>H.P.C.</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.300</td>
<td>21.800</td>
<td>20.500</td>
<td>Reduced level at A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Point B now becomes a Change Point

<table>
<thead>
<tr>
<th>BS</th>
<th>INTER</th>
<th>FORE</th>
<th>H.P.C.</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.800</td>
<td>20.000</td>
<td></td>
<td>22.500</td>
<td>Reduced level at A</td>
<td></td>
</tr>
</tbody>
</table>

Note: Staff reading booked in row relating to point B

<table>
<thead>
<tr>
<th>BS</th>
<th>INTER</th>
<th>FORE</th>
<th>H.P.C.</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.500</td>
<td>22.500</td>
<td>20.000</td>
<td>B (cp)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Staff has not moved

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<table>
<thead>
<tr>
<th>BACK SIGHT</th>
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<th>H.P.C</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.300</td>
<td>21.800</td>
<td>20.500</td>
<td></td>
<td></td>
<td>Reduced level at A</td>
</tr>
<tr>
<td>2.500</td>
<td>1.800</td>
<td>22.500</td>
<td>20.000</td>
<td>B (cp)</td>
<td></td>
</tr>
<tr>
<td>0.800</td>
<td>21.700</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Instrument aimed to new staff position

### Note
Staff reading booked in row relating to point C

### Reduced level at B

<table>
<thead>
<tr>
<th>BACK SIGHT</th>
<th>INTER MEDIATE</th>
<th>FRONT SIGHT</th>
<th>H.P.C</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.300</td>
<td>21.800</td>
<td>20.500</td>
<td></td>
<td></td>
<td>Reduced level at A</td>
</tr>
<tr>
<td>2.500</td>
<td>1.800</td>
<td>22.500</td>
<td>20.000</td>
<td>B (cp)</td>
<td></td>
</tr>
<tr>
<td>0.500</td>
<td>0.800</td>
<td>22.200</td>
<td>21.700</td>
<td>C (cp)</td>
<td></td>
</tr>
</tbody>
</table>

BS =0.500

### Always end levelling on a FS

<table>
<thead>
<tr>
<th>BACK SIGHT</th>
<th>INTER MEDIATE</th>
<th>FRONT SIGHT</th>
<th>H.P.C</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.300</td>
<td>21.800</td>
<td>20.500</td>
<td></td>
<td></td>
<td>Reduced level at A</td>
</tr>
<tr>
<td>2.500</td>
<td>1.800</td>
<td>22.500</td>
<td>20.000</td>
<td>B (cp)</td>
<td></td>
</tr>
<tr>
<td>0.500</td>
<td>0.800</td>
<td>22.200</td>
<td>21.700</td>
<td>C (cp)</td>
<td></td>
</tr>
<tr>
<td>1.200</td>
<td>21.000</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FS =1.200
From the above examples a number of observations can be made.

1. All levelling operations start with a **backsight** and end with a foresight.
2. There are the same numbers of **backsights** as **foresights**.
3. The arithmetic involved can be written as two simple formulae:
   
   a) \[ HPC = RL + BS \]
   b) \[ RL = HPC - FS \]

Where

- \( HPC \) = Horizontal Plane of Collimation (sometimes referred to as height of collimation or height of instrument.)
- \( RL \) = Reduced Level
- \( BS \) = Backsight staff reading
- \( FS \) = Foresight staff reading

**INTERMEDIATE STAFF READINGS**

Intermediate staff readings are those staff readings taken after a **backsight** is read and before a foresight. The **backsight** is used to determine the collimation level of the instrument and once this is found as many intermediate sights as required can be taken and recorded. Each reading in turn is subtracted from the collimation level to deduce the reduced level of the point. The following example shows a series of intermediate readings taken from one instrument position. Note that readings are finished with a fore-sight. This will be either a change point or the ‘circuit’ is closed there. Also note that each intermediate sight is recorded on its own line.
The problem with intermediate sights is that the arithmetic check will only relate to the back sight and the fore-sight. Hence any arithmetic error could go unnoticed. Where large numbers of intermediate sights are used the ‘Rise and Fall’ method should be used.

Errors due to misreading of the staff will also go unnoticed and can only be found by visual inspection (but only for very large errors). Extreme care must therefore be taken when reading intermediate sights.

Systematic errors due to mal-adjustment of the instrument cannot be eliminated as in flying levelling where the equal fore-sight distance and back sight distance compensated for the mal-adjustment errors. Intermediate sights can be varying distances away from the instrument and will therefore contain systematic errors proportional to that distance. Instrumental errors of this nature can be eliminated by the use of a REVERSIBLE LEVEL.
LEVELLING SOFFITS - Inverted staff readings

An inverted staff reading can be used to determine the reduced level of a point above the line of sight of the instrument such as a ceiling, underside of a bridge, balcony etc. As the name suggests, the staff is simply turned upside-down, the bottom placed against the point that the level is required, and then read. An important difference between inverted staff readings and other types is that they are treated as negative quantities, both in the booking of the readings and the reduction of the levels.

The following example will demonstrate the booking and reduction of inverted staff readings. Note the way that inverted staff readings are emphasised in the booking, surround them by a square bracket and use a negative sign. Write “inverted staff” in the remarks column. Do not forget when doing summation of back and fore-sights in the arithmetic check that negative quantities are involved.

<table>
<thead>
<tr>
<th>BACK SIGHT</th>
<th>INTERMEDIATE</th>
<th>FORE SIGHT</th>
<th>H.P.C.</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.174</td>
<td></td>
<td>33.724</td>
<td>33.550</td>
<td>OBM (=33.550) point A</td>
<td></td>
</tr>
<tr>
<td>0.738</td>
<td>2.111</td>
<td>32.351</td>
<td>31.613</td>
<td>Point B - c.p.</td>
<td></td>
</tr>
<tr>
<td>1.505</td>
<td>1.440</td>
<td>34.703</td>
<td>33.198</td>
<td>Point D - c.p.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-[2.192]</td>
<td></td>
<td><strong>36.895</strong></td>
<td>Point E - Balcony – Inverted staff</td>
<td></td>
</tr>
<tr>
<td><strong>ΣBS</strong></td>
<td><strong>ΣFS</strong></td>
<td></td>
<td></td>
<td></td>
<td>Last - First</td>
</tr>
<tr>
<td>0.814</td>
<td>BS - FS</td>
<td>-2.531</td>
<td>3.345</td>
<td>Check sums: arithmetic OK</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
RISE AND FALL METHOD

It has been seen that in the HPC method the intermediate sightings cannot be checked. The rise and fall method will check all the arithmetic because each staff reading is used to determine the reduced levels. Consider the previous example, the determination of reduced levels for points B to E are independent calculations and do not come within the arithmetic check.

With the rise and fall system each consecutive pair of staff readings are compared in turn to find their difference in height and whether the second of the two readings is higher or lower than the first.

Referring to the diagram below, comparing the first two readings A and B it can be seen that B is higher than A indicating a RISE of 0.307m, the difference between the staff readings. Between the next two readings, B and C, C is lower than B by 0.453m (the difference between staff readings). This is therefore a FALL. Finally there is a FALL from C to D of 0.291m. The rises and falls can be checked arithmetically as shown later, and it is easier to check for arithmetic error at this stage than to leave it until the reduced levels are calculated.

The reduced level of A is known, 38.329m and so is the Rise to B of 0.307m. The reduced level of B must therefore be 38.329 + 0.307m i.e. 38.636m. Similarly knowing the reduced level of B and that there is a fall to C of 0.453m, the reduced level of C must be 38.636-0.453 i.e. 38.183m. Finally, the reduced level of D is found by subtracting the Fall of 0.291 from the reduced level of C i.e. 37.892m.

The arithmetic check can now be completed, which is given by:

\[ \Sigma \text{Backsights} - \Sigma \text{Foresights} = \Sigma \text{Rises} - \Sigma \text{Falls} = \text{Last reduced level} - \text{First reduced level} \]
The main advantage of the Rise and Fall system over the HPC method for reducing levels is the ability to check the arithmetic of intermediate sights. Where you are faced with large quantities of intermediate sights this is the preferred method.
**Levelling Practice – Checks**

All levelling operations must be checked on completion of the circuit. The checks in levelling are of three types:

a) Arithmetic checks  
b) Check on accuracy  
c) Two peg test  

**a) Arithmetic checks**

The check on correct arithmetic usage in levelling is simple:

\[ \sum \text{Backsights} - \sum \text{f oresights} = \text{Last reduced level} - \text{First reduced level} \]

In other words add up the backsight column, add up the foresight column and find the difference between these two sums. Compare this with the difference between the first and last reduced level. If these values are not the same an arithmetic error has occurred. This must be found and corrected. The example below shows how to record the arithmetic check in the field book.

<table>
<thead>
<tr>
<th>BACKSIGHT</th>
<th>INTER- MEDIANE</th>
<th>FORE-SIGHT</th>
<th>R.P.C.</th>
<th>REDUCED LEVEL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.300</td>
<td></td>
<td>21.800</td>
<td>20.500</td>
<td>Reduced level at A</td>
<td></td>
</tr>
<tr>
<td>2.500</td>
<td>1.800</td>
<td>22.500</td>
<td>20.000</td>
<td>B (cp)</td>
<td></td>
</tr>
<tr>
<td>0.500</td>
<td>0.800</td>
<td>22.200</td>
<td>21.700</td>
<td>C (cp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.200</td>
<td></td>
<td>21.000</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>4.300</td>
<td>3.800</td>
<td></td>
<td>21.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 3.800</td>
<td>20.500</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0.500</td>
<td></td>
<td>0.500</td>
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</tbody>
</table>

These two values must agree
b) **Check on accuracy**

The best check for accuracy is to conduct a levelling survey between known points. This way the calculated reduced level of the final point can be compared with the known value. An equally acceptable method is to conduct a closed survey, where the final staff reading is taken at the same point as the first staff reading. Obviously this means extra work, but is worth the effort as a true assessment to the accuracy of the levelling can then be made.

The difference in value for the levels taken on the first reading and on the final reading at the same point in a closed levelling survey is referred to as the CLOSING ERROR.

There are several ways of determining the acceptable closing error and this often depends on the accuracy specified for a particular levelling operation.

One method depends on the number of instrument set-ups:

Maximum permissible error = \(0.0015\text{m} \times \sqrt{\text{number of instrument set ups}}\)

In the example given above, the permissible closing error would be:

\[0.0015 \times \sqrt{3} = 0.003\text{m}\]

Of course the magnitude of the closing error cannot be calculated unless the final level is known beforehand.

The closing error and the arithmetic check must not be confused. The arithmetic check must show the two check figures agreeing. This has no relationship to the magnitude of the closing error.

c) **Two Peg Test**

This test should be done on a regular basis to assess whether the plane of collimation is in fact horizontal when the instrument is levelled. The test will be described later.
**Exercise:**

The following sketch shows a typical flying level exercise. Record the reading on the field sheet below, reduce the levels, complete the checks and assess whether the levelling has been done accurately.

BOOKING SHEET on next page (photocopy before use)
<table>
<thead>
<tr>
<th>BACK SIGHT</th>
<th>INTERMEDIATE</th>
<th>FORE SIGHT</th>
<th>H.P.C.</th>
<th>REDUCED LEVEL</th>
<th>DISTANCE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
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</table>
**PRACTICAL EXERCISE**

The following practical exercise is to be done around prepared circuits within the campus.
- Using an Auto level, you are to start at the point assigned to you, with a reduced level of 20.000m (The Bench Mark)
- Level around the circuit in an anti-clockwise direction using each of the other points as change points and close your levelling on the point you started from.
- Reduce your levels as you proceed. Complete the checks in the classroom.
- Work in pairs. Each person is to read the staff at each set up. This will enable you to compare your results with your partner and hence discover any large errors.
- Each person to complete his own booking sheet.
- Calculate the maximum permissible error on closing and compare to your results
- Should you need to break the circuit at any time, take a foresight on to your next change point and pack the equipment up. When you set up again, simply take a backsight onto the change point and continue the circuit.
- A good sketch of the circuit will assist interpretation of the booking.
- Make full use of the comments column. This is where you will refer to if you make mistakes or need help during this practise session. Full comments will also assist in booking readings in the correct row!
- **DO NOT LEAVE ANY EQUIPMENT UNATTENDED AT ANY TIME.** Breakage or damage caused by careless use or due to ‘horseplay’ will be charged to you.
- **BE AWARE OF MOVING VEHICLES ON THE CAMPUS, ESPECIALLY AROUND BLIND CORNERS.**
Basic levelling

- **DO NOT SET THE INSTRUMENT UP IN THE MIDDLE OF ROADS.**

- **BE AWARE OF OVERHEAD POWER LINES.** The staffs are made of aluminium and as such conduct electricity very well!!!

- Ensure that the minimum length of staff is extended. Retract extensions when not in use.

- When extending staffs ensure they ‘click’ into the locked position and check the numbering on the front to ensure they are extended properly.

---

**KEEPING OF FIELD AND LEVEL BOOKS**

The keeping of accurate records is vitally important to the successful and profitable conclusion of any construction project. These records may assist in the calculation of quantities or in the resolution of disputes or claims for example. They must be clear, logical, legible, and in a standard layout if they are to be of any use. The following notes should assist you in keeping your books in the correct manner. Standard booking procedures will be shown to you and you must strictly adhere to the system.

1. Field and Level books are used to record what you do and to plan what you are going to do.

2. **IT IS ESSENTIAL TO CULTIVATE METHOD, NEATNESS AND GOOD HABITS, IN THIS ASPECT OF SITE ENGINEERING FROM THE OUTSET.**

3. The ideal to be aimed at is that any fellow engineer should be able to consult your field and level books at anytime and see:

   a) Who did some operation or measurement  
   b) Where it was done  
   c) When it was done
d) What was done
e) How it was done

and from this information be able to carry the work onto a further stage without the necessity for remeasurement or check of accuracy.

4. To assist in the proper keeping of these books always leave 2 pages at the front for the compilation of an index of its contents. Inside the cover put Name and Status, Date taken into use, Serial No. (e.g. Fd bk No. 1), Name of contract. Number the pages as you go and keep the index up to date.

5. Make liberal use of diagrams, both to make your own mind clear on what you are doing and to assist others to understand what you have done.

6. Do not be afraid of appearing over methodical or pedantic. An unmethodical engineer is a menace.

7. Remember that two minutes after anonymous figures have been recorded no one except you will know what they mean. Two weeks later you may not know either.
**SOURCES OF ERRORS IN LEVELLING**

Errors in levelling may be classified into three main areas.
- Instrumental errors
- Manipulation errors
- Reading and Booking errors

- **INSTRUMENTAL ERRORS**

When a level is in adjustment its line of sight is horizontal after the instrument has been levelled. Errors proportional to the length of sight will result if the instrument is out of adjustment. This instrumental error can be eliminated by a process known as:

**EQUAL BACK AND FORE SIGHT DISTANCES**

If the instrument is out of adjustment the line of sight will not be horizontal when the telescope bubble is centred. It will either point up or down. Consider the following sketch where the line of sight is pointing down and the distances from instrument to back and fore sights are equal.

The resultant triangle formed by the line of sight, horizontal plane and vertical plane of the level staff are congruent.

If the instrument had been in adjustment the horizontal line of sight might give a backsight reading of say 1.732 and a foresight reading of 0.336. This means that B is higher than A by 1.396 m. Suppose, now that the instrument is out of adjustment and the vertical side of the triangle was 0.015 m. This means that the staff reading on A would be 1.717 and on B will be 0.321. Note that the difference between these two readings is
1.396m, as before, indicating that instrument error can be eliminated with equal back and foresight distances. Intermediate sights are of varying distances from the instrument and errors due to maladjustment of the Level will not be eliminated.

**TWO PEG TEST**

The two-peg test is done to determine whether the instrument is in adjustment. It should be done each week on site and also when a new or borrowed instrument has been obtained.

The test is as follows:

- **a)** Mark out three points on the ground A, C and B so that they are all in a straight line and A to C = C to B = 30 m.

- **b)** Set the Level over C as accurately as possible and read the staff held at A and B. The difference between the readings will be the true difference in level, even if the instrument is out of adjustment.

- **c)** Move the Level to the higher end (B) and set it up on line with A and B, and 2 m beyond B.

- **d)** Read the staff again at A and B

![Diagram of Two Peg Test](image)
e) If the Level is in adjustment the reading on B should equal the reading on A plus the difference in height between A and B (as found in the first set of readings).

f) Any variation from the staff reading required at A will indicate the degree of maladjustment of the Level.

g) The result of the two peg test are recorded in the field book as follows:

<table>
<thead>
<tr>
<th>BACK SIGHT</th>
<th>INTERMEDIATE</th>
<th>FORE SIGHT</th>
<th>H.P.C.</th>
<th>REDUCED LEVEL</th>
<th>DISTANCE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.134</td>
<td>Difference</td>
<td>A</td>
<td>Instrument at C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.736</td>
<td>0.398</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 1.6223     | Difference    | B          | Instrument at D |
| 2.016      | 0.393         | A          |

\[0.398 - 0.395 = 0.005m\]  
\[Error of 5mm over 60m\]

h) Adjustment of Levels for modern instruments should be carried out by specialist servicing companies.

Other instrumental errors include the following:

a) Tripod – The tripod must provide a stable base from which to use the level. Check the metal feet are secure, the clamps will tighten sufficiently and the wing nuts are tight. Do not lean on or trample around the tripod once the instrument has been adjusted.
b) Levelling staff – Graduation errors due to repainting or wear of staff at the joints. Sections may not be properly clipped together when the staff is extended.

- **MANIPULATION ERRORS**

These are due to the misuse of equipment and include the following

a) Bubble not central at the instant of reading the staff. This could be due to not adjusting the tilting screw before a reading when using a Tilting Level.

b) Parallax not properly eliminated. (Refer to end of chapter)

c) Levelling in a high wind - shield the instrument and staff if possible.

d) Staff not upright - may be overcome by swaying the staff or use of a circular bubble attachment.

e) Mud on the foot of the staff.

f) Refraction on hot days - avoid reading the bottom of the staff.

g) Care must be taken to plant tripod legs firmly to avoid settlement never rest hands on any part of the tripod once the instrument has been levelled.

h) Change in height of staff between back and foresights due to the staff settling in soft ground or other unsuitable change point - make use of a staff or change plate.

- **READING AND BOOKING ERRORS**

a) Sights must be of such a length that the staff may be easily read. A suggested maximum distance is 60m.
b) Care must be taken to avoid reading a stadia hair instead of a main crosshair.

c) Similar digits can be interchanged i.e. 2.422 booked instead of 2.244.

d) Misreading staff by a whole metre.

e) Arithmetic errors – do the check.
DATUMS AND BENCHMARKS

Ordnance Datum

The ordnance datum in this country is the mean sea level at Newlyn in Cornwall. The tide gauge is situated in the Ordnance Survey Tidal Observatory on the south pier at Newlyn and readings are related to the Observatory Bench Mark, which is 4.751 metres above the datum.

Ordnance Bench Marks (OBM)

A Bench Mark is a mark whose height relative to Ordnance Datum has been determined by levelling. The types of bench marks used by the Ordnance Survey are: -

A) Fundamental Bench Mark

These marks are constructed at specially selected sites where the likelihood of damage or movement is minimal (e.g. stable bedrock). They provide a system of stable marks throughout the country. They are sited at intervals of about 40Km along lines of geodetic levelling. Each mark consists of a buried chamber containing two reference points. The published altitude is to the top of a granite or concrete pillar about 300mm square, set beside the chamber. The pillar bolt is the reference to be used. The buried chamber is only to be opened on instructions from the Ordnance Survey Headquarters.

B) Flush Bracket Bench mark

These consist of metal plates about 90mm wide and 175mm long cemented into the face of buildings. They are fixed where possible at intervals of about 1.5Km along lines of geodetic levelling and also at important junctions points along the secondary lines. A flush bracket is also set into the sides of most triangulation pillars. The recorded altitude is the small horizontal platform at the point of the broad arrow marked on the plate face. Each bracket carries a unique serial number.
Basic levelling

**PLAN**

**SECTION**

**FUNDAMENTAL BENCH MARK**
C) Cut Bench Mark (Vertical Surfaces)

These are the most common forms of bench marks, consisting of a horizontal bar cut into vertical brickwork. A broad arrow is cut immediately beneath the centre of the horizontal bar. The height value refers to the centre of the horizontal bar.
D) **Cut Bench Mark (Horizontal Surfaces)**

These are also called rivet bench marks and are found on horizontal surfaces such as parapets, culverts, ledges, steps etc. In place of the horizontal bar the reference point is usually a brass rounded rivet which is inserted at the point of the arrow.

Some of these marks may have instead of the rivet a small hollow cut out for a pivot to be inserted at the reference point. Where use is made of these marks a 16mm ball bearing is placed in the pivot hole as the staff support.

![Diagram of Cut Bench Mark](image)

E) **Bolt Bench Mark**

These are established where no suitable surface exists. They consist of a 60mm diameter mushroom headed brass bolt engraved with an arrow and the letters OSBM.

![Diagram of Bolt Bench Mark](image)
Bench mark lists are compiled for sale, by the Ordnance Survey Agency, to those who require the latest values or who need more complete information. Bench mark lists are issued in units corresponding to the one kilometre squares of the National Grid. These list show for each mark:

a) A brief description of the mark and its location
b) The full 10m National Grid reference
c) The altitude in metres and feet to two decimal places referred to the Ordnance Datum.
d) The height of the mark above ground level in metres and feet to one decimal place.
e) The year in which it was included in levelling observation.

Where a bench mark has been established on a feature which has not been surveyed, the National Grid is approximate only, such references are marked with an asterisk.

<table>
<thead>
<tr>
<th>DESCRIPTION OF BENCH MARK</th>
<th>NATIONAL GRID TEN METRE REFERENCE</th>
<th>ALTITUDE FEET</th>
<th>ALTITUDE METRES</th>
<th>HEIGHT OF BM ABOVE GROUND FEET</th>
<th>DATE OF LEVELLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>N BM NE ANG HO No1102N PORTERS WAY</td>
<td>0705 7947</td>
<td>98.29</td>
<td>29.96</td>
<td>1.6</td>
<td>0.5</td>
</tr>
<tr>
<td>N BM S ANG HO No1 LAVENDER RISE</td>
<td>0723 7955</td>
<td>96.48</td>
<td>29.41</td>
<td>1.4</td>
<td>0.4</td>
</tr>
<tr>
<td>(3.) NBM S ANG HO No43 LAVENDER RISE</td>
<td>0744 7965</td>
<td>104.28</td>
<td>31.78</td>
<td>1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>(4.) SE FACE BR NW SIDE STOCKLY RD</td>
<td>0757 7952</td>
<td>112.50</td>
<td>34.29</td>
<td>1.7</td>
<td>0.5</td>
</tr>
<tr>
<td>(2.) RIVET TOP BLY BR PARA NW SIDE STOCKLY RD S SIDE CANAL</td>
<td>07962 7991</td>
<td>115.35</td>
<td>35.16</td>
<td>11.1</td>
<td>0.3</td>
</tr>
<tr>
<td>N BM W FACE OF P E SIDE STOCKLY RD</td>
<td>0764 7930</td>
<td>111.79</td>
<td>34.07</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>N BM E ANG BLDG</td>
<td>0779 7944</td>
<td>105.64</td>
<td>32.20</td>
<td>1.7</td>
<td>0.5</td>
</tr>
<tr>
<td>N BM RIVET SUR CONCRETE WALL N SIDE CANAL OPP ASPHALT WKS</td>
<td>0788 7988</td>
<td>97.76</td>
<td>29.80</td>
<td></td>
<td></td>
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<tr>
<td>N BM S ANG BLDG</td>
<td>0799 7940</td>
<td>104.16</td>
<td>31.75</td>
<td>1.5</td>
<td>0.5</td>
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LARGE SCALE ORDNANCE SURVEY PLANS

Ordnance survey bench mark information can be found on 1:1250 or 1:2500 scale plans. An extract is shown below. The conventional sign for a bench mark is an arrow, showing the position, and a number – the reduced level.
SITE BENCH MARKS

One of the first tasks a site engineer must do on a new site is to establish height control. It is usual to establish a site MASTER BENCH MARK (MBM) from nearby Ordnance Bench Marks and the following lists the usual procedure.

a) The Master Bench Mark must be constructed in a part of the site clear of any construction activity. It must be of very stable construction. A typical MBM comprises of a steel peg firmly driven into the ground and surrounded by concrete. It should be protected by surrounding it with a fence and the reduced level of the bench mark should be written on that fence as well as being recorded in the field book.

b) The reduced level of the MBM is found by flying levelling from a nearby Ordnance Bench Mark (OBM) using the MBM as a CHANGE POINT and then closing the circuit onto a second bench mark. This not only provides the closing error but also checks the OBM for any possible movement.

c) The levelling operation must be carried out a minimum of three times, ensuring that a good closing error is obtained each time. The range of results must not exceed 5mm, if it does then further levelling must be carried out until such a range is achieved. The mean value can be adopted as the MBM level.

d) Having established the MBM, any number of temporary bench marks (TBM) can be located and levelled where and as required working of course, to the same order of accuracy as above. The ideal situation regarding TBM’s is to locate them in such positions that a Level can be set up anywhere on the site and be within sighting distance from it, thus avoiding the need to fly level to the area of operation.
**TEMPORARY ADJUSTMENTS (or setting up the instrument)**

All instruments which refer readings to a horizontal or vertical plane need to be set up so that the instrument is truly horizontal or truly vertical. The explanation that follows is also applicable to other surveying instruments such as theodolites.

The first step in temporary adjustment is to set up the tripod upon which the instrument is attached. The tripod head should be set up at approximate upper chest height with the three legs equal in length and well spread out so as to form a stable pyramid. Effort should be made to ensure the tripod head is reasonably level, this will make proceeding adjustments quicker by avoiding the problem of running out of adjustment in the instrument.

Once the tripod is set up and firmly clamped with the spikes of its legs well pressed into soft ground the instrument may be attached. This is usually via a central threaded bolt through the tripod head. All bolts and clamps etc on the instrument itself need only be finger tight. **THERE IS NO NEED TO OVERTIGHTEN ANY THREAD ON THE INSTRUMENT** – In fact damage could easily be done to delicate mechanisms by over tightening.

Most modern instruments indicate their attitude by means of a pond (or circular) spirit level. Some have also a fish plate (long) spirit level for more precise control. The spirit levels are factory adjusted to the instruments to which they are connected, but usually there are means of adjusting this connection if necessary. (This is known as permanent adjustments)

Spirit levels are curved glass tubes filled, bar a gas bubble, with a liquid. Because of gravity the gas bubble will always try to reach the highest point in the tube and it is this phenomena which is utilised in spirit levels.

The bubble is always at the highest point and is tangential to the horizontal

With the bubble centered between the central markings the tangent to the tube surface is truly horizontal
The attitude of the spirit level on instruments is adjusted by means of three thumbscrew situated at the corners of a triangle (The tribach). By rotating the thumbscrews the corners of the instrument base are raised or lowered. This affects the position of the bubble in the spirit level attached to the instrument.

**PROCEDURE** for centering bubble

*It is important to adhere to a strict method of centering the spirit level bubble, otherwise the student can spend more time trying to level the instrument than actually using it.*

1. Rotate the instrument so the spirit level is central to two thumbscrew.
2. Stand in front of these two thumbscrews.
3. Rotate the two thumbscrews simultaneously, one anticlockwise and the other clockwise. The effect of this is that your thumbs either both move away from your body or both move towards your body. **NOTE:** The direction of your left thumb will indicate the direction of the bubble movement along the primary axis. As the thumbscrews are rotated the bubble begins to move along the primary axis. Because of the domed shape of the spirit level the actual direction of travel of the bubble will be in an arc.
4. When the bubble lies along the secondary axis transfer your attention to the third thumbscrews and begin rotating this with your LEFT HAND. The direction of the
bubble movement will be indicated by the direction of movement of your LEFT THUMB.

5 Once the bubble lies along the primary axis, the instrument should be level. This is indicated by the bubble being in the centre of the pond spirit level. If the bubble is not in the centre transfer both your hands to the original two thumbscrews and again rotate these simultaneously, one clockwise the other anticlockwise. Remember the direction of bubble movement is indicated by the direction of movement of your left thumb.

6 Final adjustment to centre the bubble can now be made with the third thumbscrew.

The following diagrams illustrate the sequences explained above.
PARALLAX ELIMINATION

In all optical instruments which have stadia hairs as a reference point for measuring a phenomena known as parallax must be eliminated.

Parallax occurs when the image of the crosshairs is not focussed on the same vertical plane as the image of the staff. Therefore any slight movement of the viewers eye will appear to cause a movement between the stadia hair and the staff and hence lead to a different reading being seen. In order to avoid this error Parallax must be eliminated. This is done once the instrument has first been levelled. It is a process which depends on the focal length of the viewer eye and only needs to be done once.

PARALLAX NOT REMOVED
1. Crosshairs not as sharply focussed as could be.
2. Apparent movement between images as eye is moved side to side
To remove parallax the following sequence of events need to occur:

a. Turn the telescope’s main focussing ring to infinity; there is no need to focus on any object.

b. Turn the telescope towards a light object (NOT THE SUN!). Failing this a piece of white paper in front of the telescope will suffice.

c. Whilst looking through the telescope turn the eyepiece focus ring until the crosshair appear as sharp as possible to YOUR EYE. The position of this will depend on the strength of your eyes. Note left and right eye may have different strengths.

d. In order to satisfy yourself that this is the sharpest image continue to turn the focussing ring until the image of the crosshairs are blurred then bring them back into sharp focus.

e. The crosshairs are now set on a plane dependant on your eye’s focal length. When you adjust the telescopes main focus the image of the staff will be in sharpest focus on this plane. Hence the two images will be coincident and parallax will have been eliminated.

f. Movement of your eye from side to side or up and down should not cause the reading of the staff to change.

g. If you wear spectacles it is a good idea to keep them on and adjust your eye position in relation to the telescope so you do not keep bumping into the eyepiece with your spectacles.
LOCATING THE STAFF

Very often students have great difficulty in locating the staff when looking through the telescope. This is not unusual. The telescope has a very narrow field of view and unless the background is very distinctive you will not know which way to turn the telescope to find the staff.

To overcome this problem most telescopes have a targeting system along the top of the barrel (similar to a rifle target finder). The telescope should be aimed at the staff using this targeting system prior to trying to find the staff through the eyepiece.

Modern targeting systems utilise a small viewfinder on top or below the barrel of the telescope which appears as a white triangle. This white triangle should be aimed at the staff with the eye held about 100 –150mm from the viewfinder. As you move the telescope to get it into line follow the white triangle with your eye until the white triangle appears over the staff (keeping both eyes open will help). The staff should now be within the field of view of the telescope, although you may have to focus the telescope to actually see the staff.