Al Mustansiriyah University

Faculty Of Engineering

Civil Engineering Department

Engineering Surveying I

Lecture 2

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Linear Measurements: Direct measurement by Taping

1-Distance measurements

In construction work, distances are measured every day when setting out all types of structures. They are needed for plotting the position of detail when mapping and they provide scale in control surveys. Two methods can be used to measure, record and set out distances; these are

1- Direct measurement by taping

2- Electromagnetic measurement by total station.

In engineering surveying, three types of distance are used: slope distance, horizontal distance and vertical distance (or height difference). If the correct parameters are known, it is possible to convert from slope distances to horizontal distances and vice versa.

Slope distances are usually measured by laying the tape on the surface of the ground or structure, as shown in Figure 1(a). However, when measuring over very steep surfaces or undulating ground, the tape may be held horizontally, as in Figure 1(b), this technique being known *as stepping*. Occasionally, it may be necessary to suspend a tape between two points, as in Figure 1(c). Vertical distances (or height differences) are obtained by allowing a tape to hang freely with a weight attached to its zero end.

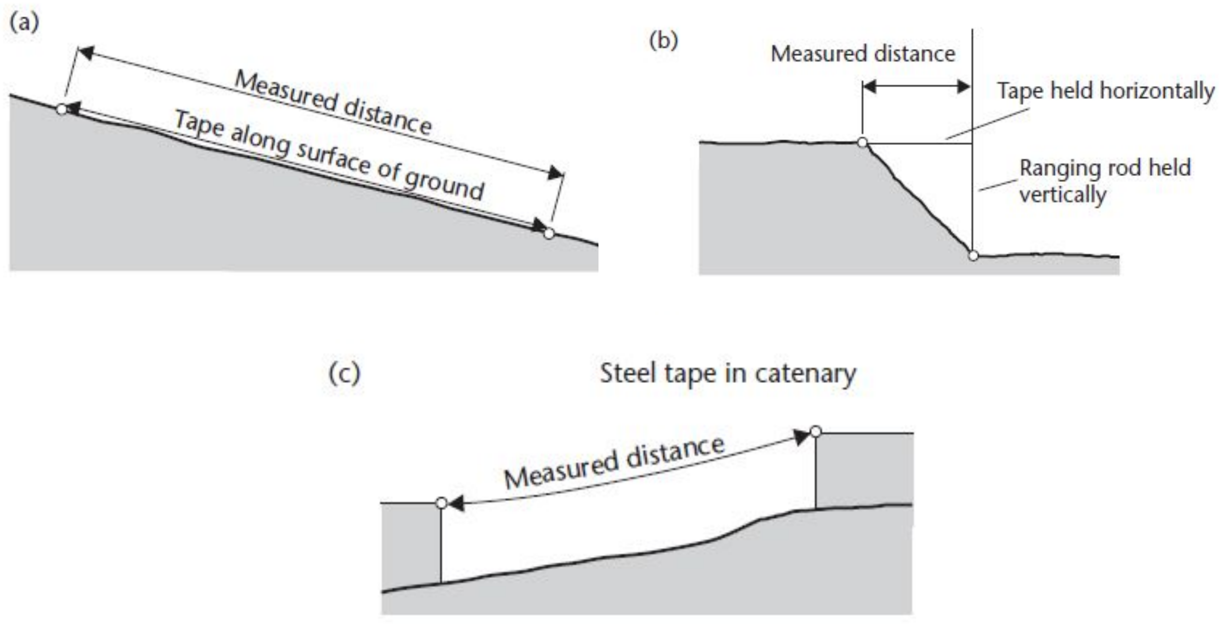


Figure 1: Tape measurement methods

2- Types of tapes used in surveying

The most common tapes used in surveying are:
1- Steel tape: all steel tapes are manufactured so that they measure their nominal length at a specific temperature and under a certain pull. These standard conditions, 20 °C and 50 N, are printed somewhere on the first metre of the tape. With care, it is possible to take measurements with a steel tape to an accuracy of better than 1 in 10,000 (a precision of 3 mm for a 30 m measured distance).

2-Fibreglass tapes: These are made from fibreglass strands embedded in PVC. Compared with steel tapes they are lighter, more flexible and less likely to break, but they tend to stretch much more when pulled. However, their advantages are that they are rust-free and rot-proof, and are electrically non-conductive when dry. Because they stretch a lot, this type of tape should only be used in mapping, sectioning and setting out where precisions in the order of 1 in 1000 (a precision of 30 mm for a 30 m measured distance) are acceptable for linear measurements.
The difference in precision between the two types of tape is evident in their graduations steel tapes are always graduated in millimetres whereas most fibreglass tapes are only graduated in centimetres.

3-Measuring distance using tapes

Distance measurement using tapes involves determining the straight-line distance between two points.
For short distances: When the length to be measured is less than that of the tape, measurements are carried out by unwinding and positioning the tape along the straight line between the points. This will be the normal procedure on construction sites, where short distances tend to be measured with a tape instead of a total station because it is a quicker and more convenient method of distance measurement.
For long distances: When the distance to be measured exceeds the length of the tape, some form of alignment of the tape is necessary. This is known as *ranging* and is achieved using ranging poles or rods, survey or marking arrows.

4-Types of error in taping

1-Mistakes: The two most common sources of error in taping are misreading the tape and incorrectly identifying where the zero is. To help detect reading errors, long distances should be checked by repeating the measurement in the reverse direction. A good way of checking shorter distances is to again take a second measurement but to use different parts of the tape – in this case the difference of each pair of readings should give the same result.

2-Systematic errors: taping is subject to a series of systematic errors that must be accounted for in order to improve the precision of a measured distance. Also, it is important to know the techniques involved and corrections that have to be applied to remove each of these errors. This includes:

- **Slope measurements and slope corrections**

Measuring distance using tape can be carried out for any line, either sloping or level. Since all surveying calculations, plans and setting-out designs are based or drawn in the horizontal plane, any sloping length measured must be reduced to the horizontal before being used for calculations or plotting. This can be achieved by calculating a slope correction for the measured length or by measuring the horizontal equivalent of the slope directly in the field. To record the horizontal distance D between A and B

1-To record the horizontal distance directly in the field using tape, the method of stepping may be employed in which a series of horizontal measurements is taken (Figure 2 a). It is recommended that the maximum length of an unsupported tape should be 10 m and that this should be considerably shorter on steep slopes, since the maximum height through which a distance is transferred should be 1.5 m. To do stepping accurately requires considerable skill and experience, and it is often better to choose another method of measuring the distance if possible.

2-The horizontal distance can be measured from the slop angle of the ground (θ). This angle can be measured using a theodolite which is set up at A and and the slope angle measured along ÁB́ parallel with the ground (Figure 2 b). In this case, h will be the height of the theodolite above ground level.

The horizontal Distance $D = L\cos\theta$
$Slop\ correction\ (Sc) = L - D$
$Sc = L - (L\cos\theta)$
$Sc = -L(1 - \cos\theta)$

When converting an observed slope distance to its horizontal equivalent, ***this correction is always negative*** and is applied to the measured length L.

3-A third method can be used if the height difference between the two points is known (for example, by levelling) and the slope between them is again uniform. In Figure 2 c, if Δh is the height difference between A and B, then
$\Delta h^2 = L^2 - D^2$
$\Delta h^2 = (L + D)(L - D)$

For slopes less than 10% $L + D = 2L$

$\Delta h^2 = 2L(L - D)$
$Sc = L - D$
$\Delta h^2 = 2L\ Sc$
$$Sc = \frac{\Delta h^2}{2L}$$

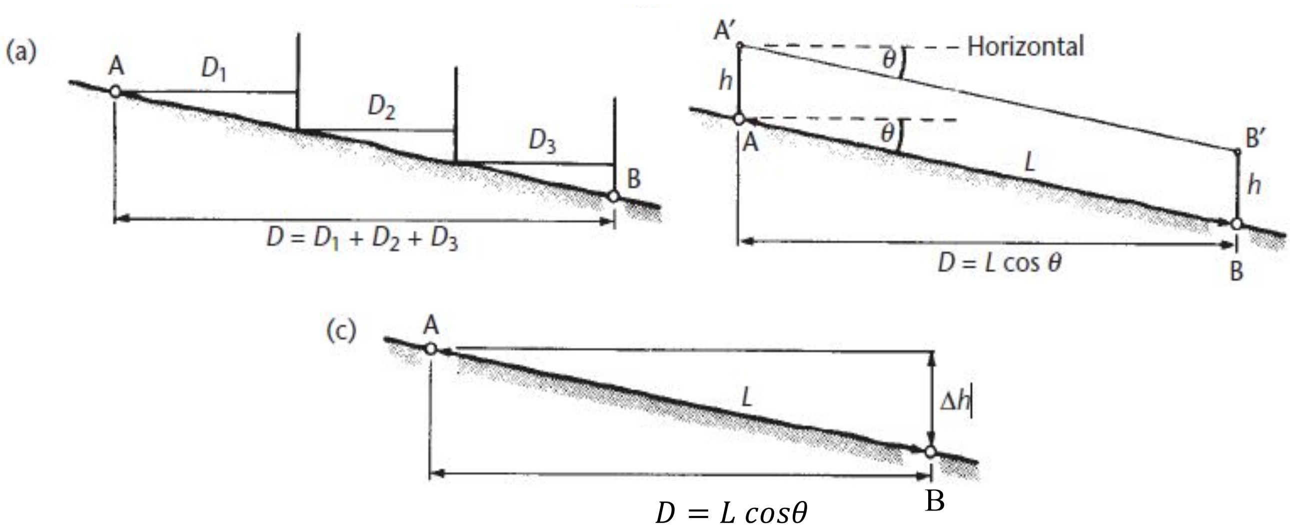


Figure 2: Slop measurements

- **Standardisation**

Under given conditions a tape has a certain nominal length. However, with a lot of use, a tape tends to stretch, and this effect can produce serious errors in length measurement. Therefore, standardisation of tapes should be carried out frequently against a reference tape or baseline. If using a reference tape, standardisation should be done on a smooth, flat surface such as a road or footpath. The reference tape should not be used for any fieldwork and should be checked by the manufacturer as often as possible. From standardisation measurements a correction is computed as follows:

$$Standardisation\ correction = \frac{L(l' - l)}{l}$$

Where

$L = recorded\ length\ of\ a\ line$

$l = nominal\ length\ of\ field\ tape\ (say\ 30\ m)$

$l' = standardised\ length\ of\ field\ tape\ (say\ 30.011\ m)$

The sign of the correction depends on the values of l and l'. However, since l' is usually greater than l, this correction is usually ***positive*** and shows that when a tape is stretched and is too long it reads too short.

- **Tension**

This correction is only considered for steel tapes. Steel, in common with many metals, is elastic, and the tape length varies with applied tension. If this is ignored, the effects of a varying tension on the precision of taping can be serious.

Every steel tape is manufactured and calibrated with a tension of 50 N applied. On site, if an accurate measurement is required, instead of simply pulling the tape taut, it should be used either with its calibration tension or a different (but known) tension applied. This can be achieved using a spring balance specially made for use in ground taping. This tension is then maintained while measurements are taken. If the calibration tension of 50 N is applied, no correction is necessary. However, if a tape is subjected to a pull other than the calibration value, it can be shown that a correction to an observed length is given by

$$Tension\ correction = \frac{L(T_F - T_S)}{AE}$$

Where

$T_F = tension\ applied\ to\ the\ tape\ (N)$

$T_S = calibration\ tension\ (N)$

$A = cross - sectional\ area\ of\ the\ tape\ (mm^2)$

$E = modulus\ of\ elasticity\ for\ the\ tape\ material\ (N\ mm^{-2})$

$(for\ steel\ tapes, typically\ 200{,}000\ N\ mm^{-2})$

The sign of the correction depends on the magnitudes of T_F and T_S, but as with the standardisation correction, if the tape is pulled at a tension greater than its calibration value it will stretch, giving rise to a positive correction.

- **Temperature variations**

As with tension, this correction is only considered for steel tapes. In addition to the effects of standardisation and tension, steel tapes contract and expand with temperature variations and are calibrated at a temperature of 20 °C by the manufacturer. Alternatively, a tape could be calibrated on a site baseline at a temperature that is not 20 °C – the temperature at which this is done then becomes the on-site calibration temperature.

$Temperature\ correction = \alpha L(t_f - t_s)$

Where

$\alpha = the\ coefficient\ of\ expansion\ of\ the\ tape\ material$

$(for\ example\ 0.0000112\ per\ °C\ for\ steel)$

$t_f =\ mean\ field\ temperature\ (°C)$

$t_s =\ temperature\ of\ calibration$

The sign of this correction is given by the magnitudes of t_f and t_s.

- **Sag (catenary)**

As with tension and temperature, this correction is only applied to steel tapes. On a construction site, this correction is only considered when measuring distances less than a tape length between elevated points on structures when the tape may be suspended for ease of measurement (Figure 3).

$$Sag\ correction = -\frac{w^2L^3cos^2\theta}{24T_F^2} = -\frac{W^2L\ \ cos^2\theta}{24T_F^2}$$

Where

$\theta =\ the\ angle\ of\ slope\ between\ tape\ supports$

$w =\ the\ weight\ of\ the\ tape\ per\ metre\ length\ (N\ m{-}\ 1)$

$W =\ the\ total\ weight\ of\ the\ tape\ (N)$

$T_F =\ the\ tension\ applied\ to\ the\ tape\ (N)$

When converting a measurement to its equivalent chord length, this correction is always negative.

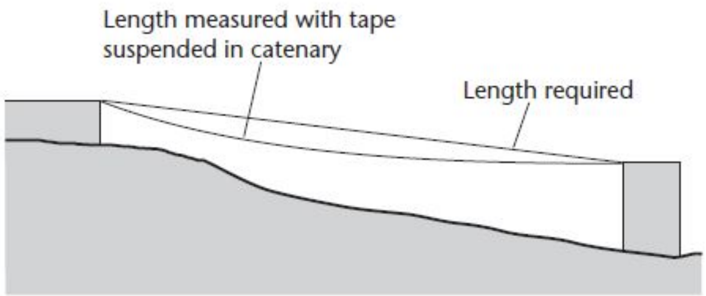


Figure 3: Measurement in catenary

Question

A steel tape of nominal length 30 m was used to measure the distance between two points A and B on a structure. The following measurements were recorded with the tape suspended between A and B:

Line	Length measured	Slope angle	Mean temperature	Tension applied
AB	29.872 m	3°40'	5 °C	120 N

The standardised length of the tape against a reference tape is 30.014 m at 20 °C and 50 N tension. The tape weighs 0.17 N m^{-1} and has a cross-sectional area of 2 mm^2. Calculate the horizontal length of AB.

Solution

$$Slop\ correction = -L(1 - \cos\theta) = -29.872\ (1 - \cos 3°40') = -0.0611\ m$$

$$Standardisation\ correction = \frac{L(l' - l)}{l} = \frac{29.872\ (30.014 - 30)}{30} = +0.0139$$

$$Tension\ correction = \frac{L(T_F - T_S)}{AE} = \frac{29\ .872\ (120 - 50)}{2 * 200000} = +0.0052$$

$$Temperature\ correction = \alpha L(t_f - t_s) = 0.0000112 * 29.872\ (5 - 20\ ) = -0.0050\ m$$

$$Sag\ correction = -\frac{w^2 L^3 \cos^2\theta}{24T_F^2} = -\frac{0.17^2 * 29.872^3 * \cos^2 3°40'}{24 * 120^2} = -0.0022m$$

$$Horizontal\ length\ AB = 29.872 - 0.0611 + 0.0139 + 0.0052 - 0.0050 - 0.0022$$
$$= 29.8228 \quad = 29.823m(to\ the\ nearst\ mm)$$

5-Types of obstacles in direct measurement of a line

1) **Vision obstructed:** In this type of obstacles, the ends of the lines are not visible e.g. rising ground, hill or jungle intervening.
   I. Both ends may be visible from any intermediate point lying on the line such as in the case of a hill. The obstacle of this kind may easily be crossed over by reciprocal ranging and length measured by stepping method of chaining.

   II. Both ends may not be visible from any intermediate point such as in the case of a jungle. The obstacle of this kind may be crossed over by "Random line method". In Figure 4, let AB be the line whose length is required. From A, run a line AB' called a random line, in the approximate convenient direction of AB and continue it until point B is visible from B' Chain the line to B' where BB' is perpendicular to AB' and measure BB'.

$$Then\ AB = \sqrt{(AB')^2 + (AB')^2}$$

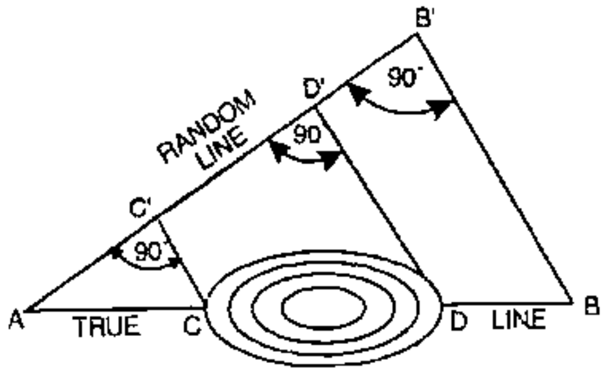


Figure 4: vision obstructed for both ends of a line

2) **Direct measurement obstructed, vision free:** The typical obstacle of this type is a sheet of water, the width of which in the direction of measurement exceeds the length of the tape. The problem consists in finding the distance between convenient points on the line on either side of obstacle. Therefore, two cases may arise:

   I. When the obstacle can be measured around, e.g. a pond. The distance between two points A and B on either side of the pond may be determined by any of the following methods convenient at site:
      a. Set out equal perpendiculars AC and BD (Figure 5 a). Measure CD which is equal to AB.
      b. Erect perpendicular AC (Figure 5 b) of such a length that CB clears the obstacle and measure AC and CB.

   $Then\ AB = \sqrt{(BC)^2 - (AC)^2}$

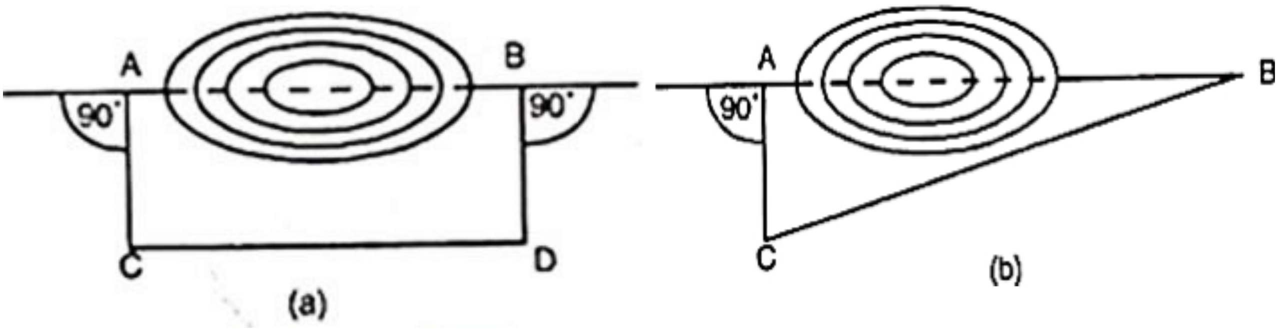


Figure 5: Direct measurement obstructed but vision free.

II. Any one of the following methods may be employed to find the width of the river along the direction of the line:

a) Select two points A and B on the line on opposite banks of the river. (Figure 6 a). From A and C, erect perpendicular or parallel lines AD and CE, such that E, D and B are in line. Measure AC, AD and CE. If a line DF is drawn parallel to AC, meeting CE in F, the triangles ABD and FDE are similar.

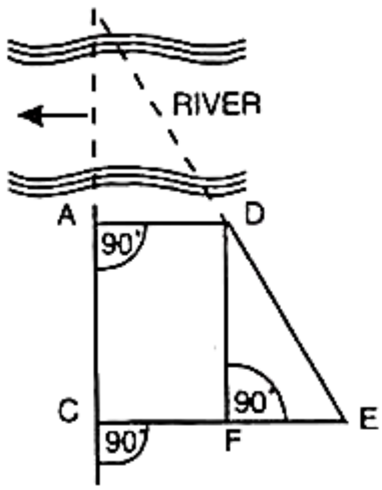
$$\therefore \frac{AB}{AD} = \frac{DF}{FE} \; (but\ DF = AC, and\ FE = CE - CF = CE - AD)$$

$$or\ \frac{AB}{AD} = \frac{AC}{CE - AD}$$

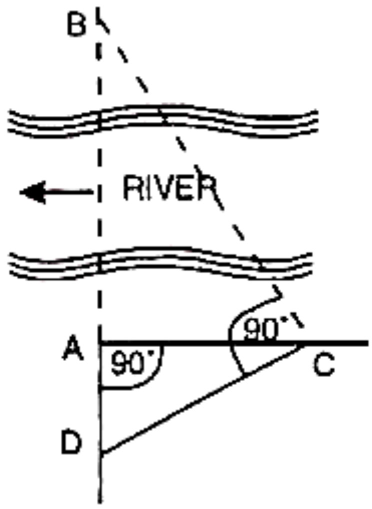
$$or\ AB = \frac{AD * AC}{CE - AD}$$

b) Select two points A and B as before (Figure 6 b). Erect a perpendicular AC and using an optical square at C, find D on the chain line so that ∠BCD is a right angle. Measure AC and AD. Triangles ABC and ACD are similar.

$$Therefore\ \frac{AB}{AC} = \frac{AC}{AD} \; or\ AB = \frac{AC^2}{AD}$$



a



b

Figure (6): (a and b) illustrate the way to find the width of the river along measured direction of the line

III. Direct measurement and vision both obstructed: Select two points A and B on the line [Figure 7]. At A and B, erect equal perpendiculars AC and BD. Join CD and produce it past the obstacle. Select two points E and F on it. At E and F, set out perpendiculars EG and FH, each equal in length to AC. The points G and H then lie on the chain line and BG = DE.

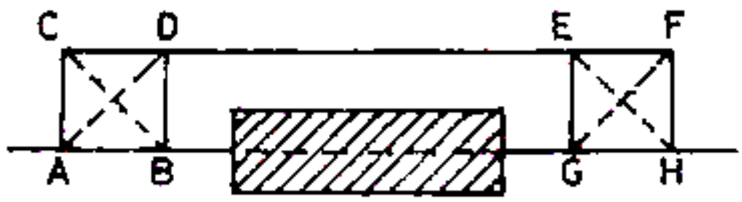


Figure (7): Direct measurement and vision both obstructed

Example

There is an obstacle in the form of a pond on the main line AB (Figure 8). Two points C and D were taken on the opposite sides of the pond. On left of CD, a line CE was laid out 100 m in length and a second line CF, 80 m long was laid out on the right of CD such that E, D and F are in the same straight line. ED and DF were measured and found to be 60 m and 56 m respectively. Find out the obstructed length CD.

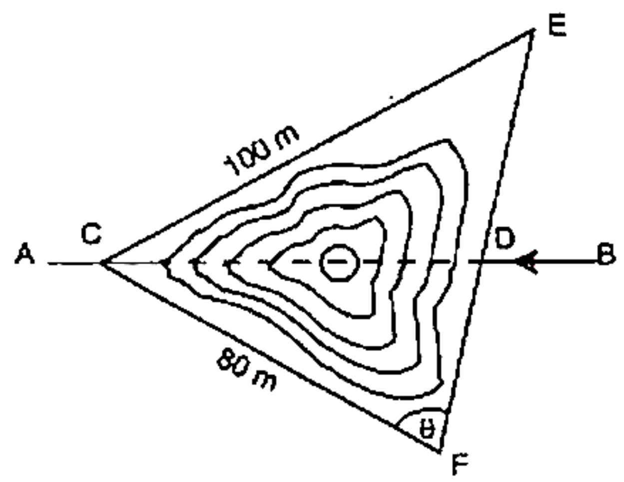


Figure 8: shows the obstacle in the form of a pond on the main line AB

Solution

In Fig. 3.24, CD is the obstructed length of the pond on the chain line AB. CE and CF are known to be 100 and 80 m respectively and EF = 60 + 56= 116 m.

Let angle CFE = θ, then in the triangle CFE,

$$\cos\theta = \frac{FC^2 + FE^2 - CE^2}{2 * FC * FE}$$

$$\cos\theta = \frac{80^2 + 116^2 - 100^2}{2 * 80 * 116}$$

Also in the triangle CFD

$$\cos\theta = \frac{FC^2 + FD^2 - CD^2}{2 * FC * FD} = \frac{80^2 + 56^2 - CD^2}{2 * 80 * 56}$$

$$\therefore \quad \frac{80^2 + 116^2 - 100^2}{2 * 80 * 116} = \frac{80^2 + 56^2 - CD^2}{2 * 80 * 56}$$

$$\therefore \quad CD = 69.123\ m$$