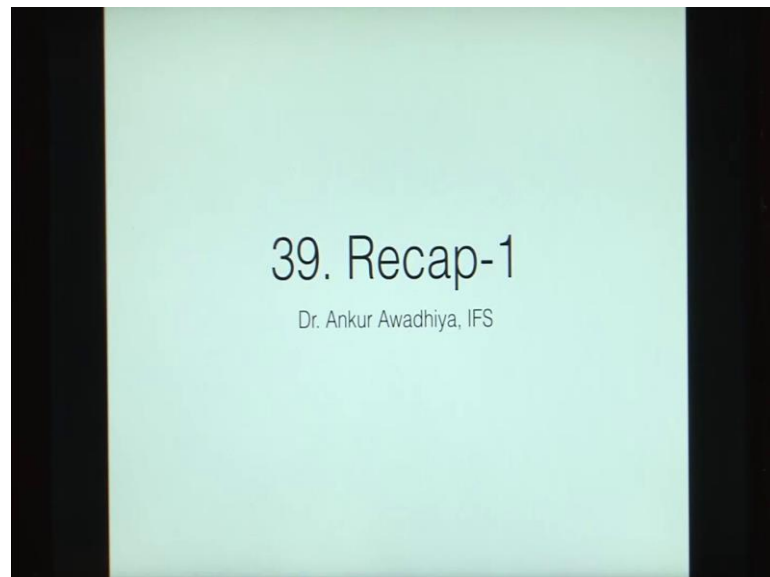


Forest Biometry
Prof. Mainak Das
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Department of Biological Sciences & Bioengineering & Design Programme
Indian Institute of Technology, Kanpur

Lecture – 39
Recap – 1

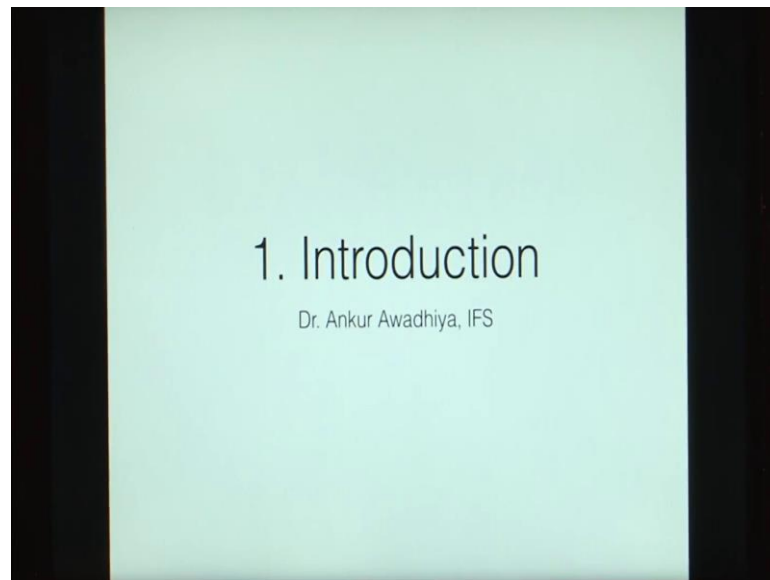
[FL], now that we are nearing the end of this course and your exams are close by let us have this class and the next class as recap or revision sessions.

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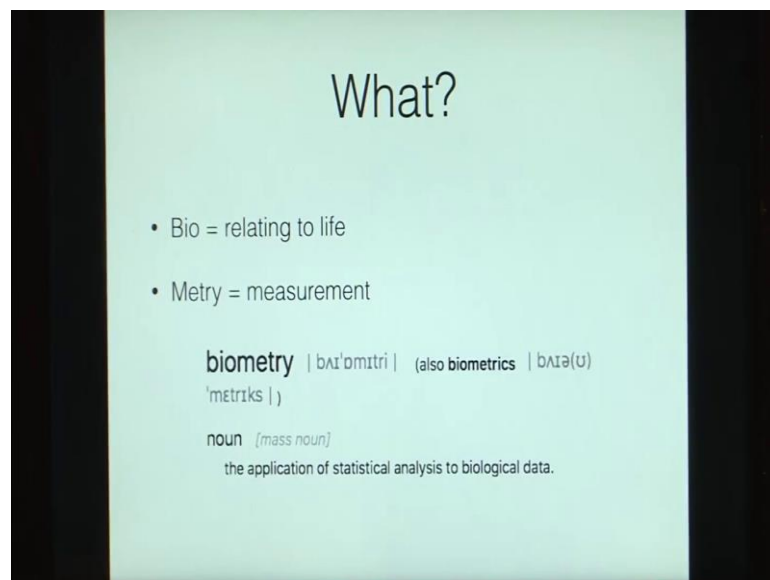
So, let us begin the first recap session.

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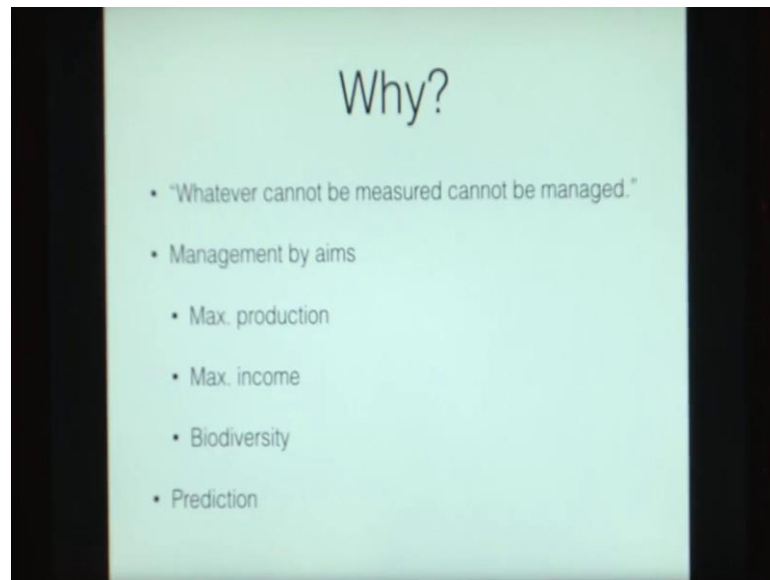
So, we began this course with the introduction, in which we looked at what do we do in forest biometry.

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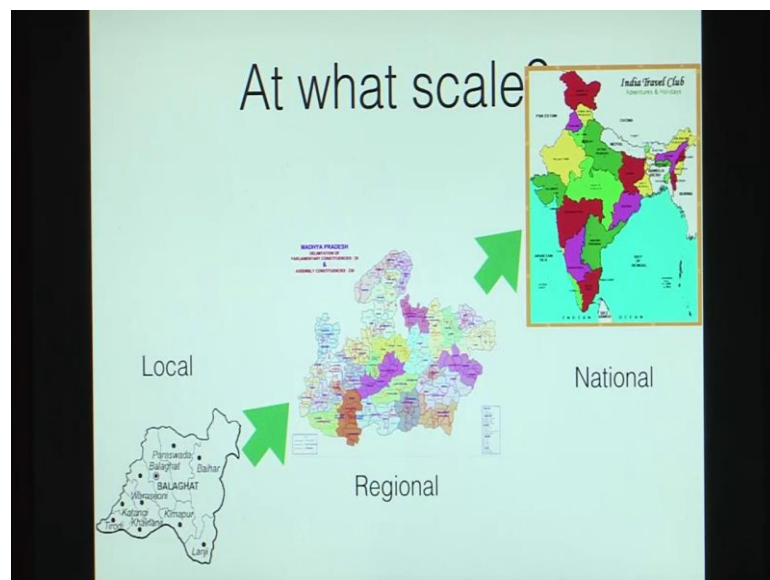
So, it was that our forest is a land covered with trees and undergrowth, it is outside biometry is a measurement that is related to life, so we are essentially measuring the parameters that are related to the life in the forest.

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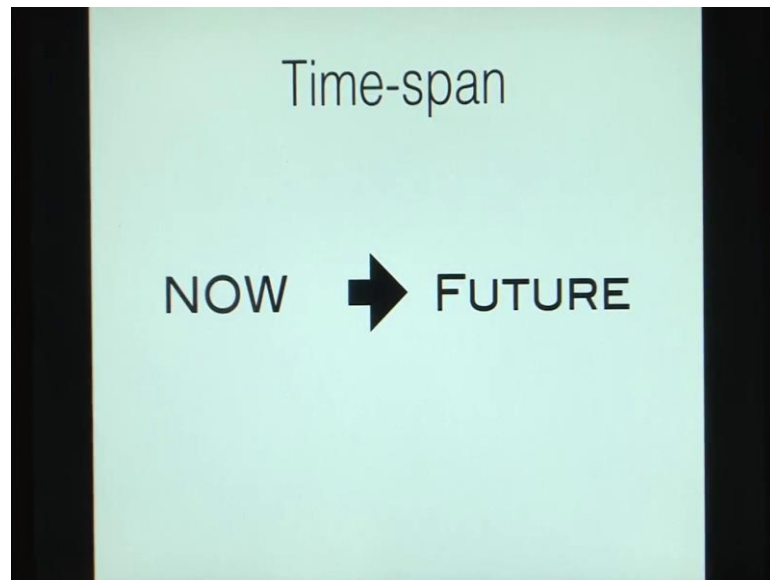
Why do we do it? Because we need to manage our forest stands for different purposes, and we need our measurements, so that we can properly manage our forest.

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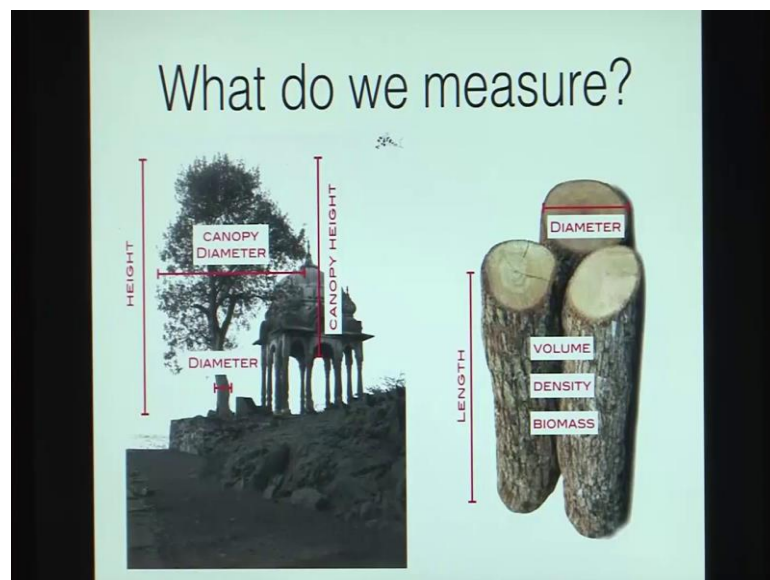
We do forest biometry at different scales. So, one instance you can measure a small forest that is in a local region, you can take district wise measurements, you can take regional managements or state wise measurements or you can even go for a national or an international level of biometry for say things like carbon sequestration global warming and so on.

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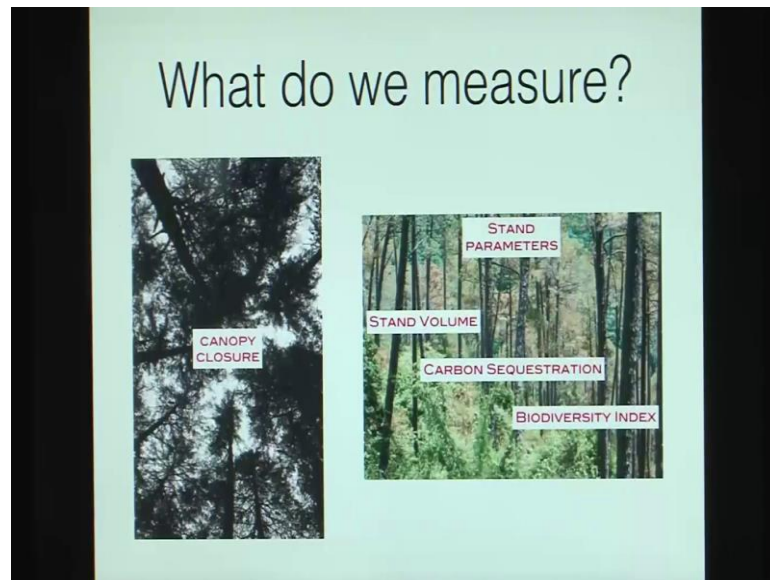
The time span is now as well as future. So, you can take measurements now and you can use it to predict the future. So, that is the utility of forest biometry.

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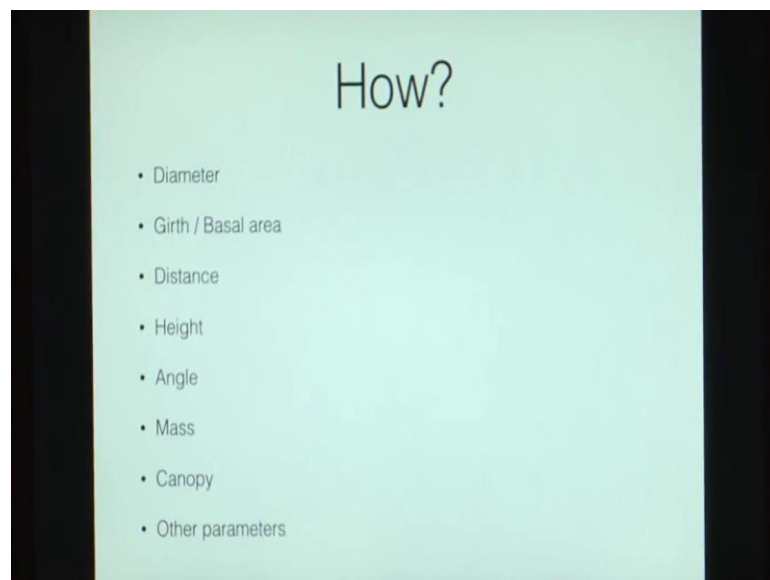
Now what do we measure in the case of forest biometry? We measure a number of things that we have already seen. So, those are the canopy diameter, canopy height the diameter of the tree, the height of a tree the length of a log, diameter of a log volume of a log density biomass also in this case we can look at the canopy cover and the canopy closure we know the difference between both of these.

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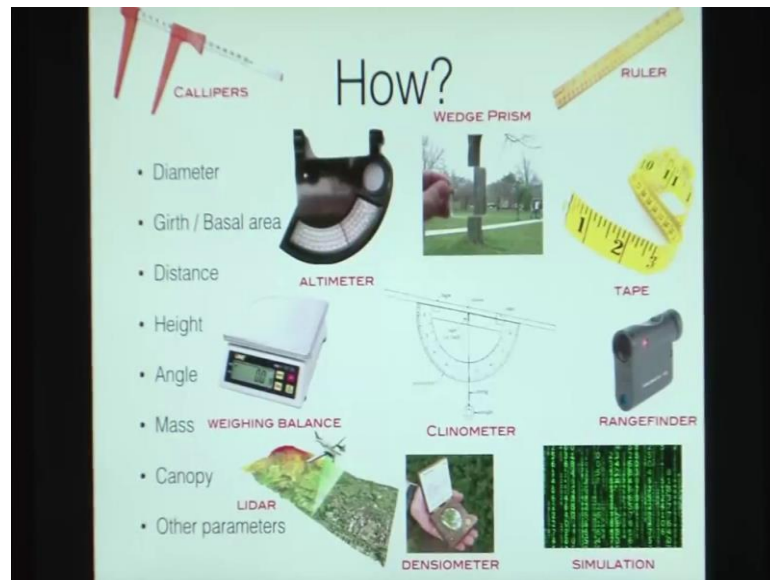
And also we can look at the stand parameters like stand volume carbon sequestration bio diversity index.

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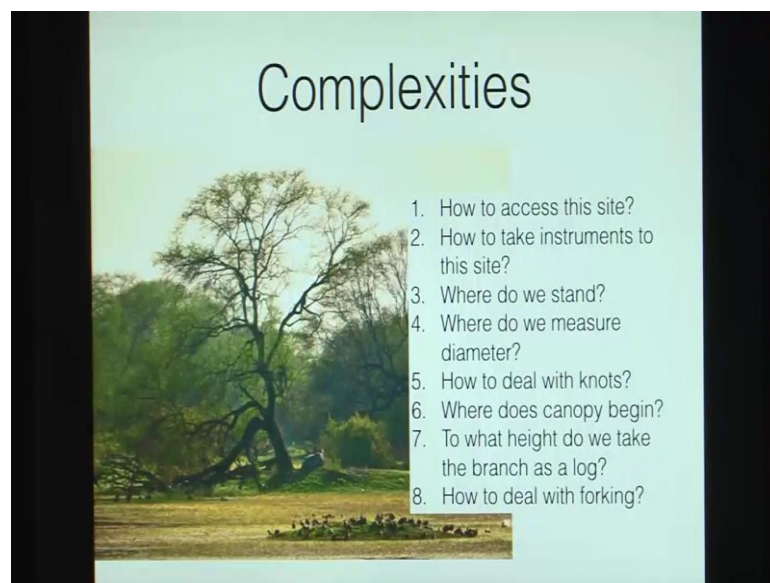


We measure a number of values that we have seen in this course, we use a number of equipments.

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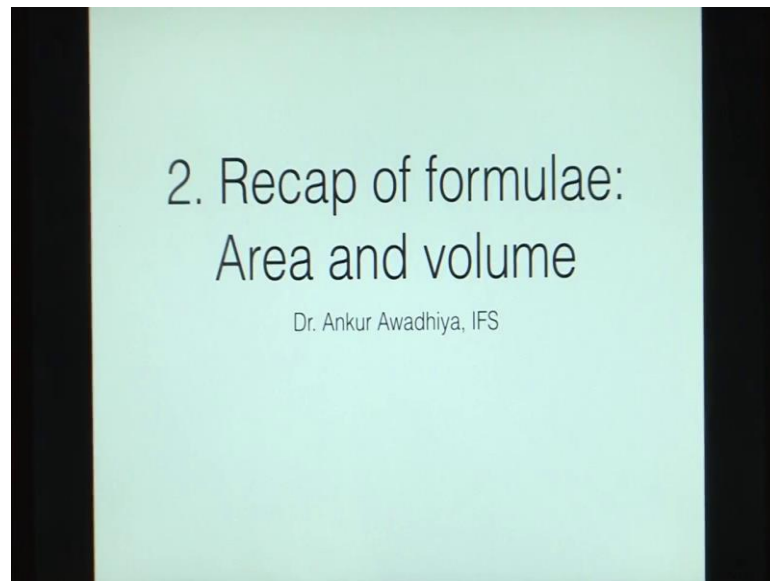


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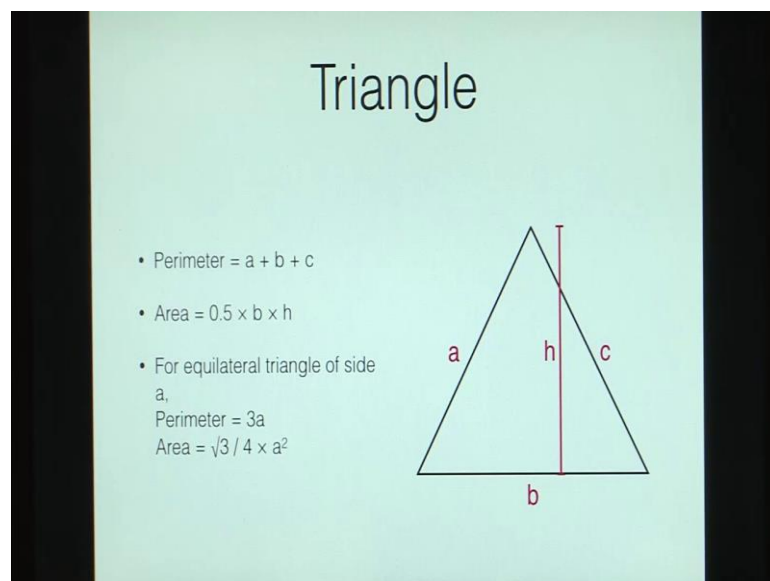
There are also a number of complexities that are involved, that we have seen where do we go to measure the height of the tree, what are the different ways of measuring heights of these trees, what are the standard places at which we measure heights, what does diameter at breast height and so on.

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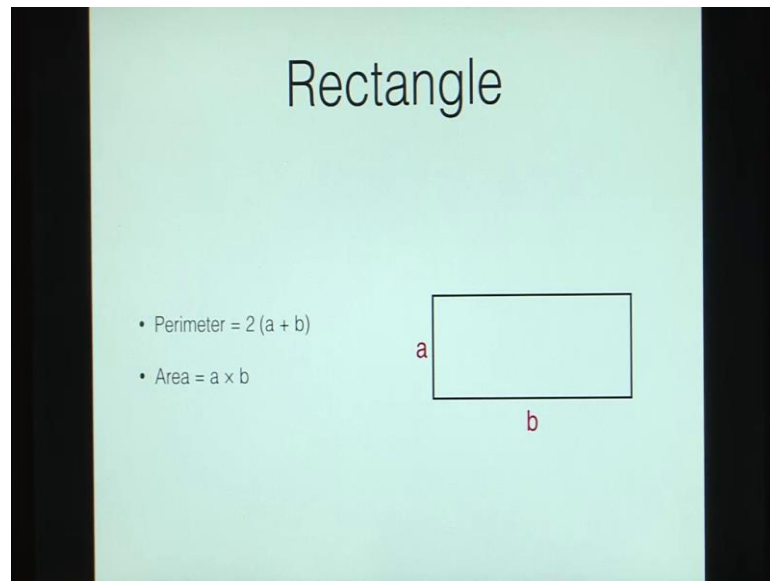
In the second class we looked at a recap of formulae for area and volume.

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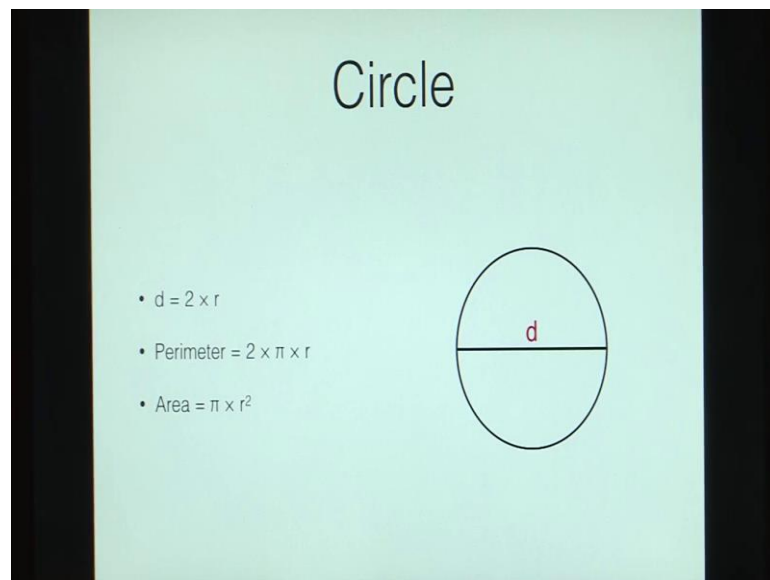
So in the case of a triangle, the perimeter is the sum of the sides the area is half of base cross a base and height. In the case of an equilateral triangles the perimeter is $3a$ the area is $\frac{\sqrt{3}}{4} a^2$.

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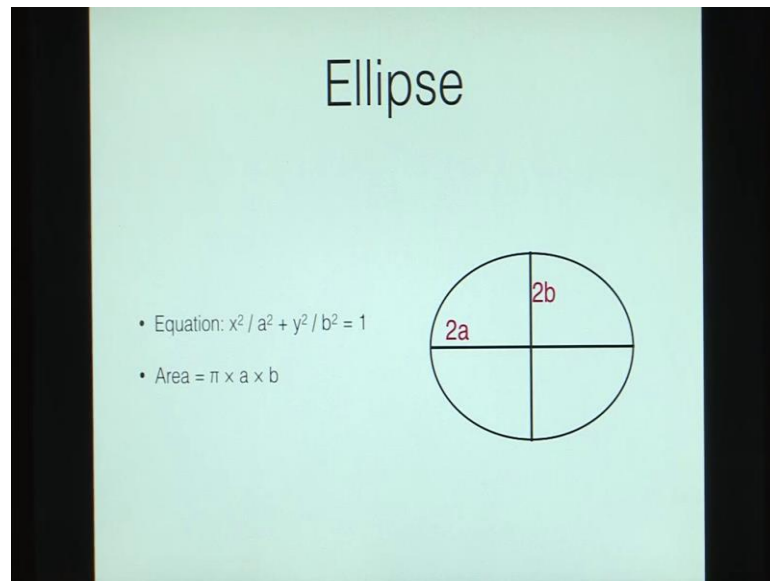
In the case of a rectangle the perimeter is twice of a plus b, the area is a times b in the case of a circle.

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We have diameter is twice of the radius perimeter is $2 \pi r$ area is πr^2 , in the case of an ellipse with these two axis $2a$ and $2b$.

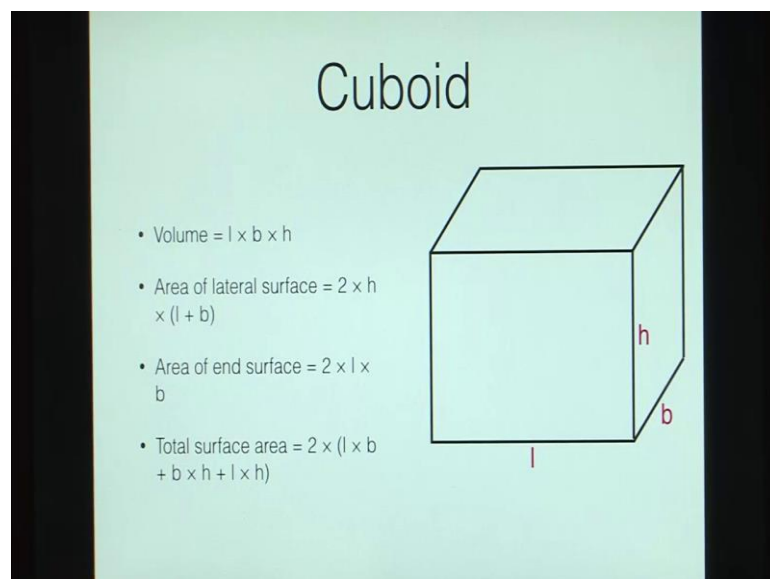
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We have the equation of the ellipse as $x^2/a^2 + y^2/b^2 = 1$, the area is given by $\pi \times a \times b$.

So, in the case of most trees we take their cross sectional areas as either circular or elliptical.

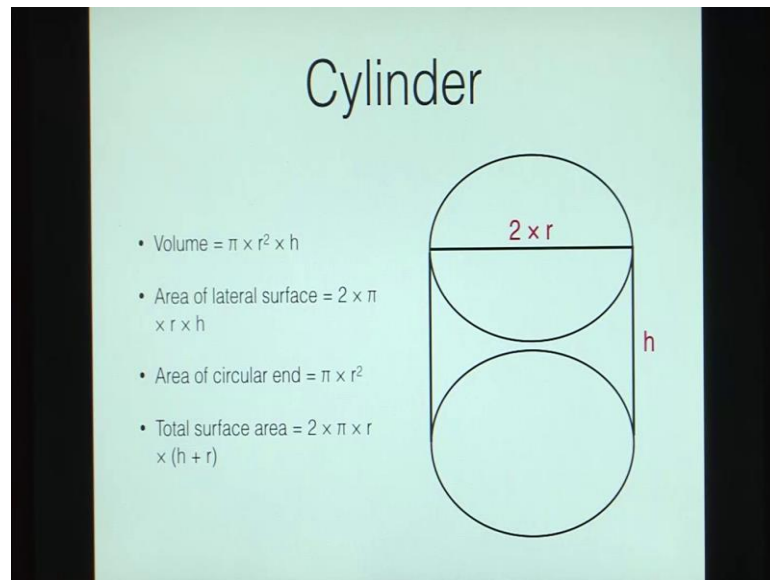
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Now in the case of a cuboid we take the volume as length times breadth times height $l \times b \times h$, the area of the lateral surfaces is the area of these rectangles that are making the

lateral surfaces. So, 1 2 3 on the back and 4 on this side, area of the end surface is this area plus the area of the bottom surface, the total surface area is the sum of all these areas.

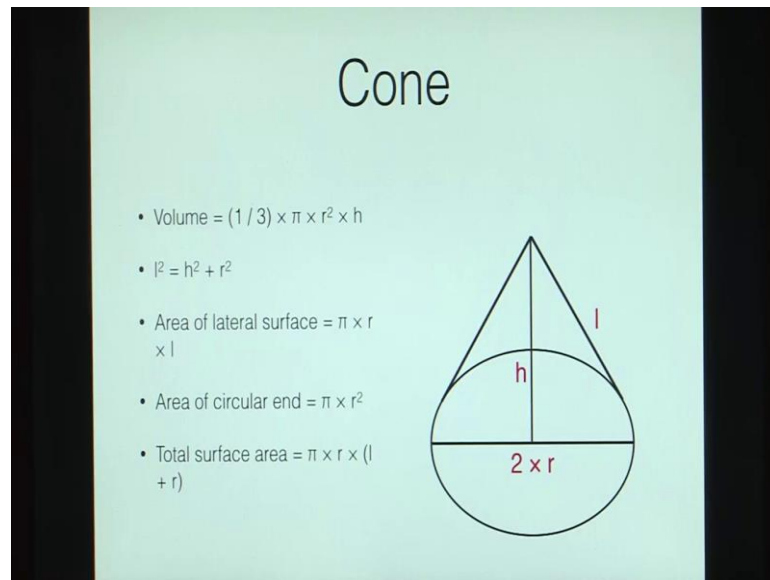
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In the case of a cylinder, we have volume given by $\pi r^2 h$, the area of the lateral surface is $2 \pi r h$.

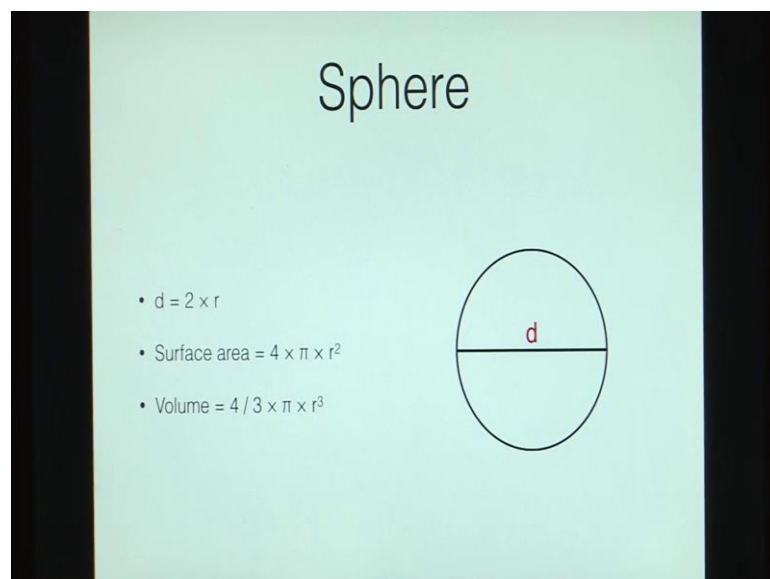
So, we used this equation of volume when we were taking our stem to be of a cylindrical shape or form, now we also know the area of the circular end and the total surface area. So, area of the circular end is used to calculate the basal areas.

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Now in the case of cones, so this conical shape is used in the case of canopies volume as 1 by 3 the volume of the cylinder, and the lateral surface area is $\pi r l$ and the end surface area is πr^2 giving us our total area of $\pi r l + \pi r^2$.

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Now, in the case of a sphere the diameter is twice of radius, the surface area is $4 \pi r^2$ and the volume is $4/3 \pi r^3$.

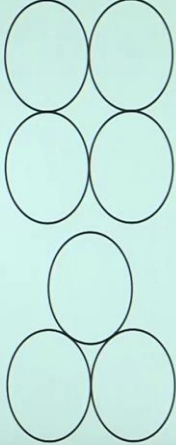
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Example

Calculate packing density of trees for

1. square packing
2. hexagonal packing

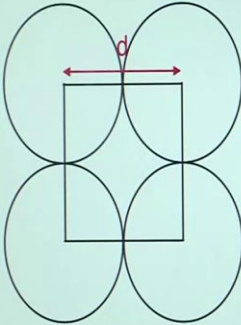
Which of these should be recommended for the highest number of trees per hectare of the forest?



Now we used these equations to calculate the packing density of trees in a forest. So, we can put our trees in a squarish packing or in the case or we can put it as hexagonal packing in which they form an equilateral triangle and we calculated the packing density for both of these.

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Solution



In the square of side d , there are four quarter-circles, or 1 full circle.

Area of square = d^2

Area of circle = $\pi d^2 / 4$

Thus, packing density
= Area of circle / Area of square
= $\pi / 4$
= 78.5%

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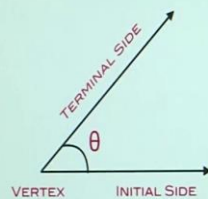
Etymology

- Trigon = Triangle
- Metron = Measurement
- Trigonometry = Measuring the sides of a triangle

Now, next we did a recap of trigonometry, in which we looked at what this word means, it means measuring the sides of a triangle.

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Angle

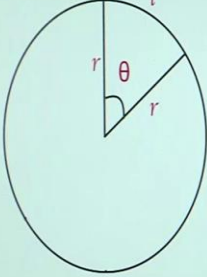


- Measure of rotation of a ray about its initial point called vertex
- Measured in degrees
- One full rotation = 360°
- $1^\circ = 60'$
- $1' = 60''$

We defined what an angle is.

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Angle



The diagram shows a circle with a central angle θ (in radians) subtending an arc of length l . Two radii of length r are drawn from the center to the endpoints of the arc.

- Angle is also measured in radians
- The radian measure is the ratio of the length of an arc to the radius of the arc
- Thus, $\theta = l/r$
- One full rotation = $2 \times \pi \times r / r$
= 2π radians
- Thus, $360^\circ = 2\pi$ radians

It is measured either in degrees or in radians.

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Example

- Convert $40^\circ 20'$ into radians

And we can convert a degrees into radians and also radians into degrees.

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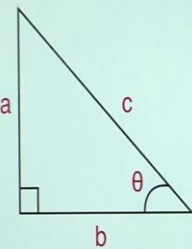
Example

- Convert $40^\circ 20'$ into radians

$$20' = (20 / 60)^\circ = 0.33^\circ$$
$$40^\circ 20' = 40.33^\circ$$
$$360^\circ = 2\pi \text{ radian}$$
$$\Rightarrow 1^\circ = 2\pi / 360 \text{ radian}$$
$$\Rightarrow 40.33^\circ = 40.33 \times 2\pi / 360 \text{ radian}$$
$$\Rightarrow 40.33^\circ = 0.224 \pi \text{ radian}$$
$$\Rightarrow 40.33^\circ = 0.703 \text{ radian}$$

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Basic relations

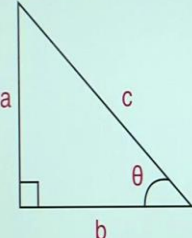


- $a = c \times \sin(\theta)$
- $b = c \times \cos(\theta)$
- $a = b \times \tan(\theta)$

Next we saw some basic relations what is sin theta cos theta and tan theta. So, sin theta is the perpendicular divided by the hypotenuse, the cos theta is the base divided by the hypotenuse, tan theta is the height divided by the base and tan theta is something that we use most frequently when we are trying to measure the heights of trees.

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Basic relations

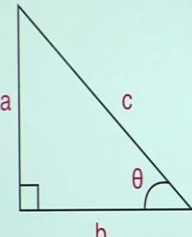


- $\operatorname{cosec}(\theta) = 1 / \sin(\theta)$
- $\sec(\theta) = 1 / \cos(\theta)$
- $\cot(\theta) = 1 / \tan(\theta)$

We also refined some other values cosec secant cot theta.

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Basic relations



- $\tan(\theta) = \sin(\theta) / \cos(\theta)$
- $\cot(\theta) = \cos(\theta) / \sin(\theta)$
- $\sin^2(\theta) + \cos^2(\theta) = 1$
- $1 + \tan^2(\theta) = \sec^2(\theta)$
- $1 + \cot^2(\theta) = \operatorname{cosec}^2(\theta)$

And these basic relations between these various values we also.

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Basic relations

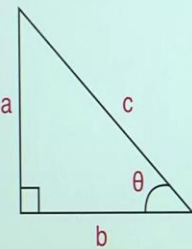
θ	$\sin(\theta)$	$\cos(\theta)$	$\tan(\theta)$
0°	0	1	0
30°	$1/2$	$\sqrt{3}/2$	$1/\sqrt{3}$
45°	$1/\sqrt{2}$	$1/\sqrt{2}$	1
60°	$\sqrt{3}/2$	$1/2$	$\sqrt{3}$
90°	1	0	Not Defined

Looked at these some these standard values. So, now, you can measure you can just remember one thing. So, for these standard angles 0, 30, 45, 60 and 90 your sin theta is 0 half one by root 2 root 3 by 2 and one in the case of cos you write it in the opposite direction. So, that is also goes as 0 half one by root 2, root 3 by 2 and 1 and you can calculate the your tan values by dividing the sin values by the cos values. So, at 0 by 1 as 0, half by root 3 by 2 is 1 by root 3 and so on. So, these are some values that you should remember.

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Example

• In the triangle given below, $\theta = 60^\circ$ and $c = 2$ cm. Find a and b .



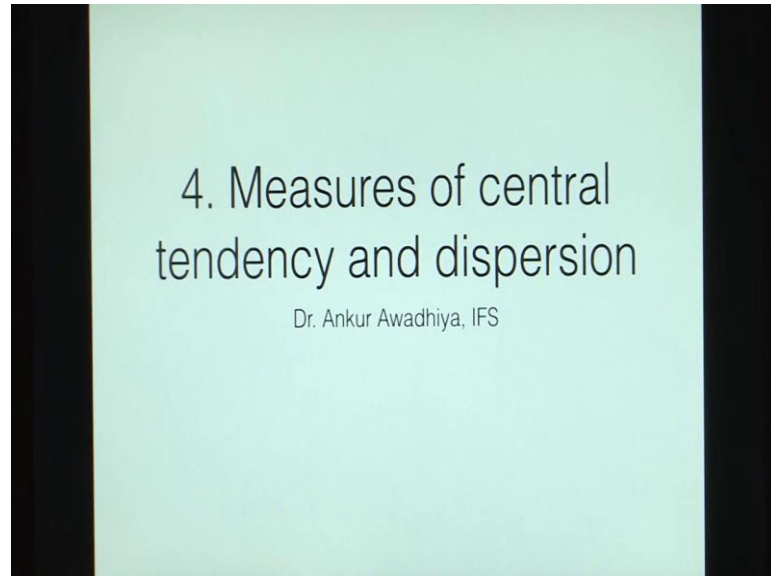
$a = c \times \sin(\theta)$
 $\Rightarrow a = 2 \times \sqrt{3}/2 = \sqrt{3}$ cm

$b = c \times \cos(\theta)$
 $\Rightarrow a = 2 \times 1/2 = 1$ cm

Check: $a^2 + b^2$
 $= 3 + 1$
 $= 4$
 $= 2^2$
 $= c^2$ (Pythagoras theorem)

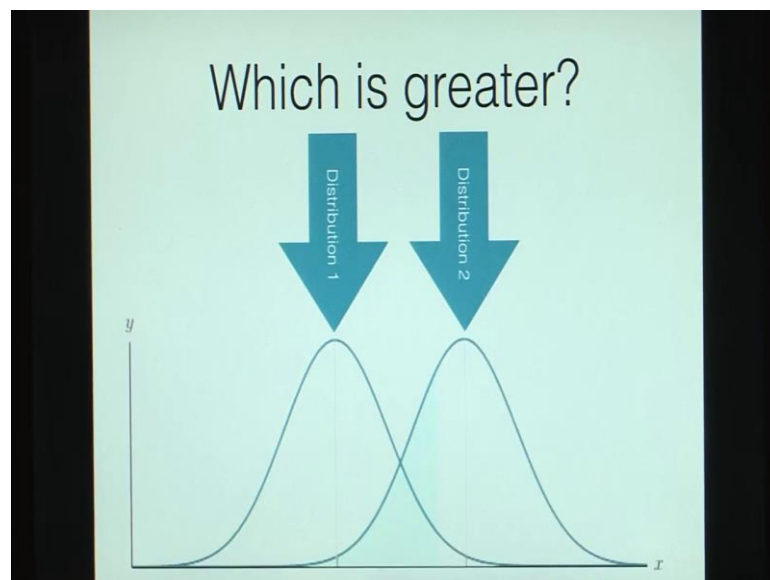
Then we did some problem statements in which we could find out the sides of a triangle using a trigonometry.

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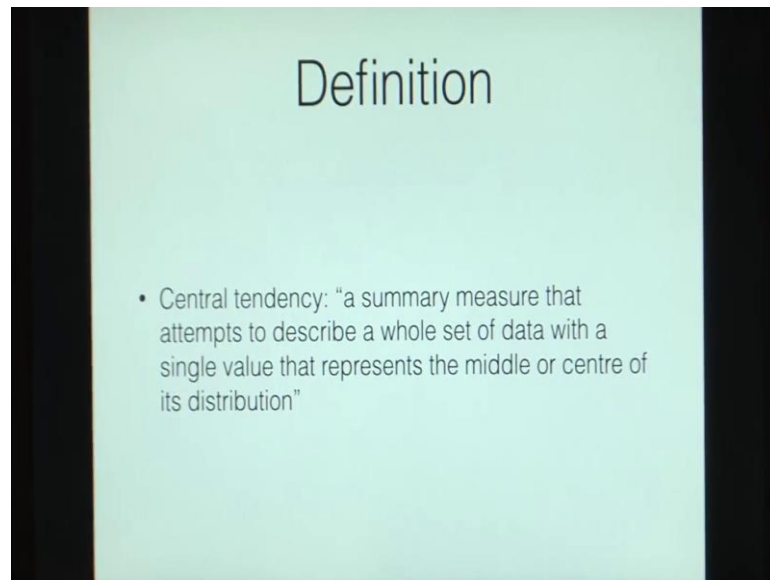
Next we looked at the measures of central tendency in dispersion.

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So in this case we wanted to say which of these curves is the larger curve.

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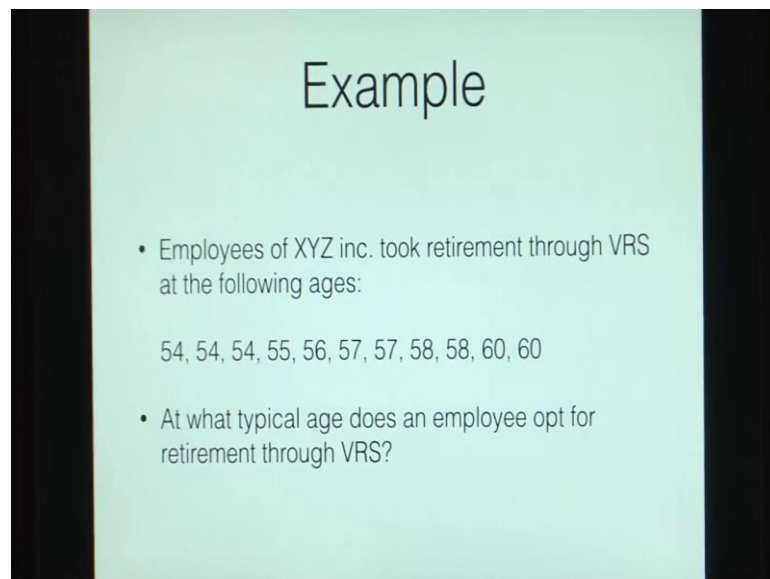


Definition

- Central tendency: "a summary measure that attempts to describe a whole set of data with a single value that represents the middle or centre of its distribution"

We defined central tendency, which were mean.

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Example

- Employees of XYZ inc. took retirement through VRS at the following ages:
54, 54, 54, 55, 56, 57, 57, 58, 58, 60, 60
- At what typical age does an employee opt for retirement through VRS?

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Mean

$$\bar{x} = \frac{\sum x}{n}$$

- Mean =
(54+54+54+55+56+57+57+58+58+60+60) / 11
= 623 / 11
= 56.64 years
- Advantage: Can be used for continuous and discrete data; easy to calculate
- Disadvantage: Influenced by outliers

So, mean is the sum of all the values divided by the total number of values.

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Median

- "the middle value in distribution when the values are arranged in ascending or descending order; when the distribution has an even number of observations, the median value is the mean of the two middle values"
- Arranged values: 54, 54, 54, 55, 56, 57, 57, 58, 58, 60, 60
- Total number of values = 11
- Median = the 6th value = 57
- Advantage: Less affected by outliers
- Disadvantage: Data needs to be in ascending / descending order

We also defined a median which is the central value when you arrange things in ascending or descending order.

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Mode

- “the most commonly occurring value in a distribution”
- In the current distribution, 54 occurs 3 times, which is the maximum
- Thus, mode = 54 years
- Advantage: Useful even for non-numerical data
- Disadvantage: Data can even have zero, two or multiple modes

Age	Frequency
54	3
55	1
56	1
57	2
58	2
60	2

Mode is the value that appears most frequently, but your values might be unimodal, bimodal, trimodal or even multimodal in some cases.

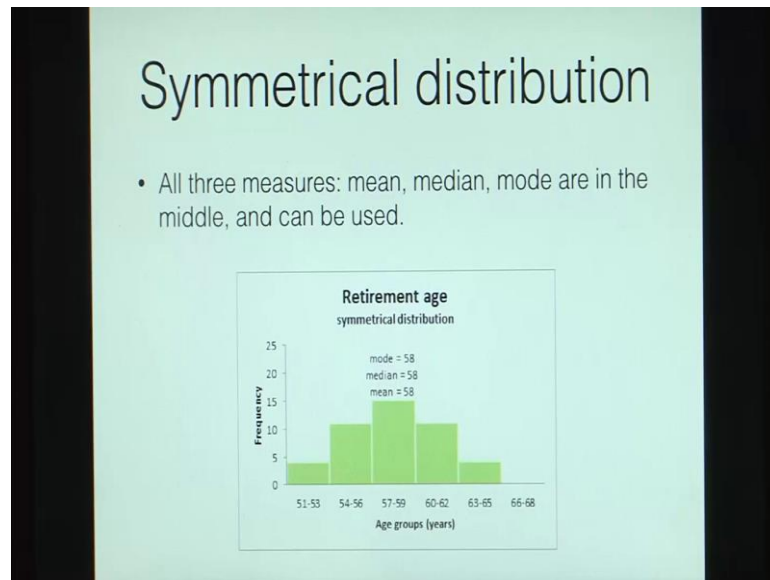
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Pearson's approximation

- Median - Mode = 2 × (Mean - Median)
⇒ Median - Mode = 2 × Mean - 2 × Median
⇒ Mode = 3 × Median - 2 × Mean

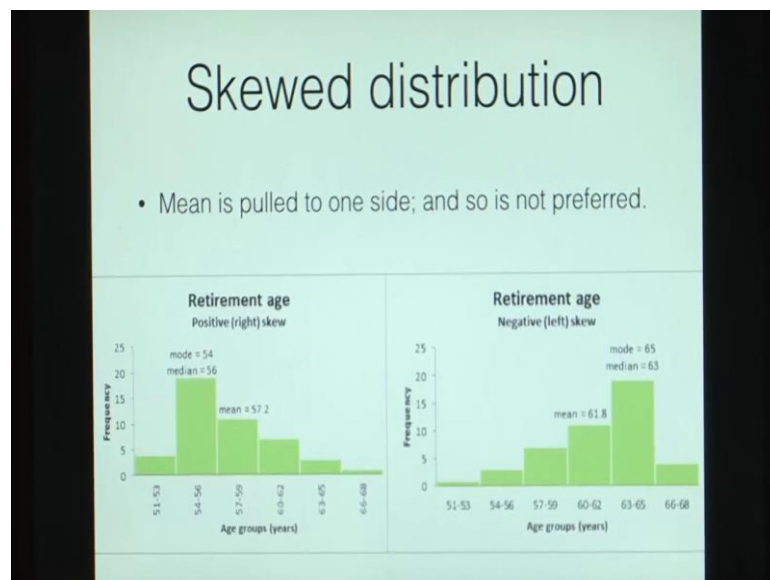
We also looked at Pearson's approximation that says that mode is 3 times median minus 2 times mean.

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We also looked at symmetrical distributions in which we can use any three of these mean median or mode as the middle value.

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And in the case of squid distribution because mean is pulled towards one side, and so, it does not show us the most representative value and so, it is not used in these situations.

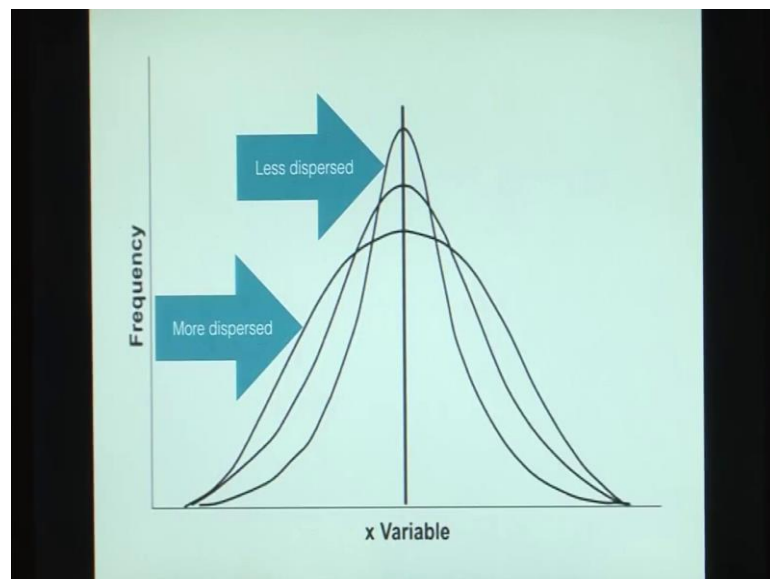
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Dispersion

- Definition: “the extent to which a distribution is stretched or squeezed”
- aka variability, scatter, or spread

We also looked at dispersion which tells us.

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This spread between the values.

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Range

- "the difference between the maximum (x_m) and the minimum (x_0) observation of the given data"
- Range = $x_m - x_0$
- Range coefficient of dispersion = $\frac{x_m - x_0}{x_m + x_0}$

So, we looked at range which is the maximum minus the minimum value, the range coefficient of dispersion that is the maximum minus minimum divided by maximum plus minimum.

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Example

- The number of seeds per pod in a tree is as under

# seeds	1	2	3	4	5	6	7	8	9	10
# pods	26	113	120	95	60	42	21	14	5	4

- Find the range and the range coefficient of dispersion

So, we also did some examples for this.

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# seeds	1	2	3	4	5	6	7	8	9	10
# pods	26	113	120	95	60	42	21	14	5	4

$x_m = 10$
 $x_0 = 1$
 $Range = x_m - x_0 = 10 - 1 = 9$
Range coefficient of dispersion
$$= \frac{x_m - x_0}{x_m + x_0} = \frac{10 - 1}{10 + 1} = \frac{9}{11}$$

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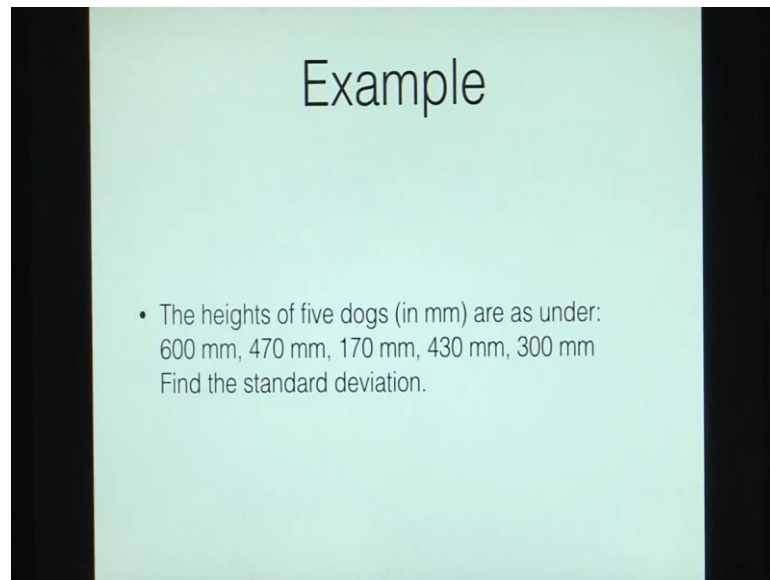
Standard deviation

- “the positive square root of the mean of the square deviations taken from arithmetic mean of the data”

$$s = \sqrt{\frac{\sum (X - \bar{X})^2}{N}}$$

We also looked at standard deviation S, S defined as square root of sum of the squared of a deviations around the mean divided by the total number of values.

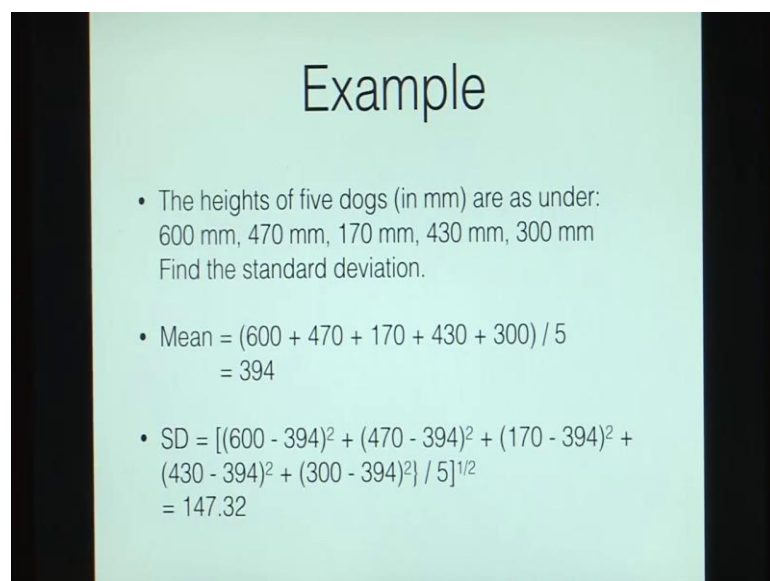
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Example

- The heights of five dogs (in mm) are as under:
600 mm, 470 mm, 170 mm, 430 mm, 300 mm
Find the standard deviation.

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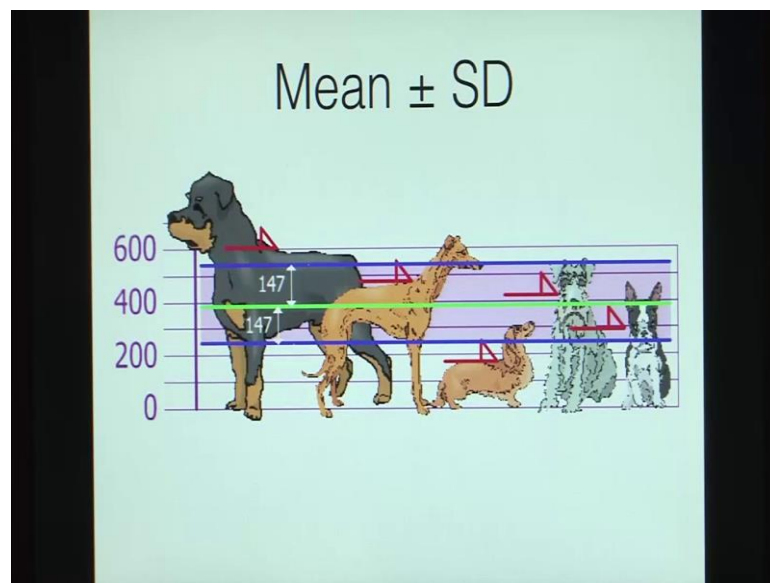


Example

- The heights of five dogs (in mm) are as under:
600 mm, 470 mm, 170 mm, 430 mm, 300 mm
Find the standard deviation.
- Mean = $(600 + 470 + 170 + 430 + 300) / 5$
= 394
- SD = $[(600 - 394)^2 + (470 - 394)^2 + (170 - 394)^2 + (430 - 394)^2 + (300 - 394)^2] / 5$ ^{1/2}
= 147.32

We also calculated some examples and we also looked at, what it means in the physical sense.

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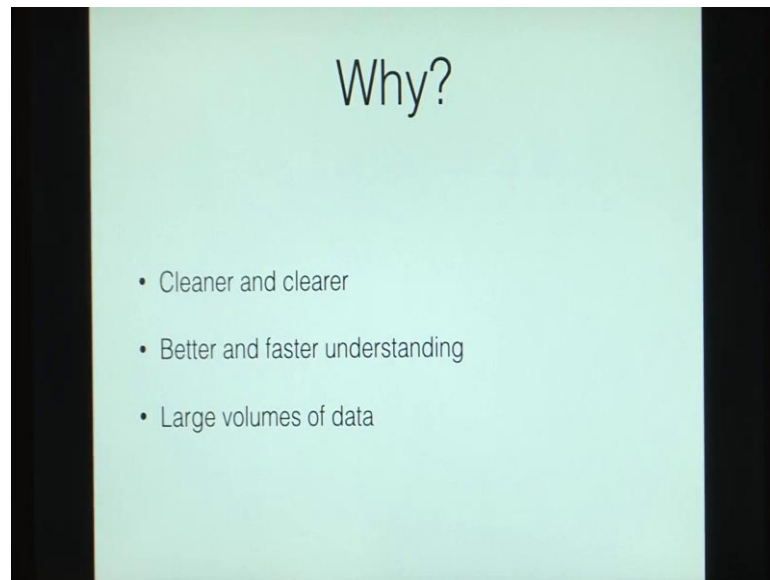
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5. Graphical presentation of data

Dr. Ankur Awadhiya, IFS

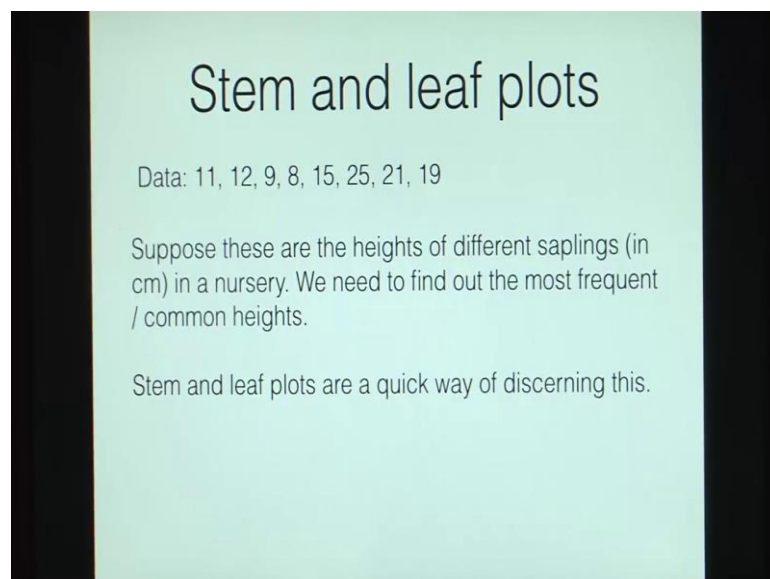
Next we looked at the graphical presentation of data.

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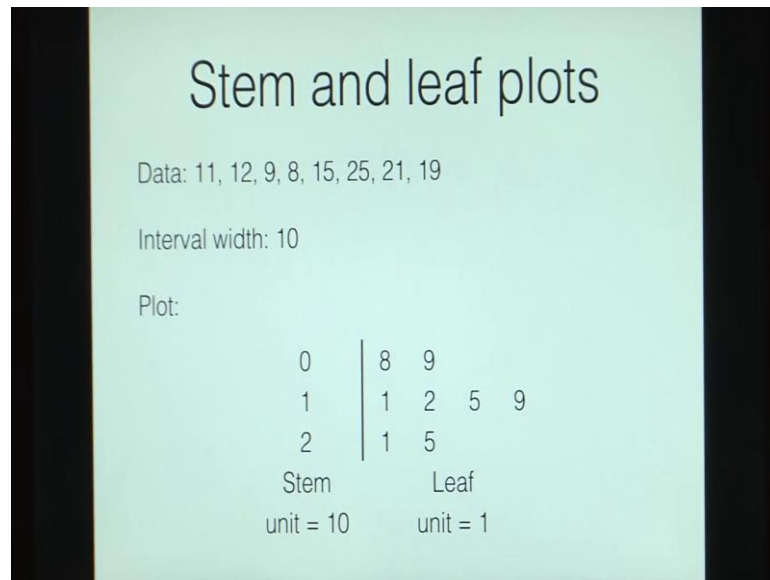
So graphical presentation is used because it is clearer and cleaner, it permits better and faster understanding and you can show large volumes of data to be processed very quickly.

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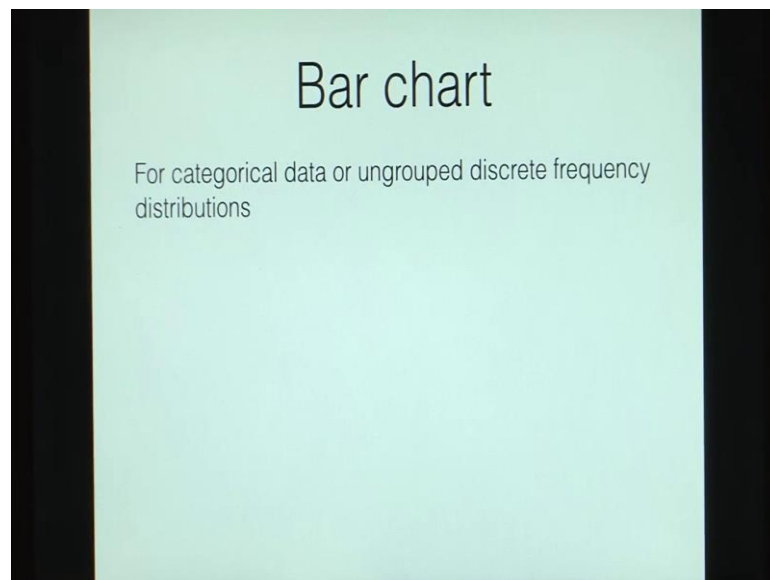
So, we looked at stem and leaf plots.

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So for instance here we developed stem and leaf plot from this data, and we were able to say that this value is showing a. So, this a width of 10, values between 10 to 20 are the most frequent values in this case.

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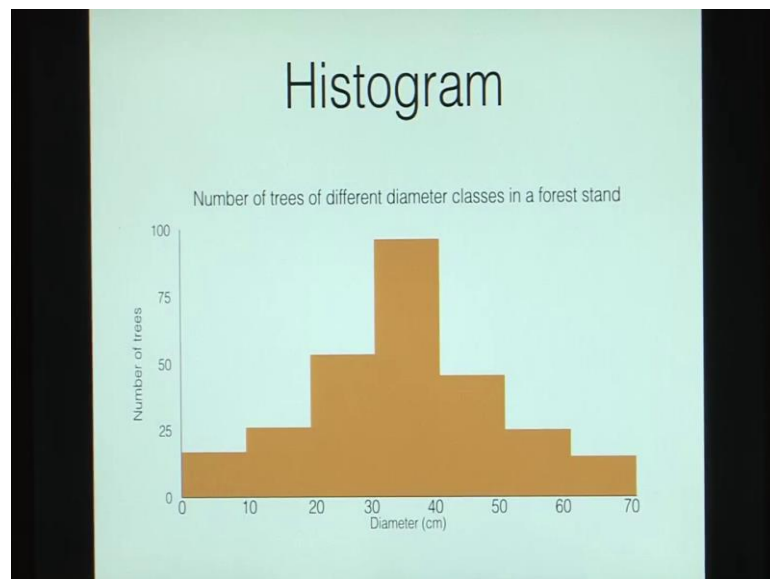
We also looked at bar charts.

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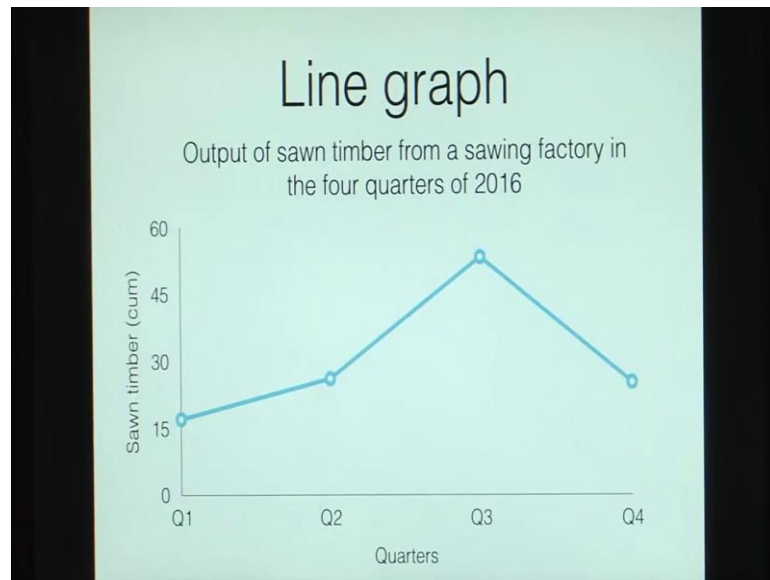
Histograms.

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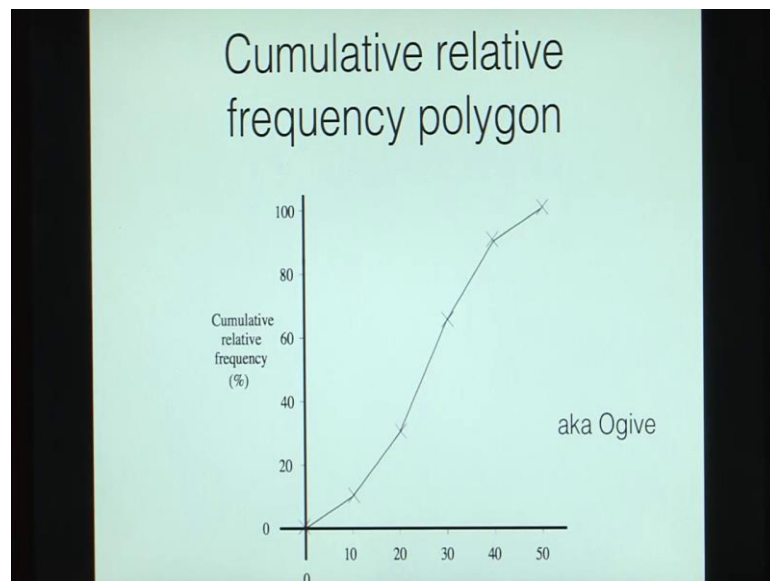
Line graphs.

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A cumulative.

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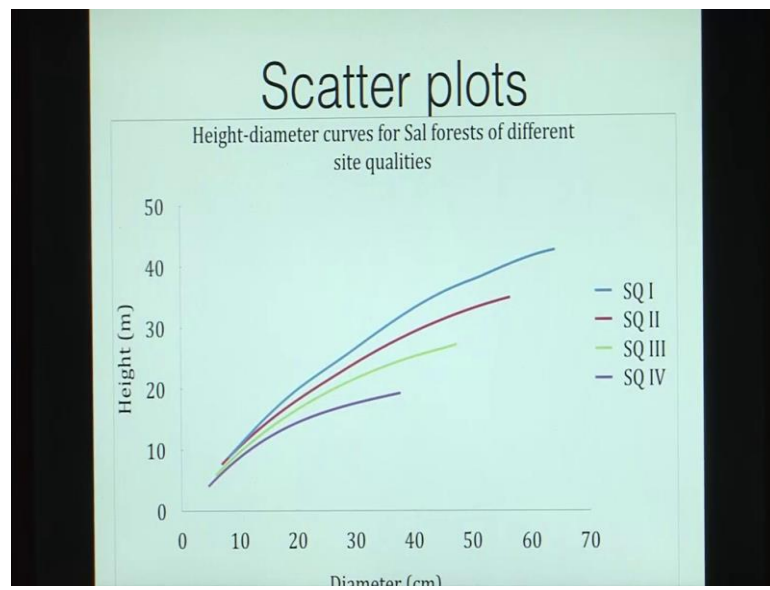
Relative frequency polygons or Ogives multiple bar charts.

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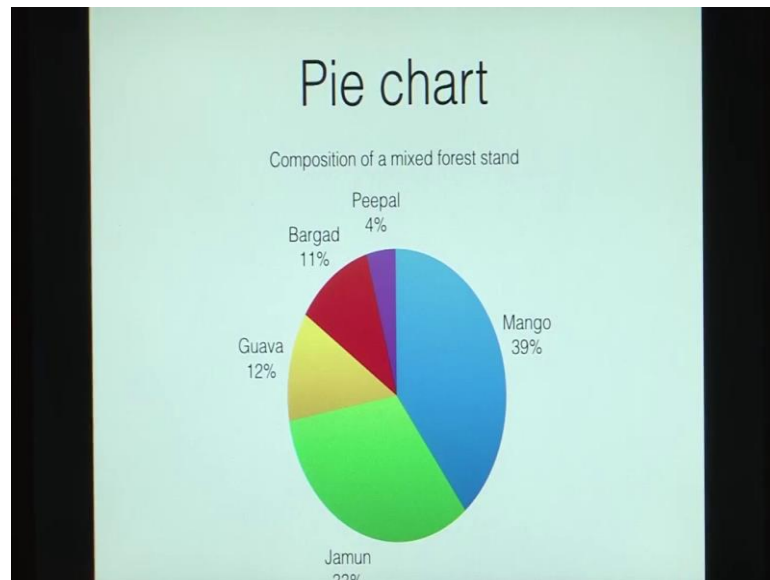
Scatter plots.

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That we have used later on, and also pi charts.

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6. Shape of a tree: Form and Taper

Dr. Ankur Awadhiya, IFS

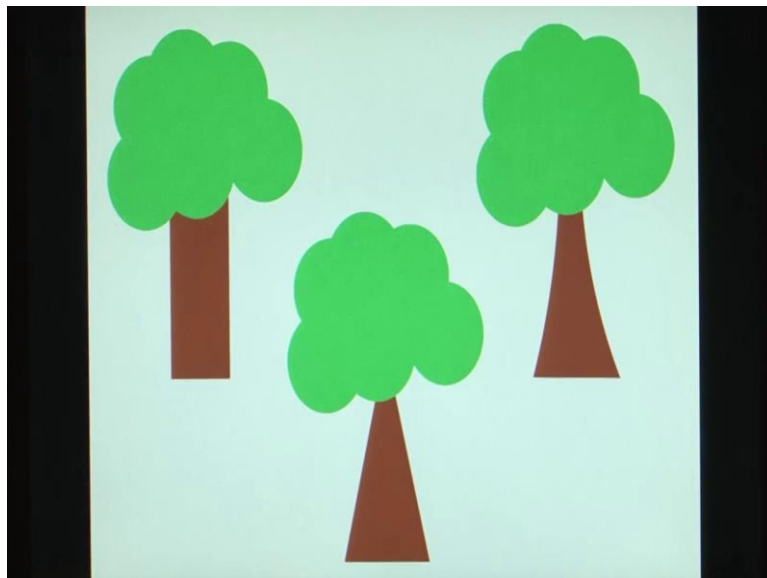
Next we went to see the shape of a tree in the form of its form and taper.

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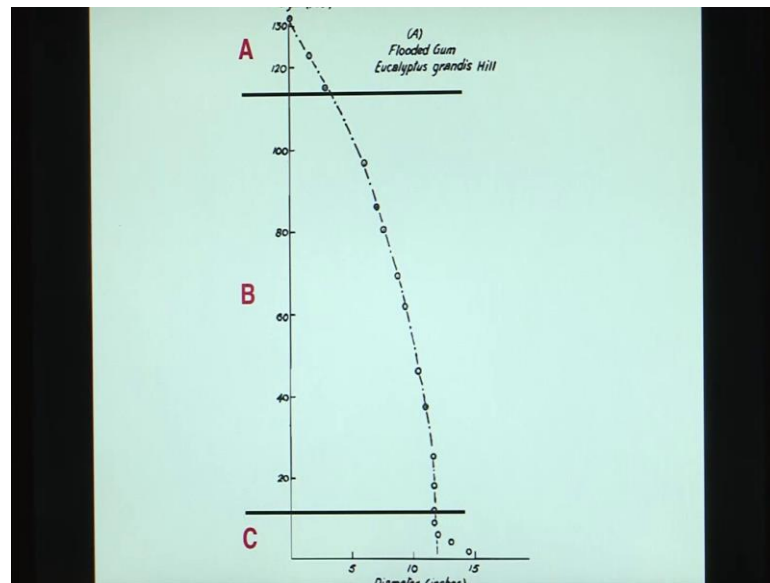
So, essentially if you look at any tree the diameter goes on reducing as you go upwards.
So, that is known as a taper.

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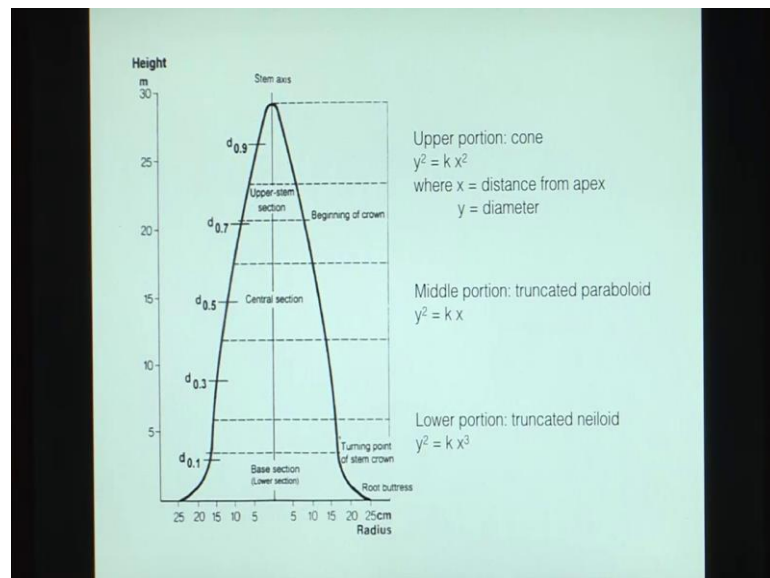
And form refers to the shape of a tree.

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So, a shape of a tree is found out by plotting it is a diameters at various heights, and we saw that we could divide a tree into three portions the upper is.

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The conical portion followed by a paraboloid portion, followed by a neiloid portion or it could error truncated neiloid portion.

(Refer Slide Time: 10:10)

Tree form

'Form' refers the shape of a solid, the diameter / height curve of which is determined by the power index of x in the equation:

$$y^2 = k x^n$$

So, tree form is the shape of the tree which is the index of X in this equation, Y square is equal to k X to the power of n.

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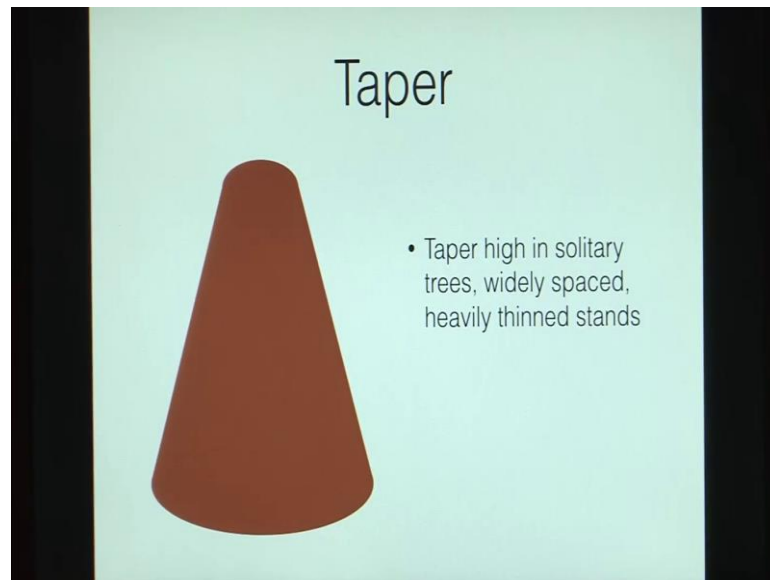
Taper



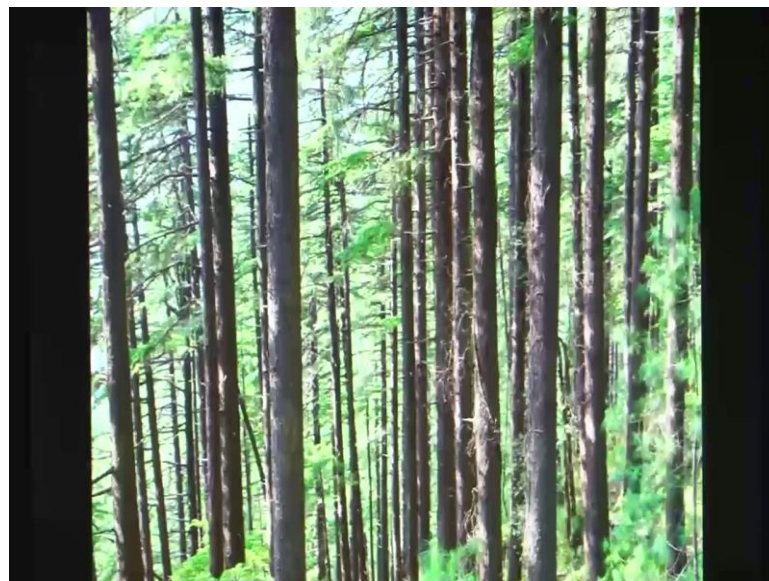
- 'Taper' refers to the rate of narrowing in diameter in relation to increase in height of a given 'shape' or 'form'.
- Expressed as centimetre per metre stem length

Taper is the rate of narrowing and we saw that a taper varies in different conditions in if trees are close together.

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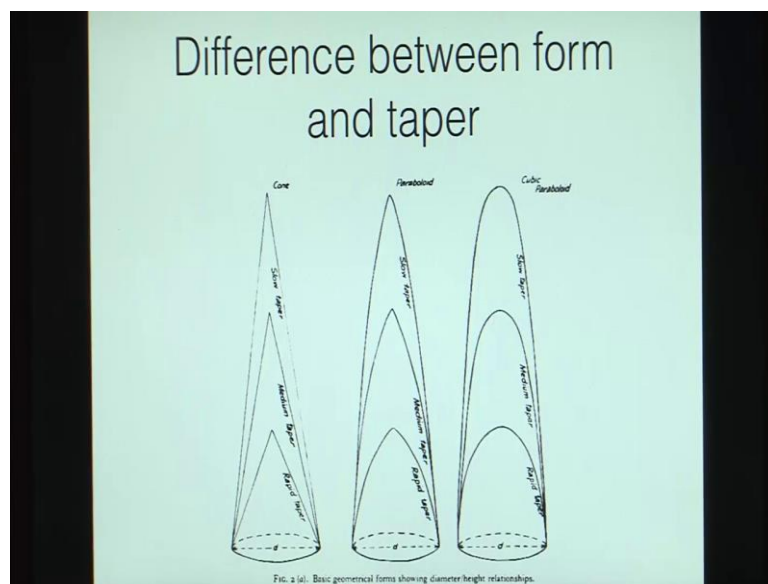


Then your taper will be less; whereas, on a windy location the taper will be high.

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We looked at the differences between form and tapers. So, essentially form tells you the shape of figure and taper tells you how quickly or how slowly does that shape go towards a point.

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Theories of tree form

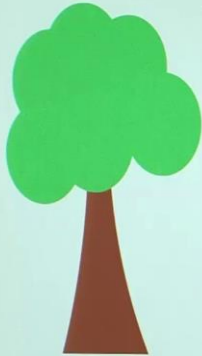
1. Nutritional theory and Water conducting theory:
The form is related to the need of a tree to transport water and nutrients within the tree
2. Hormonal theory: Growth substances (hormones) originate in the crown and are distributed around and down the bole, causing radial growth and affecting tree form
3. Metzger's beam theory: Mechanistic theory

Then we looked at theories of tree form nutritional and water conducting theories hormonal theory and the Metzger's beam theory.

So, in the case of nutritional theory and water conducting theory, the form is related to the need of a tree to transport water and nutrients within the tree, in the case of hormonal theory the hormones are generated at the tip of the tree and then they are distributed down and around the bole which causes difference in its growth and we also looked at Metzger's mechanistic beam theory.

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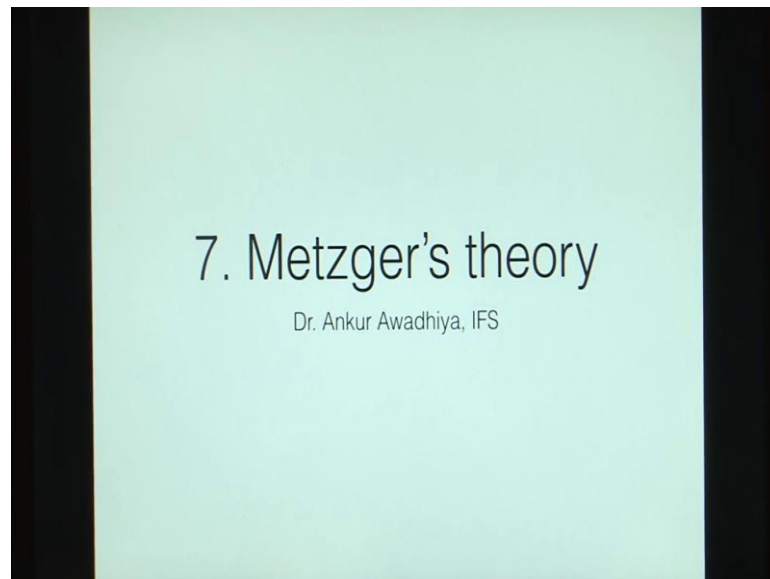
Factors affecting the stem profile of individual trees



- social position within the stand
- site
- silvicultural treatments, including
 - stand density
 - planting espacement
 - fertiliser treatment
- genetic parameters

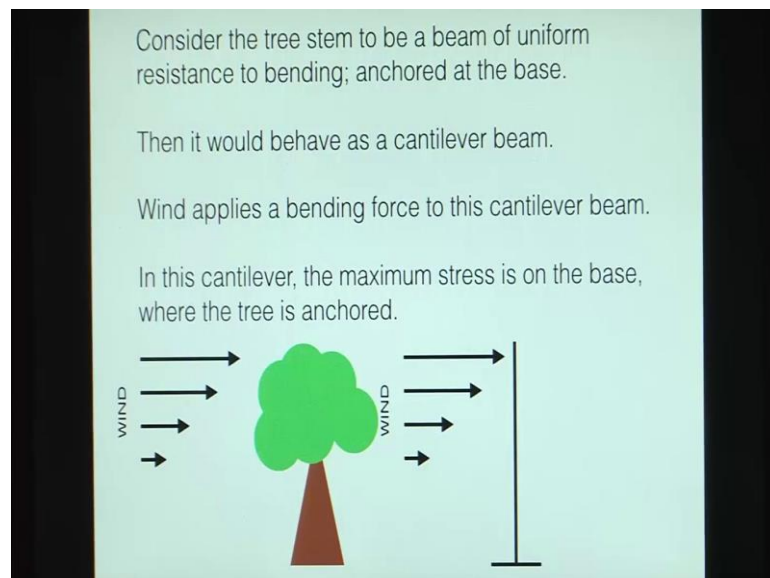
Then we saw a different factors can affect the stem profile of individual trees.

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Next we went into Metzger's theory in greater detail.

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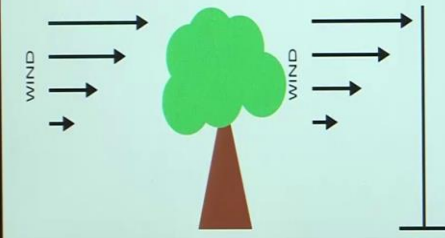
So, in this case a your tree was a considered to be a beam of uniform resistance to bending that is anchored at the base. So, it acts as a cantilever beam, and this beam is subjected to wind pressures and these pressures lead to stresses and because your tree has this uniform resistance to bending. So, it can be toppled to its side and the maximum amount of stress will be at the base.

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Thus, the tree needs to reinforce this point by adding more materials.

As we move upwards, away from the base, the stresses are lower. Thus, the tree needs lesser reinforcements at upper locations.

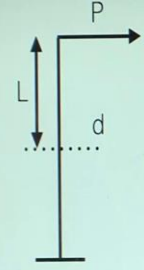
This results in a tapered form of the tree stem.



The diagram shows a green tree with a brown trunk on the left and a black tapered beam on the right. Both are subjected to horizontal wind forces represented by arrows labeled 'WIND'. The tree's trunk is wider at the base and tapers towards the top, while the beam is a simple tapered rod.

And to counteract that your tree goes on depositing substances near the base. So, the base becomes broader, the diameter goes on increasing towards the base and decreasing towards the top.

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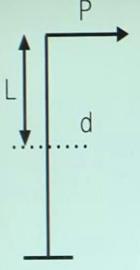
P: force applied at free end
L: distance of a given cross-section from the point of application of force
d: diameter of beam at the point

Then, bending stress is given by

$$S = \frac{32 P \times L}{\pi \times d^3}$$

Then we also looked at how we can derive the shape of a tree by using this mechanistic beam theory. So, we looked at this stress.

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P: force applied at free end
L: distance of a given cross-section from the point of application of force
d: diameter of beam at the point

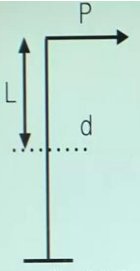
Now, P is given by

$$P = W \times A$$

where W = wind pressure per unit area
A = crown area

Now a pressure is given by your wind pressure multiply. So, your force is given by wind pressure multiplied by the area.

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P: force applied at free end
L: distance of a given cross-section from the point of application of force
d: diameter of beam at the point

Thus, $S = \frac{32 P \times L}{\pi \times d^3} = \frac{32 \times W \times A \times L}{\pi \times d^3}$

Since the material is considered homogeneous, S is constant.

Thus, $d^3 = k \times L$ (Cubic paraboloid)

And we use that to get the shape of a tree in the form of a cubic paraboloid and we used Metzger theory to explain why these trees are having a less amount of taper.

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Thus, the shape of a tree bole is given by a cubic paraboloid:

$$d^3 = k \times L \text{ (Cubic paraboloid)}$$

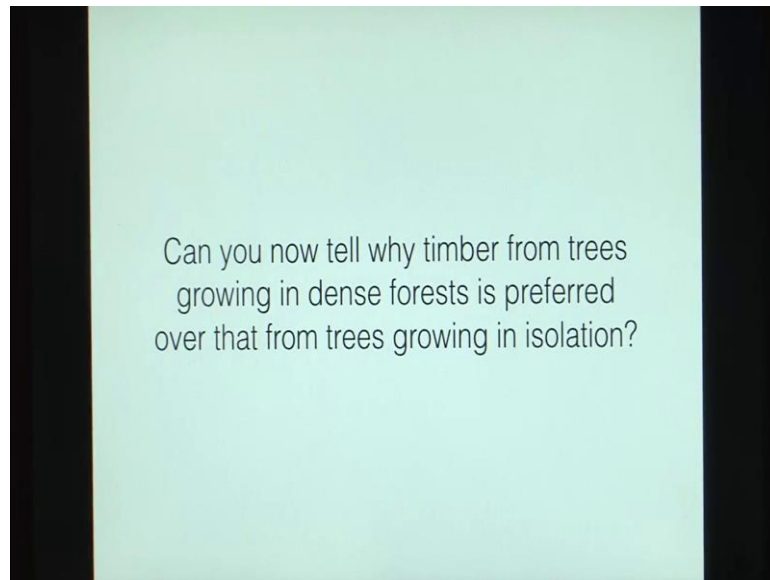
Metzger confirmed this for many stems, particularly of conifer species.

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Applications

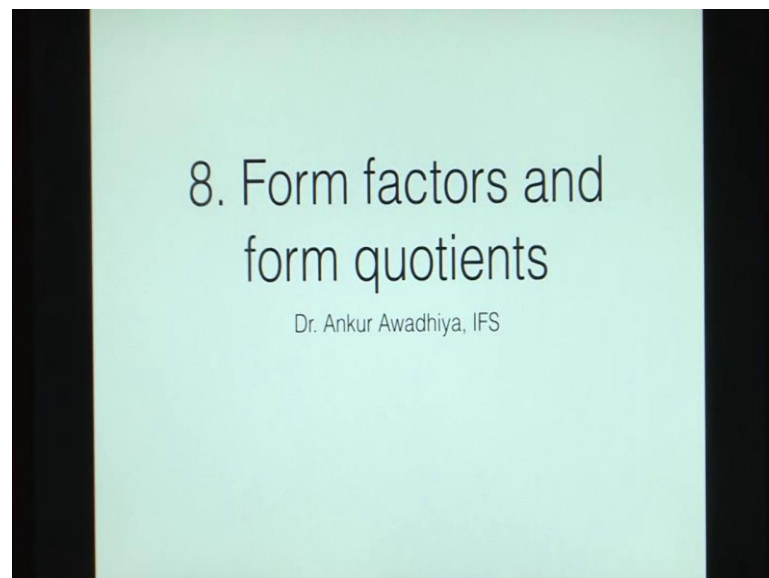
- Trees growing inside a dense forest will have less wind pressure \Rightarrow longer and cylindrical bole
- Trees growing in isolation, especially in windy locations will have greater wind pressure \Rightarrow shorter, tapered bole

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Whereas this tree is having a greater amount of taper and this is also used in the case of forest management because trees that are growing in dense forest have very less amount of taper they are more cylindrical and. So, more volume of material from that tree can be utilized and so, they are preferred over trees that are growing in isolation.

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In the next class we looked at form factors and form quotients.

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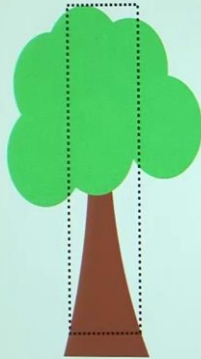
Form factor

- Summary of tree shape
- Represents the ratio of the volume of the tree to the volume of a specified geometrical solid of similar height and basal diameter
- The geometrical solid is generally a cylinder
- So, form factor = $\frac{\text{Volume of tree}}{\text{Volume of cylinder}}$

So, we used form factor as a summary of the tree shape, and we defined it as the volume of the tree divided by volume of a cylinder. From where do we take the values of the diameter and height of that cylinder gives us different kinds of form factors.

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Form factor



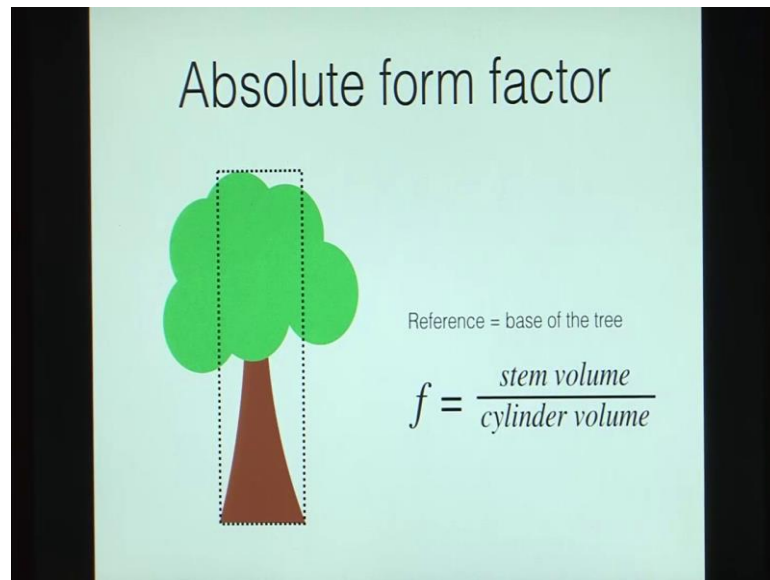
The form factor of a tree or stem is defined as stem volume, expressed as a proportion of the volume of a cylinder of the same height, with a diameter equal to the stem diameter at the selected reference point:

$$f = \frac{\text{stem volume}}{\text{cylinder volume}}$$

Used due to the ease of measuring the cylindrical values

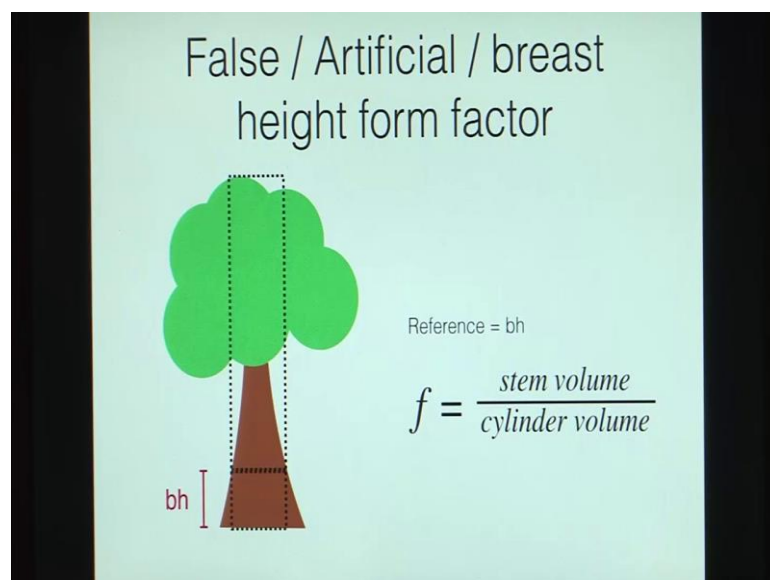
So, form factors stem volume by the cylinder volume we took.

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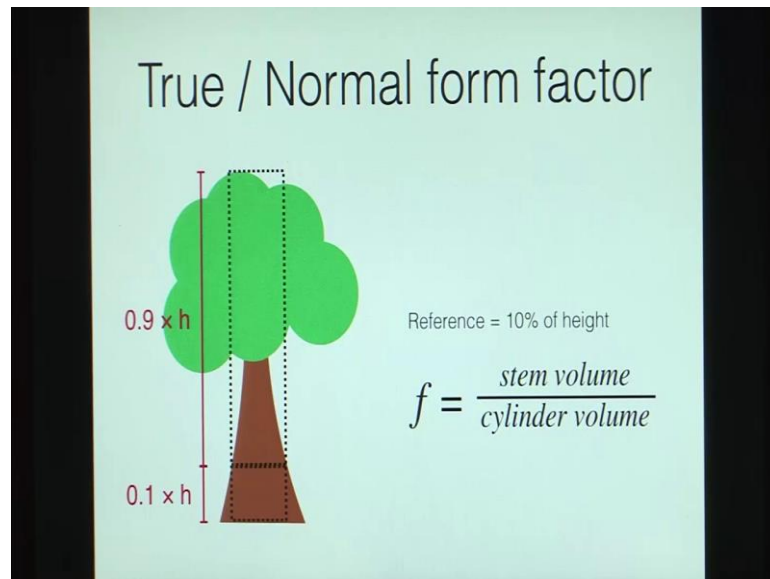


The absolute form factor in which your basis of your cylinder is taken at the base of the tree or the reference is taken at the base of the tree will look at the artificial form factor that is the most commonly utilized form factor also called as the false form factor or the base the breast height form factor, in which your reference was a cross section at the breast height.

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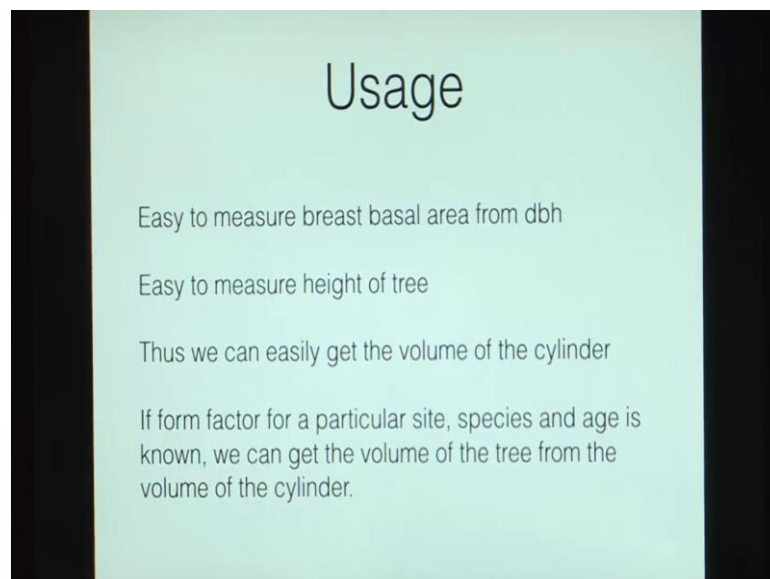


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We also looked at true or normal form factor in which you are reference was a percentage of the height and what is the utility of form factors?

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Well it is easy to measure the breast basal area from your dbh it is easy to measure the height of the tree. So, we can get the volume of the cylinder and if you know the form factor, then we can get to the volume of the tree itself.

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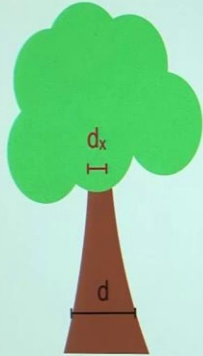
Specific breast height form factors

Shape	FF
Cylinder	1
Neiloid	0.25 (0.2 - 0.3)
Conoid	0.33 (0.3 - 0.45)
Quadratic paraboloid	0.5 (0.45 - 0.55)
Cubic paraboloid	0.6 (0.55 - 0.65)

So, we also looked at specific breast height form factors next we defined.

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Form quotient



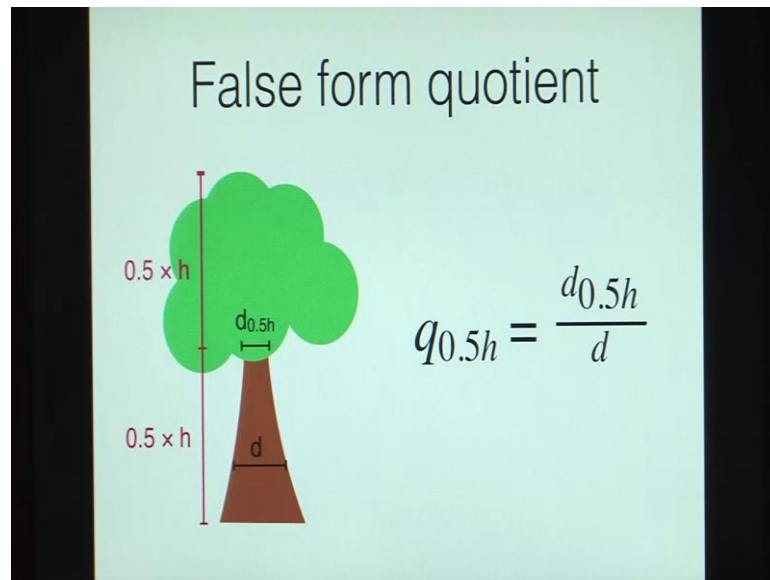
A single number depicting the rate of decrease in stem diameter; a ratio of diameter at two different places on the tree

$$q = \frac{d_x}{d}$$

To a form quotient as a single number that depicts the rate of decrease in a stem diameter.

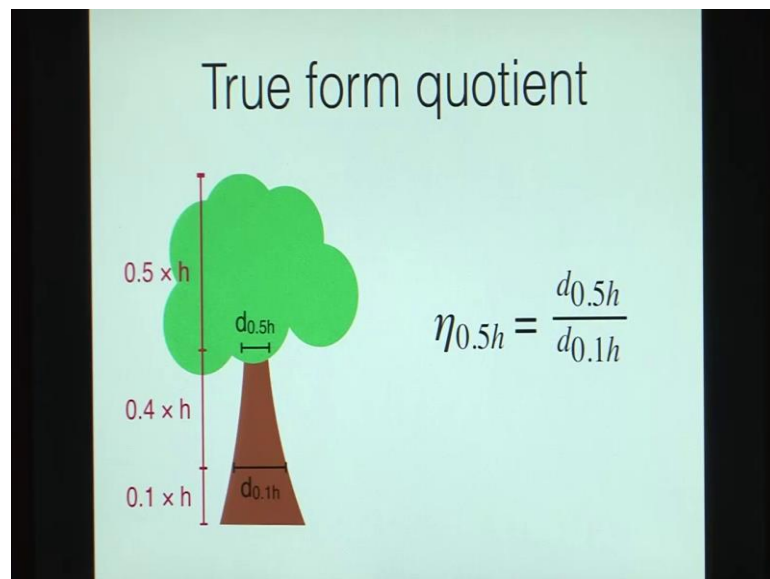
So, it is the ratio of the diameter at two different places on the tree. So, we defined false form.

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Quotient as your diameter at half the height we defined two form.

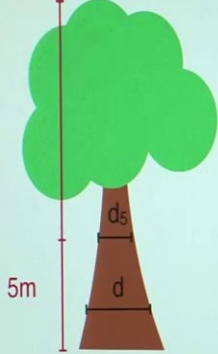
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Quotient as the ratio of two diameters at two difference percentages we also looked at Mitscherlich form quotient and also Hohenadl's form quotient.

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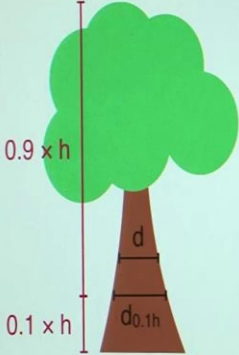
Mitscherlich form quotient


$$q_M = \frac{d_5}{d}$$

Used for merchantable trees

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Hohenadl's form quotient


$$q_H = \frac{dbh}{d_{0.1h}}$$

> 1 if tree height > 13 m
Affected by age

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Problem

For a *Pinus patula* tree with dbh = 45.6 cm, height = 27.4 m and total stem volume of 1.782 cum, the bole diameters at various heights are given in the next slide. Find the

1. True form quotient
2. False form quotient
3. True form factor
4. False form factor

Then we looked at a problem statement in which we were given the dBh height, and the stem volume and the diameters at various heights and we were able to calculate the form quotients and the form factors.

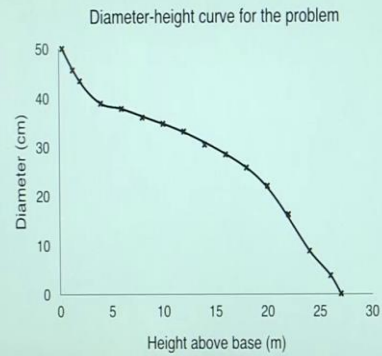
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Height (m)	Diameter (cm)	Height (m)	Diameter (cm)
0.3	50	14	30.3
1.3	45.6	16	28.3
2	43.4	18	25.6
4	38.8	20	21.9
6	37.7	22	16.1
8	35.9	24	8.7
10	34.6	26	3.7
12	33	27	0

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Solution

We plot the diameter-height curve:



By plotting it, getting the presentative diameters at different height and then getting the form factors and the form quotients.

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Next, we find the interpolated diameters at various heights:

$$d_{0.1h} = 40.2 \text{ cm}$$

$$d_{0.5h} = 30.7 \text{ cm}$$

We already know that $d = 45.6 \text{ cm}$. Thus,

$$\text{False form quotient, } q_{0.5h} = \frac{d_{0.5h}}{d} = \frac{30.7}{45.6} = 0.673$$

$$\text{True form quotient, } \eta_{0.5h} = \frac{d_{0.5h}}{d_{0.1h}} = \frac{30.7}{40.2} = 0.76$$

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- Volume of cylinder with reference diameter 45.6 cm (dbh) and height 27.4 m, $V_F = \pi / 4 \times (0.456)^2 \times 27.4 = 4.47$ cum
- Volume of cylinder with reference diameter 40.2 cm ($d_{0.1h}$) and height 27.4 m, $V_T = \pi / 4 \times (0.402)^2 \times 27.4 = 3.48$ cum
- Actual volume of the tree, $V = 1.782$ cum
- Thus, true form factor = $V / V_T = 1.782 / 3.48 = 0.512$
- And false form factor = $V / V_F = 1.782 / 4.47 = 0.399$

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9. Taper equations

Dr. Ankur Awadhiya, IFS

Next we looked at taper equations. So, taper is defined as the Change in stem diameter between 2 points, divided by the length of the stem between those 2 points.

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Taper and taper equations

Taper is the rate of change in stem diameter, often calculated as

$$\text{Taper} = \frac{\text{Change in stem diameter between two points}}{\text{Length of the stem between the two points}}$$

Taper equations try to describe taper as a function of tree variables, viz. dbh, height, etc.

And we looked at these taper equations in which you are a diameter at different heights was given in terms of diameter at the reference height mostly the breast height.

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In its simplest form, taper can be mathematically expressed as (Ormerod, 1973)

$$\frac{d}{D_r} = \left(\frac{H-h}{H-H_r} \right)^b$$

where d = diameter measured at height h
 D_r = diameter measured at a reference height (usually breast height)
 h = height of diameter d
 H_r = reference height (usually breast height, 1.3 m or 4.5 ft)
 H = total tree height
 b = taper coefficient

In the form of this equation in which we measured height and we took the height of the reference and the height of the tree.

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Volume calculation from
taper equation

If $d = f(D, H, h)$

Volume is given by: $V = \int_{h_1}^{h_2} \frac{\pi}{4} d_i^2 dh_i$

So, $V = \int_{h_1}^{h_2} \frac{\pi}{4} [f(D, H, h)]^2 dh_i$

So, a taper equation is useful because you can calculate volume from the taper equation and it can be.

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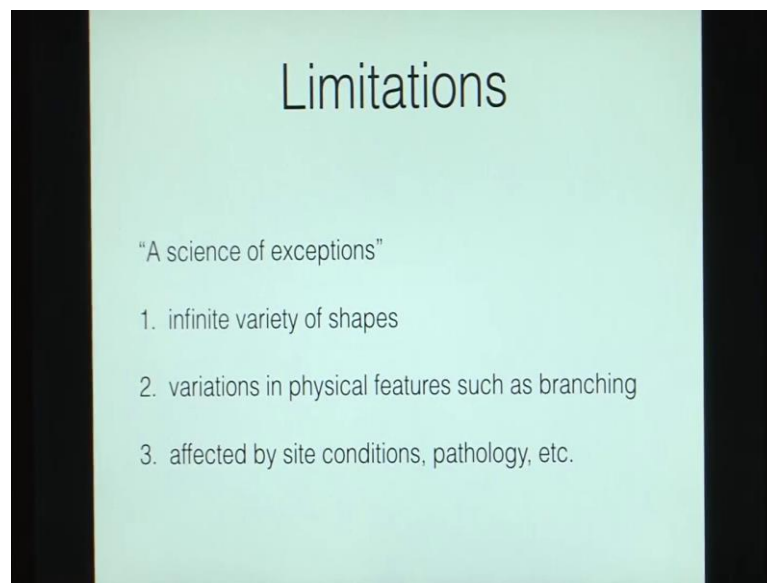
Use

Taper equations can be used to predict

1. stem diameter at any point of the stem
2. individual log volume
3. total stem volume
4. merchantable stem height
5. merchantable stem volume

Used to predict a number of things for instance if your tree is decreasing in diameter as we go up. So, if we want to measure the length of your of the commercial timber we can get it from there, if you wanted to get the volume of commercial timber we can get it from there individual log volume stem volume merchantable stem height and so on can be found out using the taper equations.

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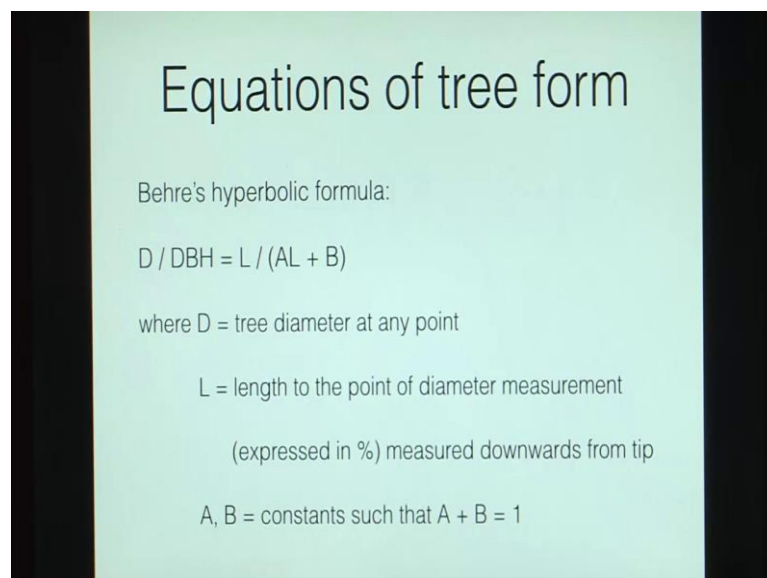
Limitations

"A science of exceptions"

1. infinite variety of shapes
2. variations in physical features such as branching
3. affected by site conditions, pathology, etc.

However it has some limitations because of the exceptions we also looked at.

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Equations of tree form

Behre's hyperbolic formula:

$$D / DBH = L / (AL + B)$$

where D = tree diameter at any point

L = length to the point of diameter measurement
(expressed in %) measured downwards from tip

A, B = constants such that $A + B = 1$

Equations of tree form in which we looked at two major equations one was Behre's hyperbolic formula and the second one was Hojer's formula.

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Timber form factor table

Height class (ft)	Sal	Chir	Deodar
41 - 50	-	-	0.17
51 - 60	0.16	-	0.23
61 - 70	0.20	0.24	0.29
71 - 80	0.24	0.33	0.32
81 - 90	0.28	0.34	0.34
91 - 100	-	0.35	0.36

And we also looked at some form factor table and the taper tables.

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Taper table

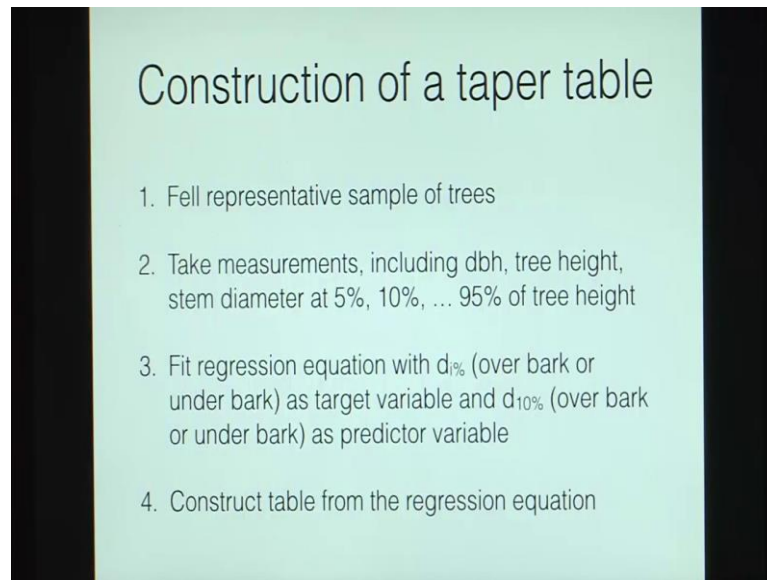
Presents stem diameter at different heights in the form of a ready-reckoner table

Types:

1. False taper table: Gives diameters at fixed distances from the base of the tree
2. True taper table: Gives diameters at relative distances from the base of the tree

So, in the case of taper tables we have two kinds of taper tables false taper tables and the true taper tables.

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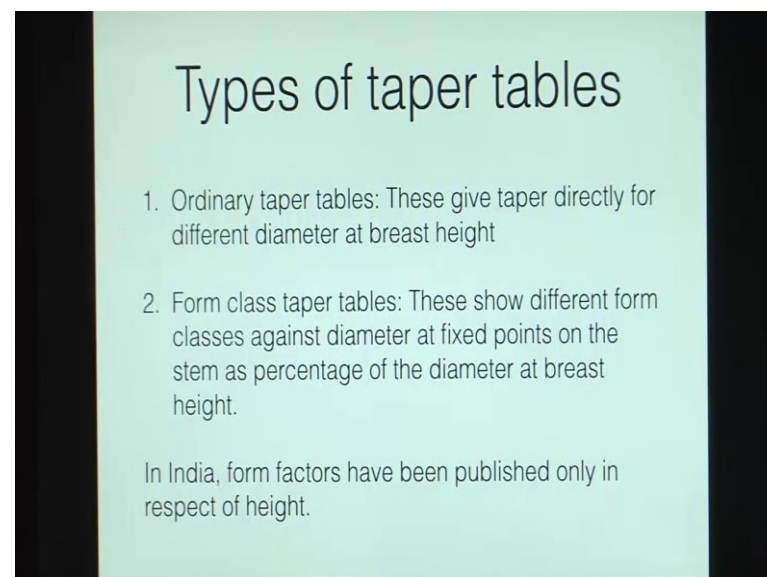


Construction of a taper table

1. Fell representative sample of trees
2. Take measurements, including dbh, tree height, stem diameter at 5%, 10%, ... 95% of tree height
3. Fit regression equation with $d_{i\%}$ (over bark or under bark) as target variable and $d_{10\%}$ (over bark or under bark) as predictor variable
4. Construct table from the regression equation

We also saw how a taper table is constructed and they are also of two other way another way of classifying the taper tables, is in these two types ordinary taper tables and form class taper tables.

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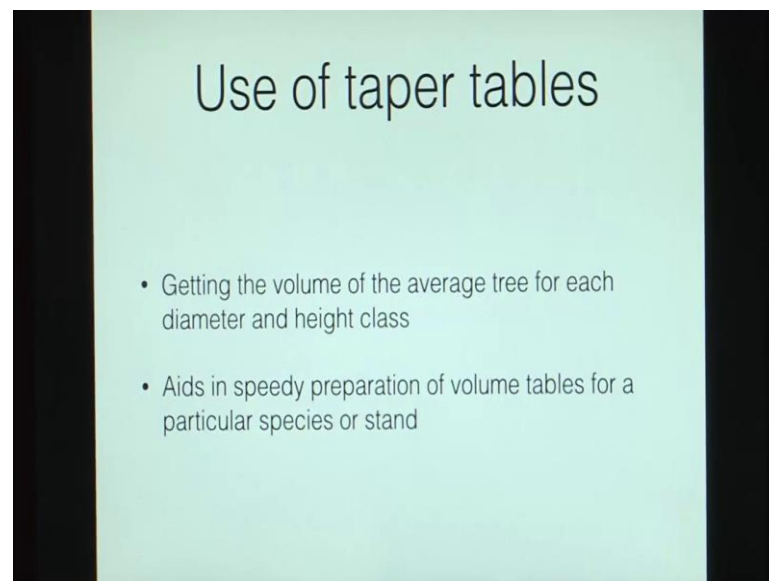


Types of taper tables

1. Ordinary taper tables: These give taper directly for different diameter at breast height
2. Form class taper tables: These show different form classes against diameter at fixed points on the stem as percentage of the diameter at breast height.

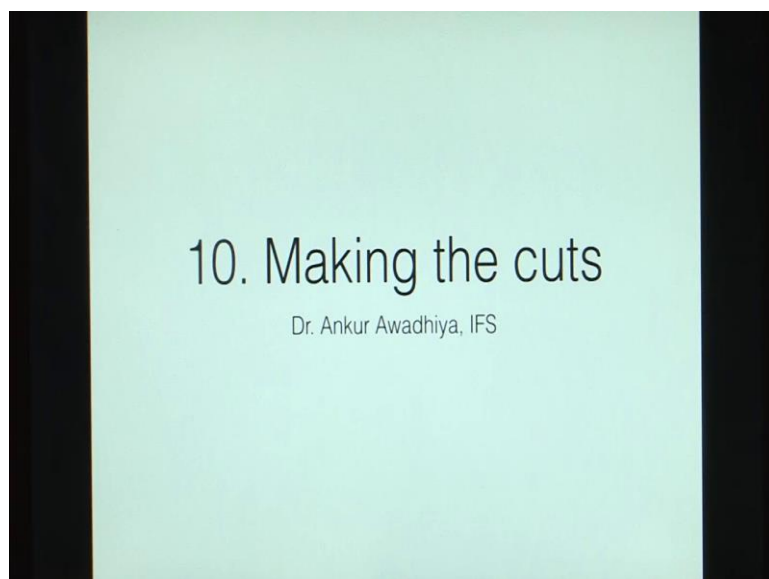
In India, form factors have been published only in respect of height.

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And then it is the use of taper tables is to get the volume of an average tree from each diameter and height class, and thus two to prepare a volume table. So, volume table we also looked into greater detail later in the course.

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At making the cuts.

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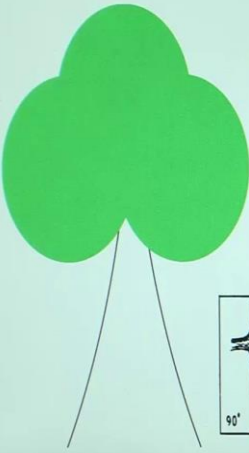
Why tree form?

1. Management for biomass / C-fixation
2. Management for maximum income
3. Management for highest net return on investment
4. Technical management: crop should yield the maximum material of a specified size or suitability for economic conversion or for special use
5. Management for biodiversity? Need to know inputs for various organisms

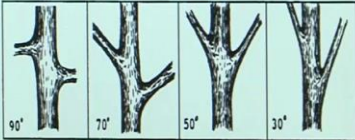
So, why do we go for a tree form what is the perfect tree form.

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Perfect tree form



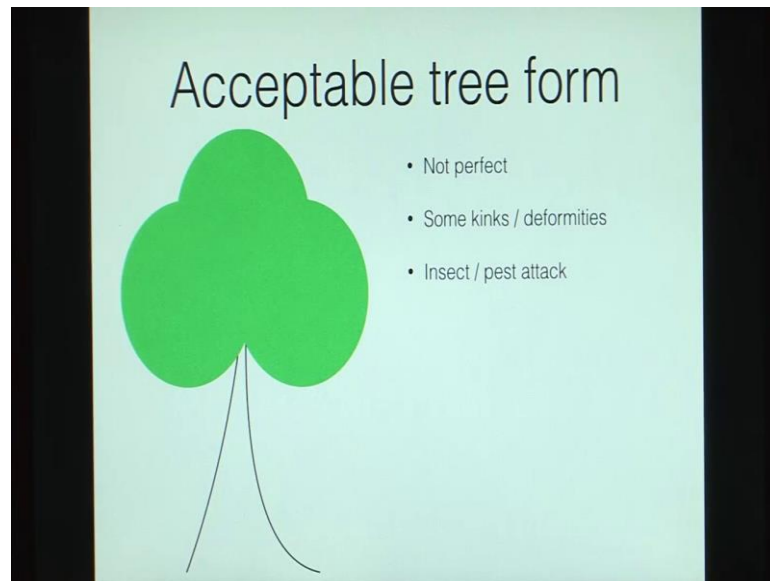
- Straight bole
- Thin branches
- No apparent defect
- No forking
- Wide branching angles



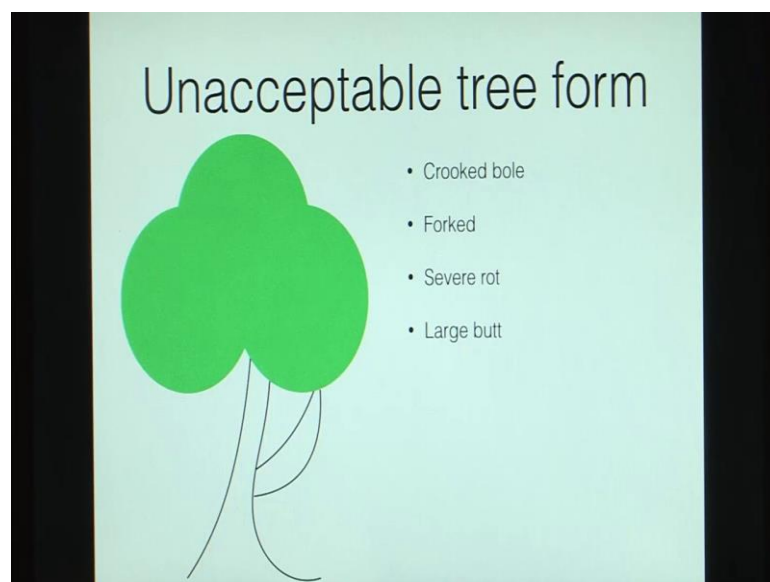
The diagram illustrates the concept of a 'perfect tree form'. It features a stylized tree with a straight, vertical bole and three rounded, green canopies. To the right of the tree, a list of characteristics defines the perfect form: a straight bole, thin branches, no apparent defects, no forking, and wide branching angles. Below this list, four small diagrams show different branching angles: 90°, 70°, 50°, and 30°. The 90° angle shows a horizontal branch, while the 30° angle shows a very steep branch. The 70° and 50° angles represent intermediate branching angles.

So, a perfect tree form is a tree in which your tree has a straight bole thin branches no apparent defect no forking and wide branching angles. So, that maximum amount of the volume of this tree is usable we also looked at acceptable tree forms and unacceptable tree forms.

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And then we looked at this problem in which we learnt how a tree is cut for measurement purposes.

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Example

A tree has a height of 11 m. Its diameter at different heights is as follows:

$dbh = 31$ cm
 $d_{4.24m} = 23$ cm
 $d_{7.24m} = 14$ cm
 $d_{8.74m} = 9$ cm

Calculate the volume of the tree.

This is the standard way a tree is cut for measurement purposes.

So, we measured diameters at these reference locations we divided.

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Example

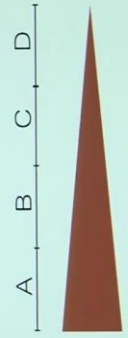
A tree has a height of 11 m. Its diameter at different heights is as follows:

$dbh = 31$ cm
 $d_{4.24m} = 23$ cm
 $d_{7.24m} = 14$ cm
 $d_{8.74m} = 9$ cm

Calculate the volume of the tree.

Solution

Consider the tree to be made up of four sections: A, B, C, D.



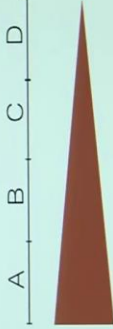
Into sections in which your first section A is twice the breast height and all the other sections are 3 meters and your top section is a cone. So, we measure these diameters and then we can calculate the volume of the tree by this method.

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The conical section D has a base diameter $d_{0.74m} = 0.09$ m and a height of 2.26 m

Thus, $V_D = (1/3) \times (\pi/4) \times d^2h$
 $\Rightarrow V_D = 0.005$ cum

Volume of the tree
 $= \Sigma$ volumes of sections
 $= V_A + V_B + V_C + V_D$
 $= 0.207 + 0.125 + 0.046 + 0.005$
 $= 0.383$ cum



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Example

Find the artificial form factor of a tree based on the following data:

dbh = 49 cm; height = 29 m; volume = 3.26 cum

Solution

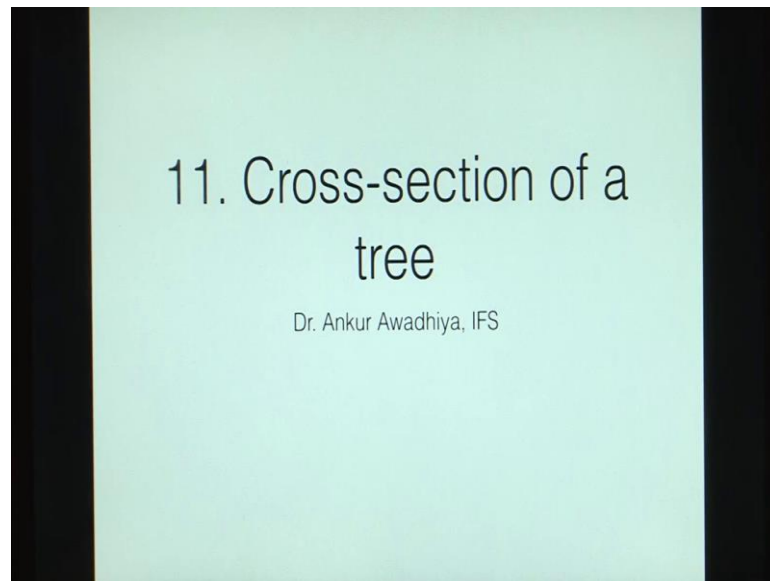
Volume of cylinder of dia 0.49 m and height 29 m,
 $V_c = \pi / 4 \times (d^2h) = 3.14 / 4 \times (0.49^2 \times 29) = 5.47$ cum

Volume of tree, $V_t = 3.26$ cum

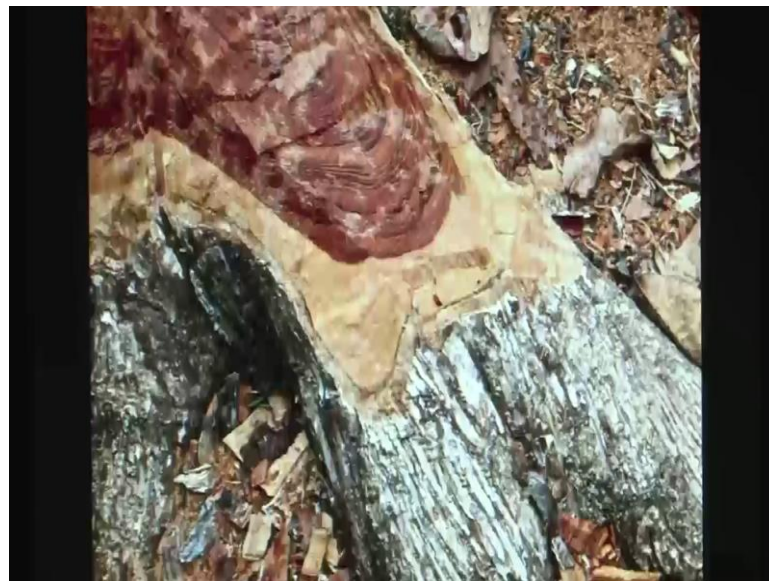
$f = V_t / V_c = 3.26 / 5.47 = 0.60$

We also looked at the calculation of artificial form factors and we also looked at the Cross section of a tree in the next lecture.

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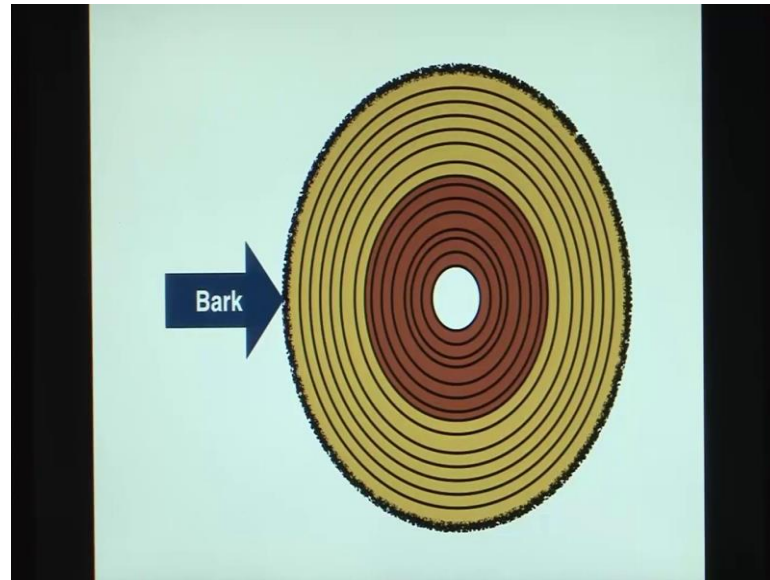


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So in the case of the cross section of a tree we saw that there is a difference of colors in this wood.

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So, in this case we have defined a number of portions. So, we bark as the outer most portion followed by. So, this is what bark is.

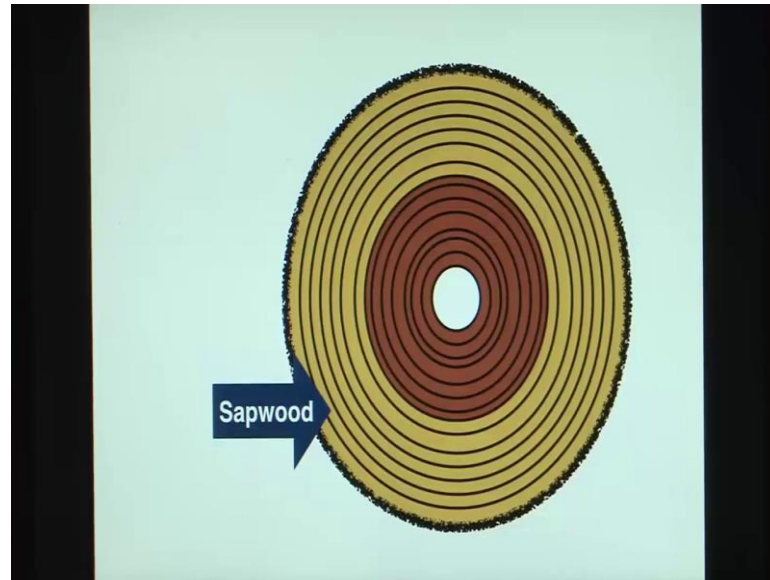
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Bark

- Outermost layers of stems and roots of woody plants
- Comprised of two parts:
 1. Outer bark: Corky, protective, made of dead and dying cells
 2. Inner bark: Living portion

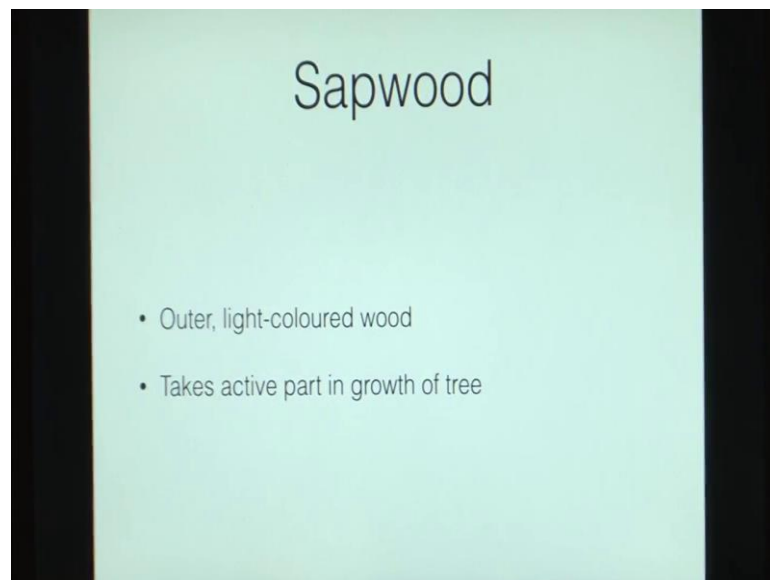
So, it is comprised of outer bark and inner bark it is followed by Sapwood.

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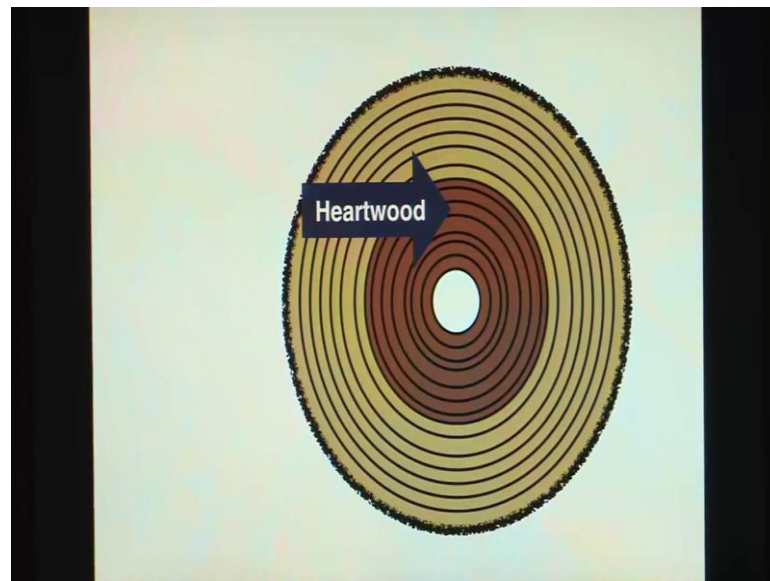
Sapwood is the light colored portion of your stem. So, in this case this is the sapwood this is the heart wood which is the darker color portion.

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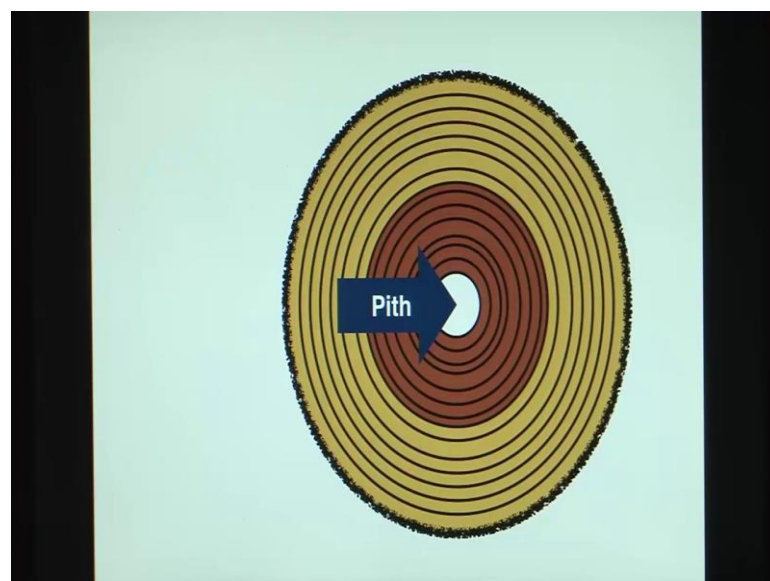


So, sapwood takes active part in the growth of the tree whereas, heartwood that is this darker portion it is a physiologically not active in the growth of the tree we also have pith.

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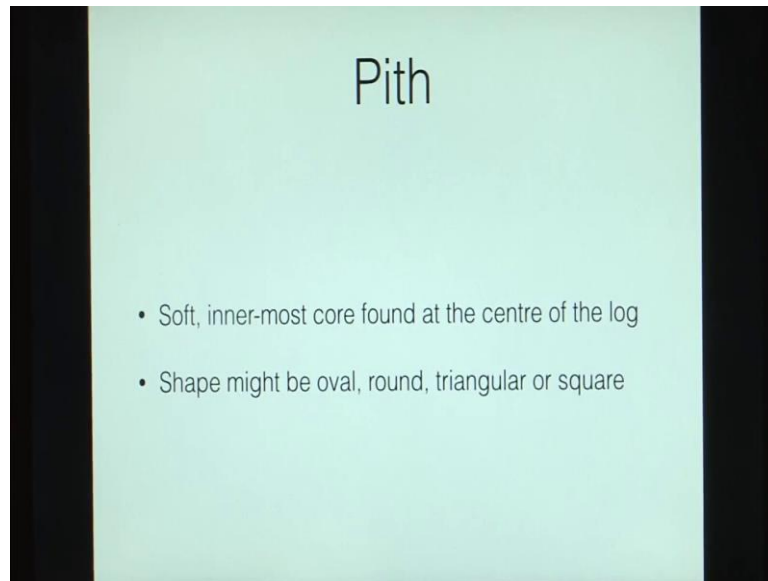


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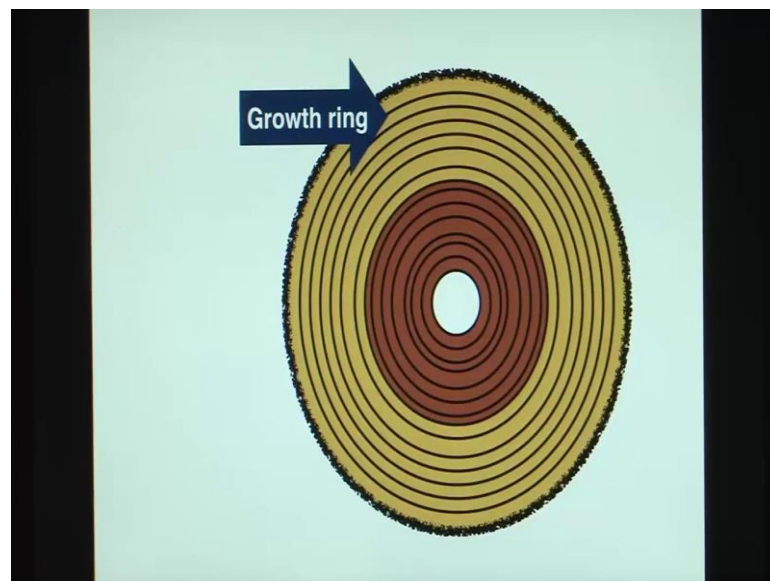


Which is the soft inner most core found at the center of the tree, and which has different shapes which might be oval, round irregular or squarish shape we also looked at growth rings, growth rings.

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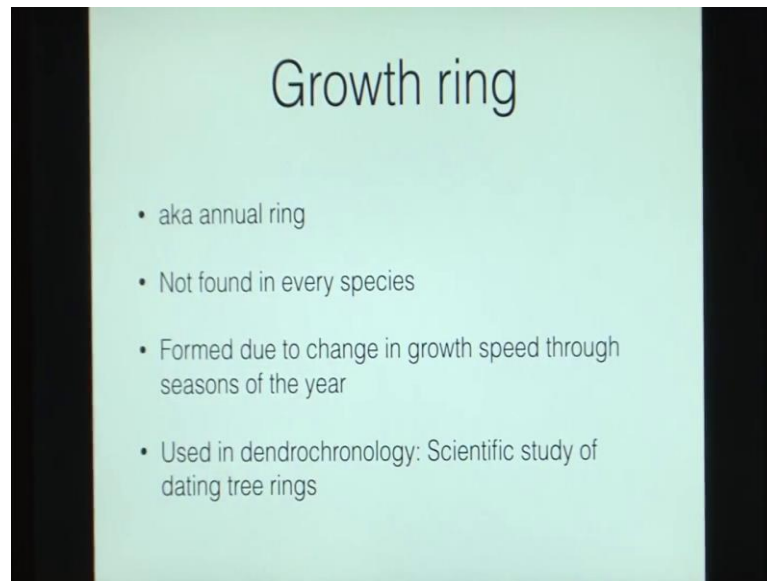


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So, in this case also you can see these rings that are formed. So, these are the growth rings growth rings are formed annually.

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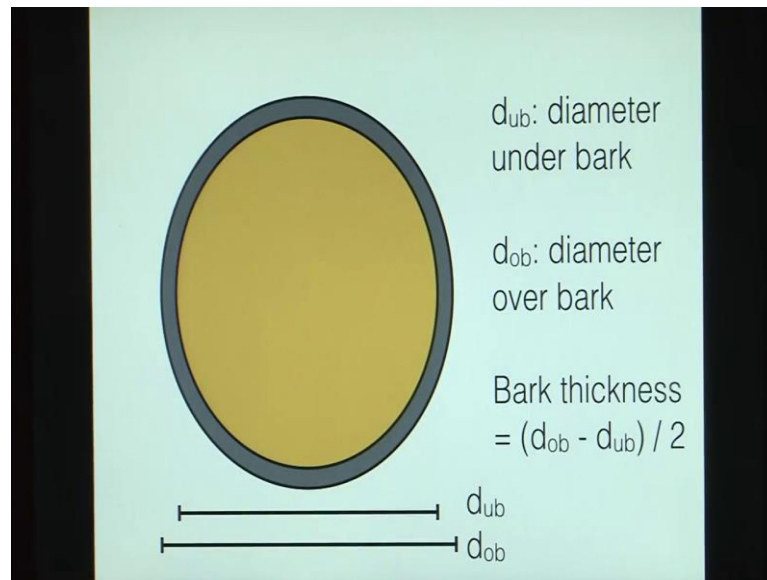
And there are also known as annual rings and they are formed because of change in growth speed during different seasons of the year, and these are used in dendrochronology which is the scientific study of dating tree rings. So, this is your tree.

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Now, when you have you have logs then you take measurements outside.

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So, you take measurements of diameter over bark and the diameter under bark and. So, you can also get the bark thickness.

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Example

A felled log has the following measurements:

$d_{ob} = 130$ cm; $d_{ub} = 124$ cm; length = 4.08 m

Find out:

1. bark thickness
2. total volume
3. bark volume
4. bark percentage to total volume

Then we looked at this problem in which we were given the over bark diameter the under bark diameter and the length, and we were able to calculate the bark thickness the total volume the bark volume and the bark percentage to total volume.

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12. Where to measure the diameter?

Dr. Ankur Awadhiya, IFS

Next in a lecture 12 we looked at where to measure the diameters, because your trees are tapered.

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What's the point?



- Diameter varies with height from base
- Need for a standard

So, the diameter is different at different heights. So, we need to define a height.

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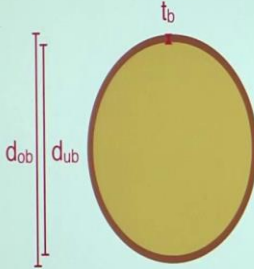
What's the standard?

- dbh = diameter at breast height
- breast height = 1.3 m (most countries)
= 1.37 m (4.5' for the USA)
= 1.2 m (Japan and Korea)
- IUFRO (International Union of Forestry Research Organisations) recommends the use of d for dbh
- d_{ob} = diameter over bark
- d_{ub} = diameter under bark

And that height is defined as these values in different countries, in our country we have 1.37 meters as the breast height and the diameter is traditionally measured at the breast height called as dbh or d which is the diameter at breast height.

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Relationship between d_{ob} and d_{ub}

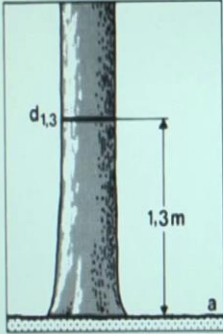


- $d_{ob} = d_{ub} + 2 \times t_b$
- where t_b is the thickness of the bark of the tree

Then we looked at there a relationship between the over bark diameter the under bark diameter and the bark thickness, we looked at these formal rules.

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Formal rules



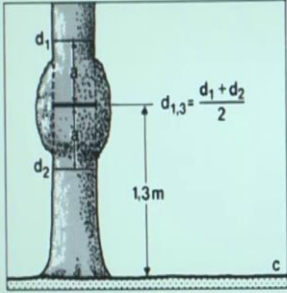
The diagram shows a vertical tree trunk on level ground. A horizontal line indicates a diameter measurement at a height of 1.3m from the ground, labeled $d_{1,3}$. A vertical line also indicates the 1.3m height. The ground surface is labeled 'a'.

- For standing vertical trees on level ground, measure at 1.3 m vertically

So, the height is measured at the breast height.

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Formal rules

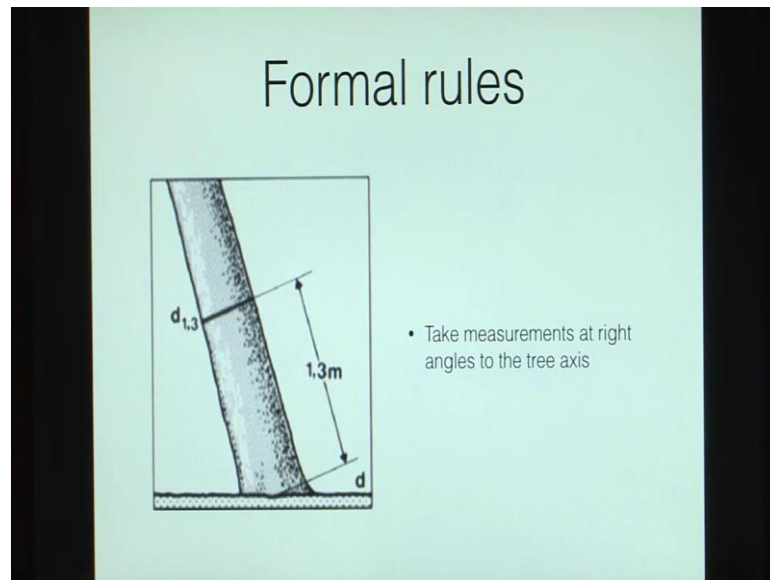


The diagram shows a tree trunk with a bulge. Two diameter measurements, d_1 and d_2 , are taken at a height of 1.3m from the ground, one above and one below the bulge. The average diameter is given by the formula $d_{1,3} = \frac{d_1 + d_2}{2}$. The ground surface is labeled 'c'.

- In the case of irregular stem cross sections, for example, due to protruding branch stumps, two diameters are measured, at a cm above and below the correct position respectively. The average of the two readings estimates the true diameter.
- $d = 0.5 \times (d_1 + d_2)$

If your tree is on slopy ground then the upslope portion is from where you are going to measure the this 1.37 meters, if you have a bulge then you take a reading above the bulge and a reading below the bulge and then take the average of both of those readings if your tree is sloping.

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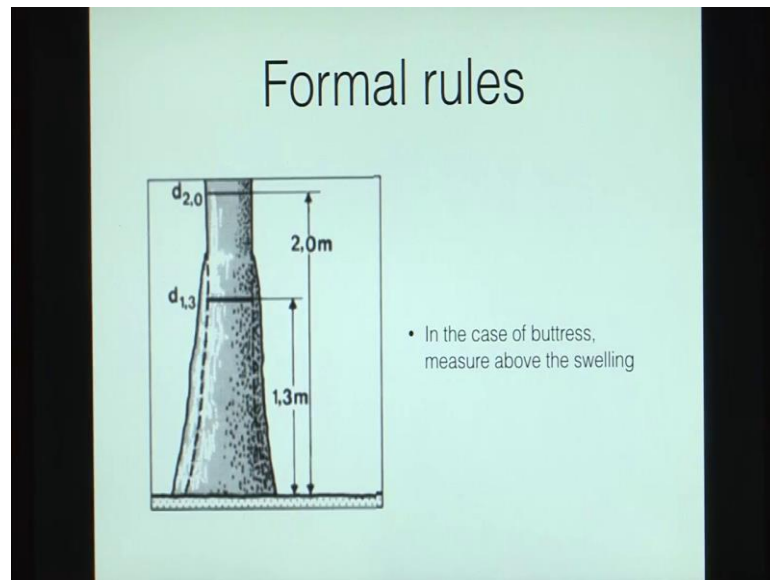
So, in that case you take measurements at right angles to the tree axis as in the case of this tree.

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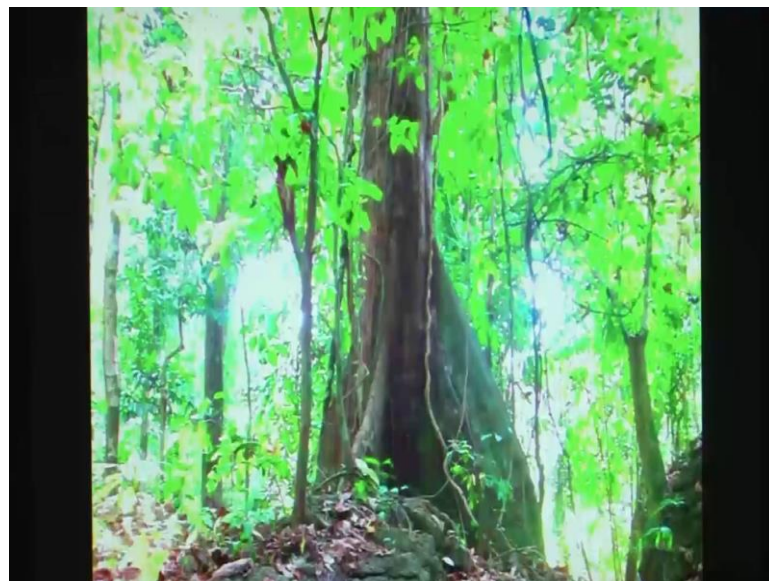


If your tree has a buttress then you take a measurement above the swelling as in the case of this tree.

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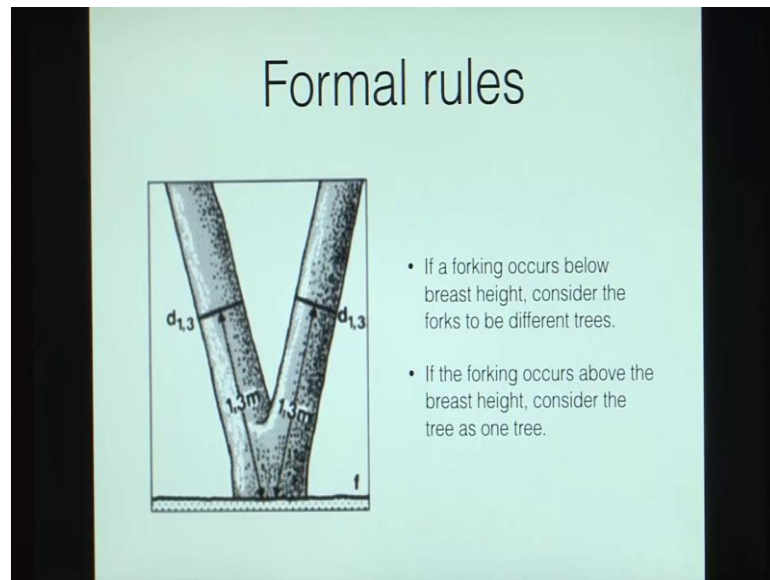


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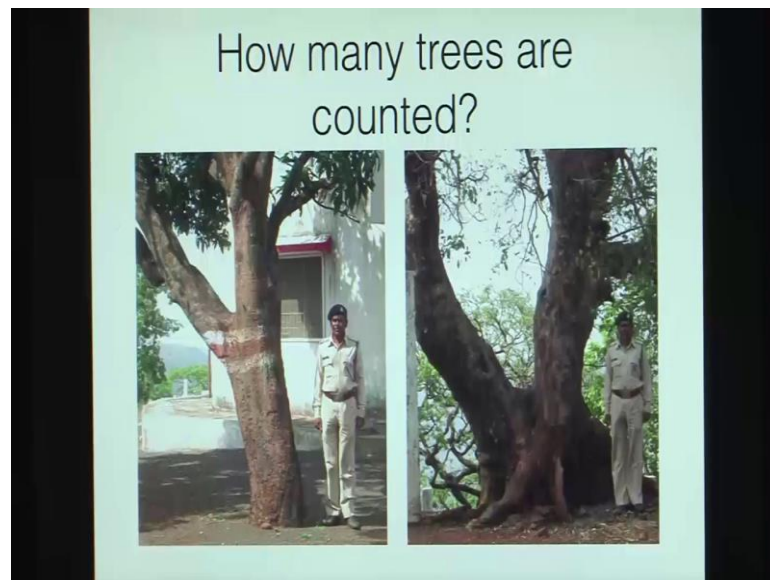
This tree now if your tree is having forking.

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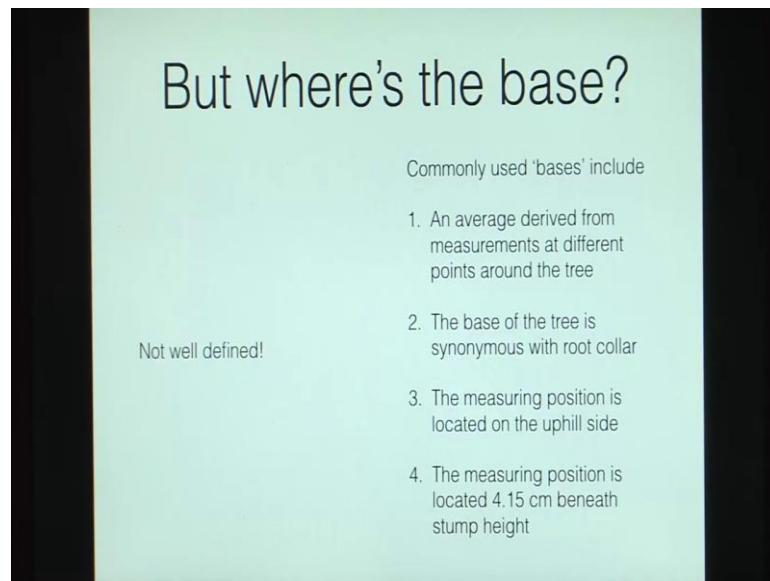
Then if the fork is if the forking starts a before a height of breast height then you take it as two trees or else you will take it as one tree.

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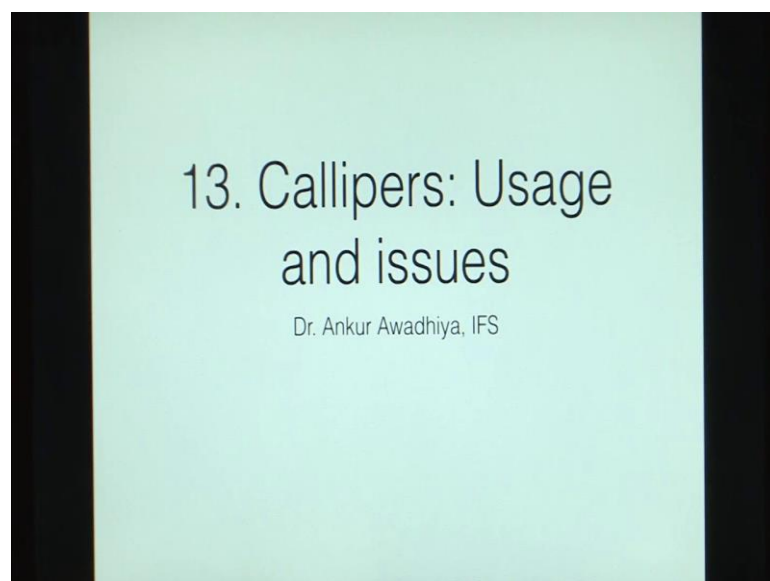
So, in this case in the left side figure it is one tree whereas, on the right side figure it is two trees.

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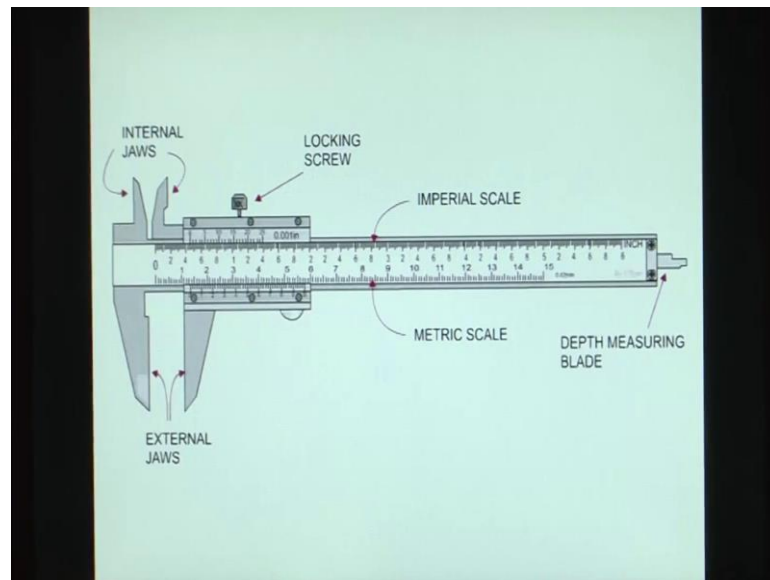
Now, bases not very well defined.

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Now in the next class we looked at calipers their usage and issues.

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So, a caliber is very similar to a Vernier caliber. So, this is how it looks.

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It is made out of either wood or made out of aluminum, it has two jaws one is called a fixed jaw one is called a moving jaw and the moving jaw can be tightened by a screw.

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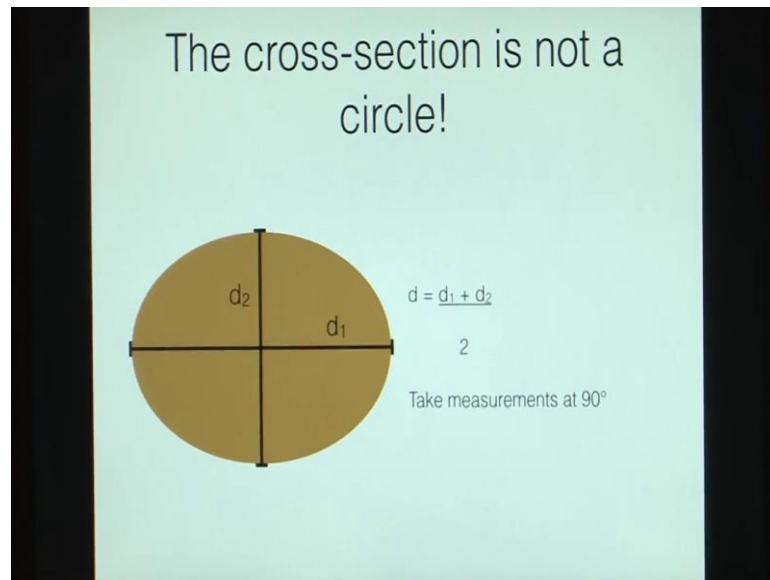


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And it is it can be used to measure the diameter of the tree at the breast height and in some cases, your when the cross section is elliptical or even irregular.

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Issues

1. Non-circular cross-section of tree stems
2. Weight and size of the instrument

Then it is difficult to take readings with this, the instrument is bulky.

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Then it is, so this is how you carry it in a forest and you can see that the size of the instrument is roughly equal to the height of a person then in some cases you might have 0 error on your device, so that needs to be corrected every time in some cases you might have a plane the in your instruments.

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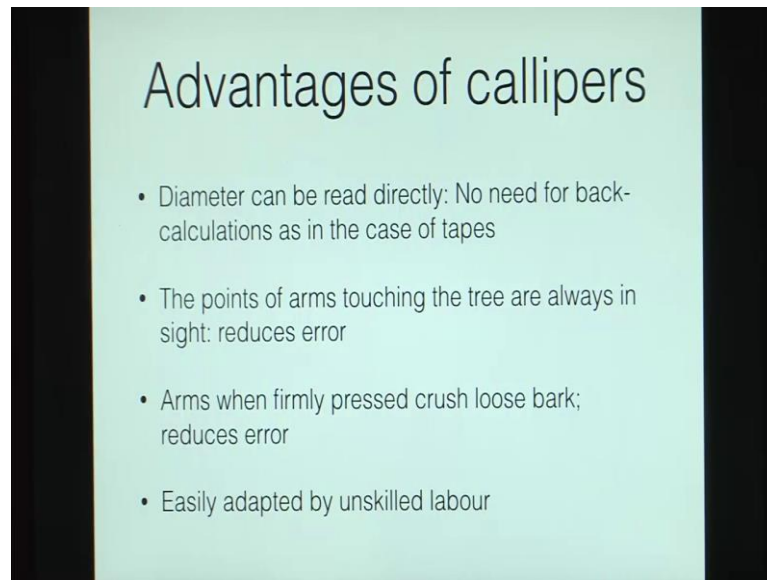


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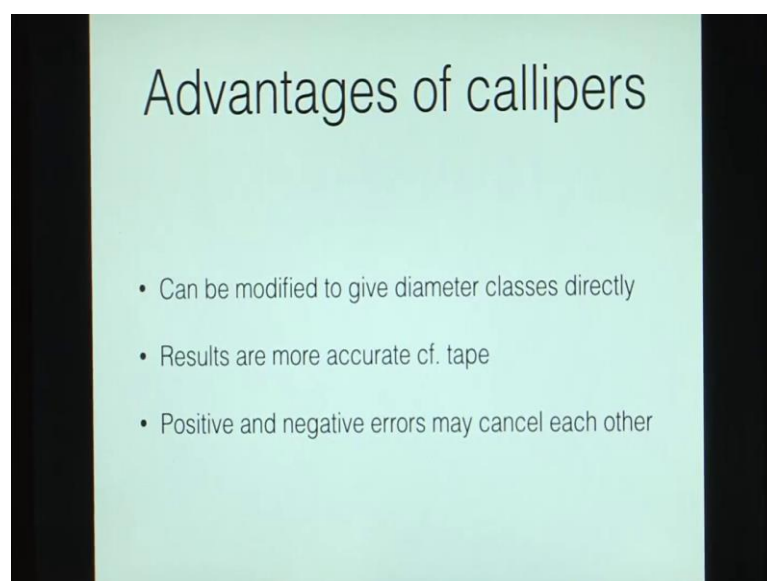
So, in which case both the jaws are not parallel to each other then we looked at some advantageous and some disadvantages of the calibers.

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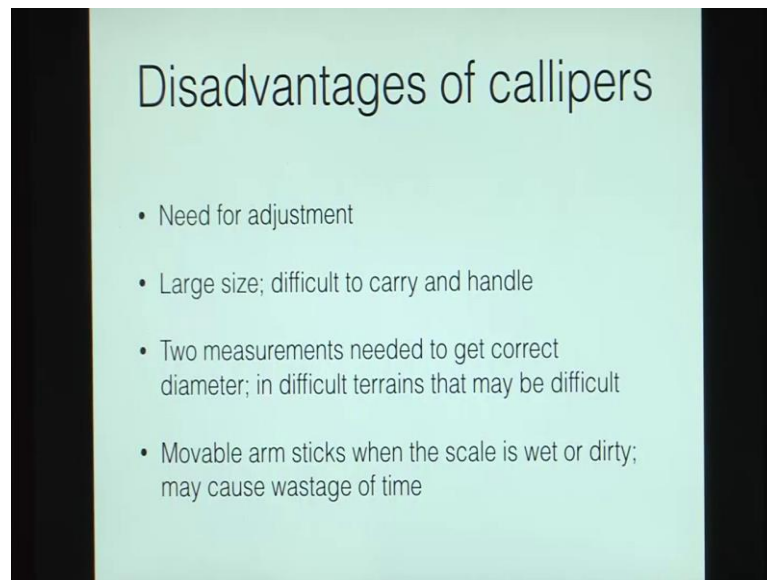
So, in the case of calipers the diameter can be read directly there is no need for back calculations. So, for instance if you take the girth readings from a tape then for finding out your diameter you need to use the equation $\text{girth} = \pi \times d$. So, when you divide it by 3.14 you will get the diameter in the case of calipers you can get it directly then the points of arms that are touching the tree are always in sight. So, that reduces error they also crush loose bark and we are more interested in the diameter under bark, it is easily adapted by unskilled laborers. So, you can directly use it to get the diameter classes and not a directly diameters.

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By painting your scale in different colors it can be modified to give diameter classes directly the results are more accurate as compared to tape and positive and negative errors because they are both they are in the device. So, they might cancel each other, but also there are some disadvantages.

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There is a constant need for adjustment the size is large it is difficult to carry its bulky ,then you need two measurements whereas, in the case of a tape you require only one measurement, and then the movable arm because it is a mechanical device. So, if the movable arm sticks when the scale is wet or dry. So, wet or dirty. So, in that case it might cause wastage of time.

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14. Tape: Usage and issues

Dr. Ankur Awadhiya, IFS

Then in the next class we looked at tapes.

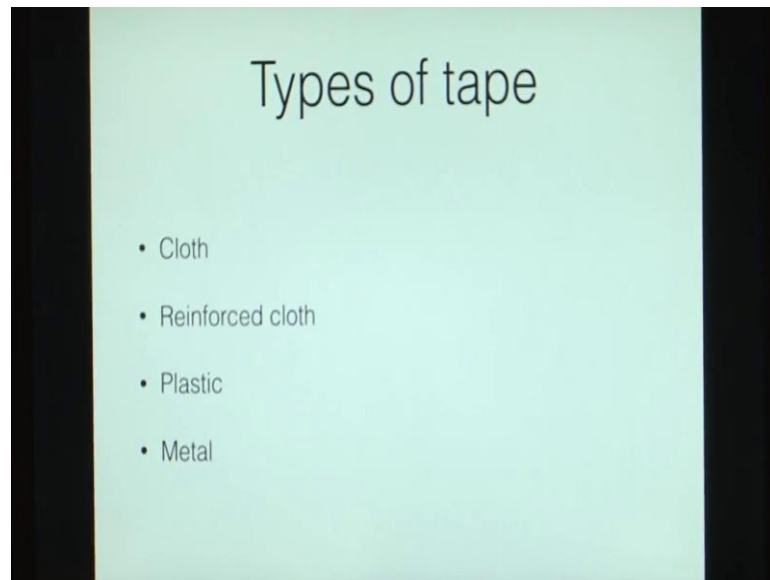
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Tape

- Used for measuring girths of trees, logs, stumps
- May be used for measuring diameter in some cases
- Graduated in centimetres or inches
- One end may have a hook or spike to place around one end of tree

So, tapes are used to mostly in the measurement of girths and you can also measure the diameters of the ends in some cases. So, you can use an inch tape or a centimeter tape, and they might also have a hook or spike at one end.

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So, we looked at the types of tape cloth reinforced cloth plastic and metal tapes their advantages and disadvantages.

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So, a tape can be used to measure horizontal distances, or vertical distances or the girth.

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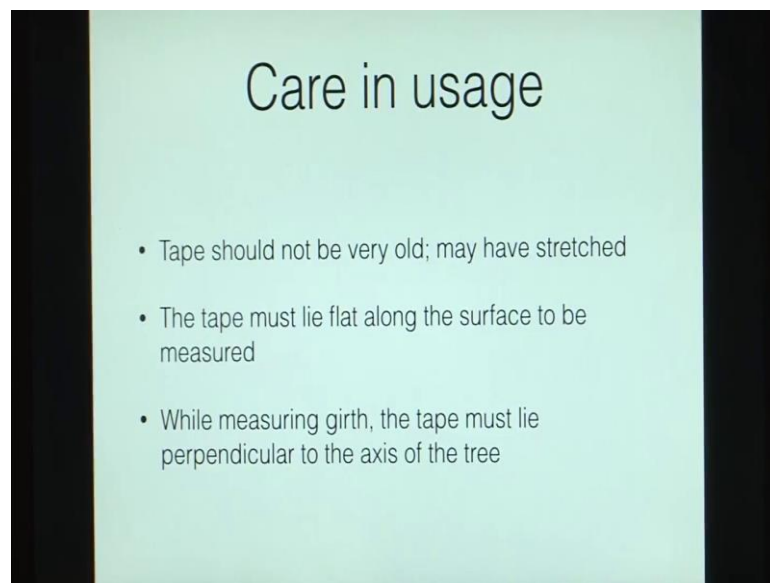


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However, there are some care in the usage. So, it must not be very old.

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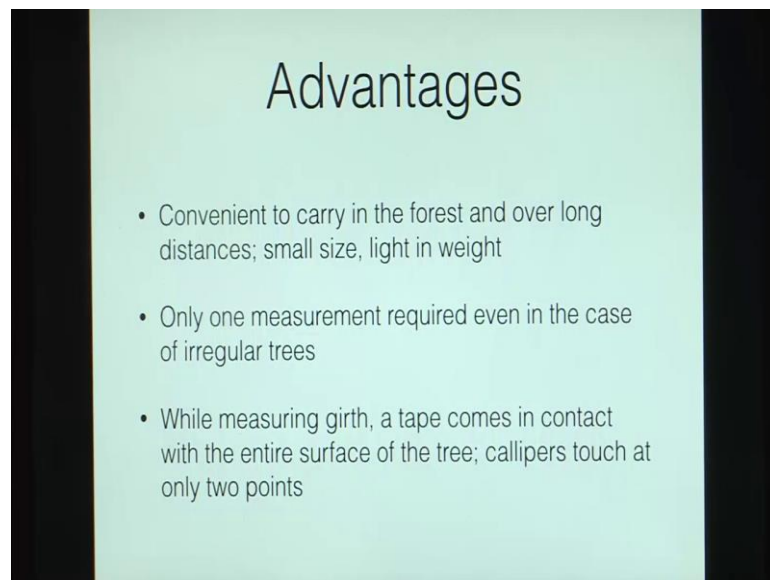
Because an old tape might have stressed or at surface might have become freed and it must lie flat along the surface, it must be perpendicular to the tree axis there must not be any knots or turns in the tape as we saw in this figure.

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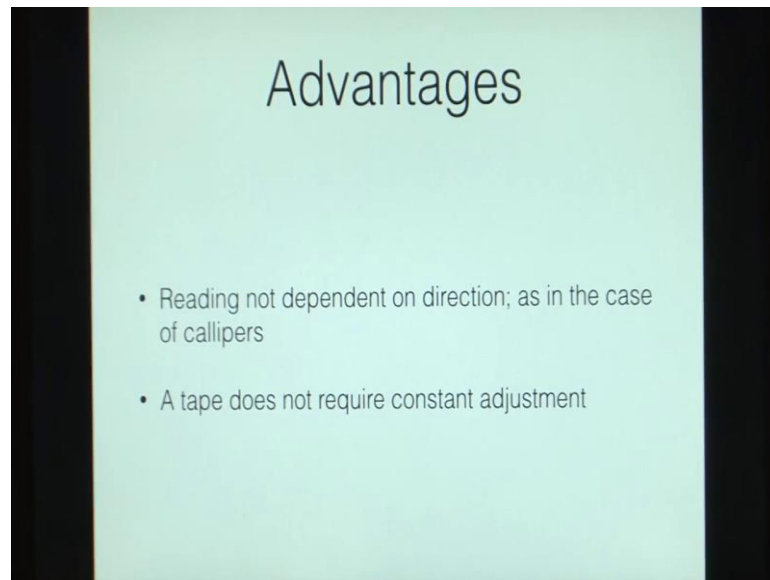
So here we have a tape that is showing a knot. So, in this case the girth that will measure will be greater than the girth of the tree, then there should not be any climber that has gone along with the tree and it should be stored carefully.

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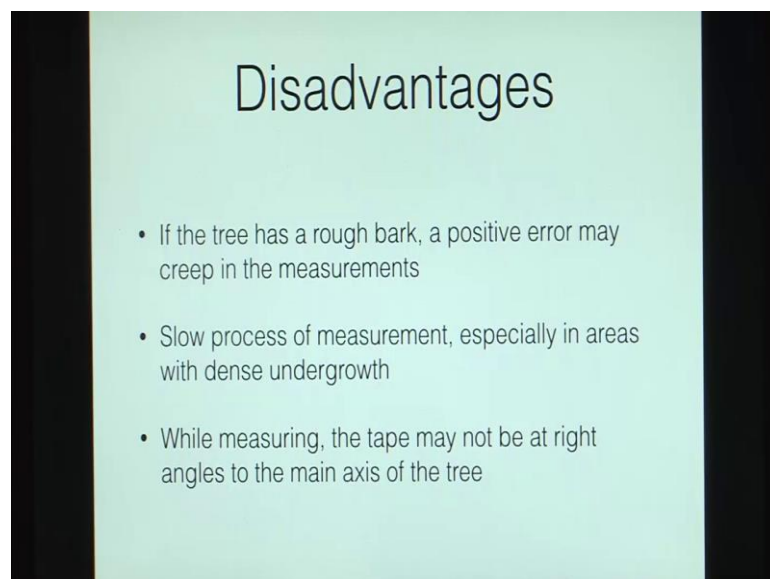
Then we looked at some advantages unlike calipers it is very small and its very light. So, you can easily carry it in your pocket, only one measurement is required in the measurement of girth it comes across it comes in contact with the entire surface of the tree.

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Then the reading is not dependent on direction as in the case of callipers if your tree had an irregular cross section. So, your readings might be highly direction dependent and it does not require any adjustment because it is not a mechanical device.

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On the other hand if your tree has a rough bark then might give you a positive error, it is a slow process of measurement especially in areas with dense undergrowth where it is difficult to go around your tree completely, at the same time your measurements have to be taken at right angles.

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Disadvantages

- The elasticity of tape may affect the measurement
- The observer may not have a full view of the circumference, and knots may creep in during measurement

So, that needs to be taken care of the elasticity of the tape might affect the measurement, and the observer may not have a full view of the circumference. So, some knots may creep in during the measurement.

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For a non-circular cross-section, girth tape over-estimates the sectional area. Prove.

Assume the cross-section to be an ellipse with half-axes a and b :

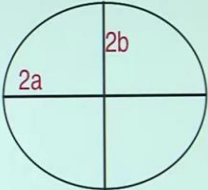
Perimeter as measured by tape:

$$P = 2\pi \sqrt{[(a^2 + b^2) / 2]}$$

Area derived from P :

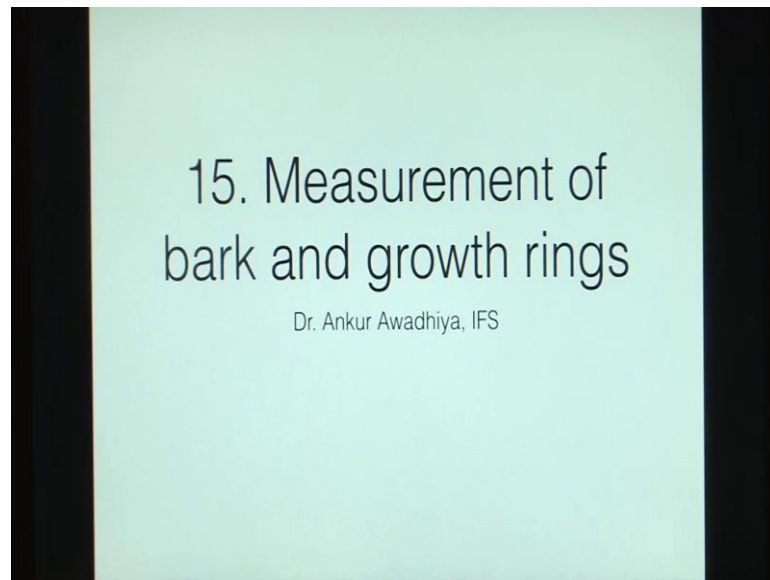
$$A_P = P^2 / 4\pi = \pi [(a^2 + b^2) / 2]$$

Area from callipers, $A_C = \pi ab$



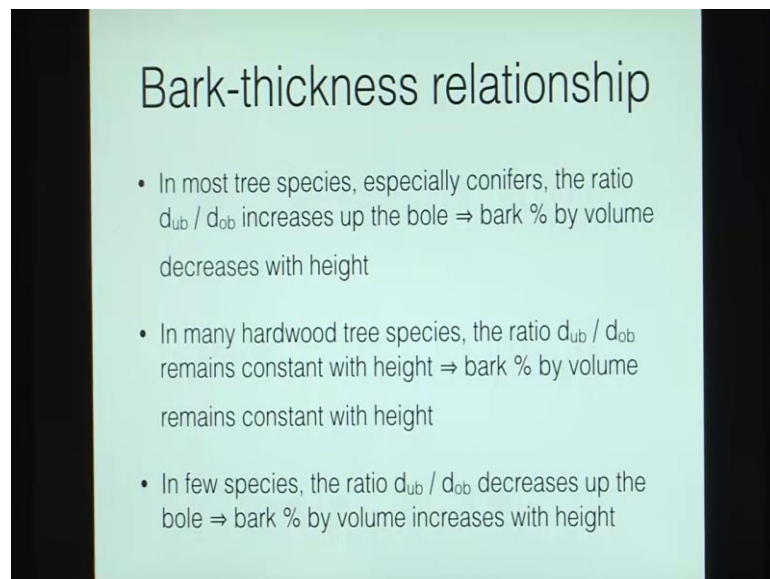
Then we looked at this problem, for a non circular cross section the girth tape over estimates the sectional area. So, this is one thing that we need to keep in mind when we are comparing the cross sectional areas as measured using a tape and as measured with the calipers.

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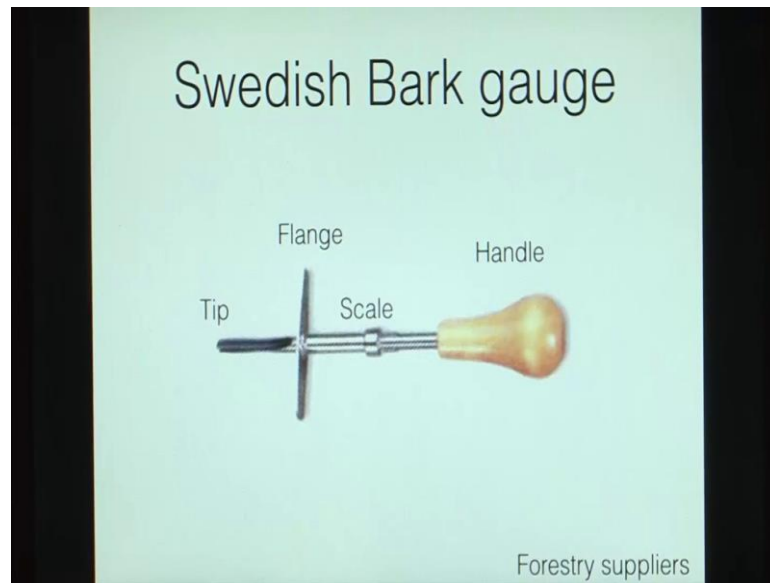
Next we looked at the measurement of bark and growth rings.

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So, bark and thickness relationship was seen, now bark thickness is measured with a Swedish bark gauge or with a bark probe.

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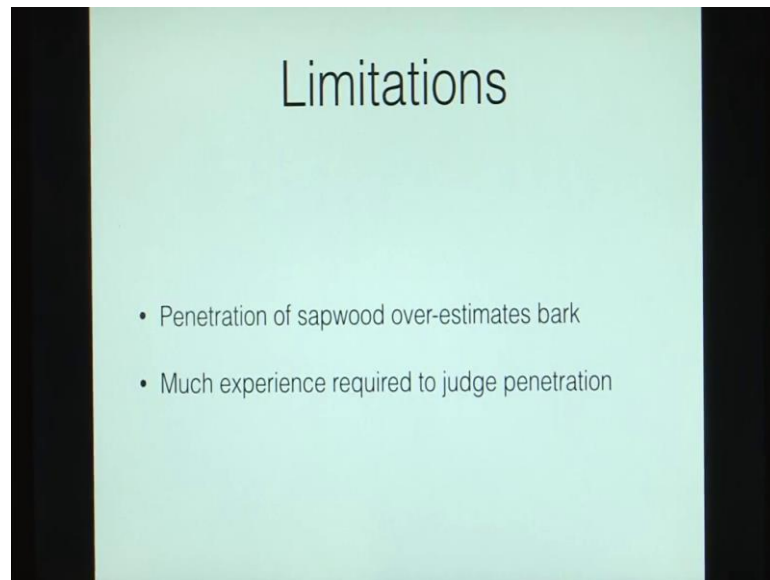


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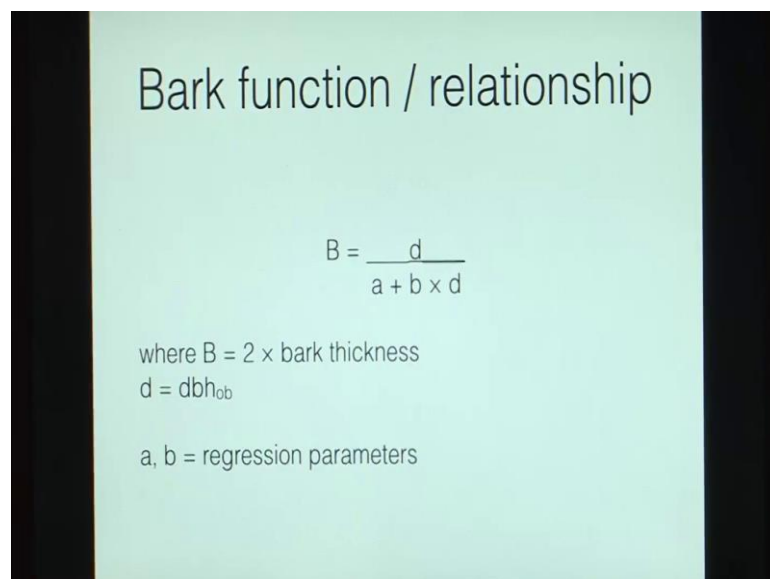
Then we looked at their limitations.

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Because they might even be penetrating into the sapwood, thus overestimating the bark and. So, quite a lot of skill and experience is required to correctly judge how much of penetration needs to be made.

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When we looked at bark function and relationship, as compared to the diameter at breast height and the regression parameters.

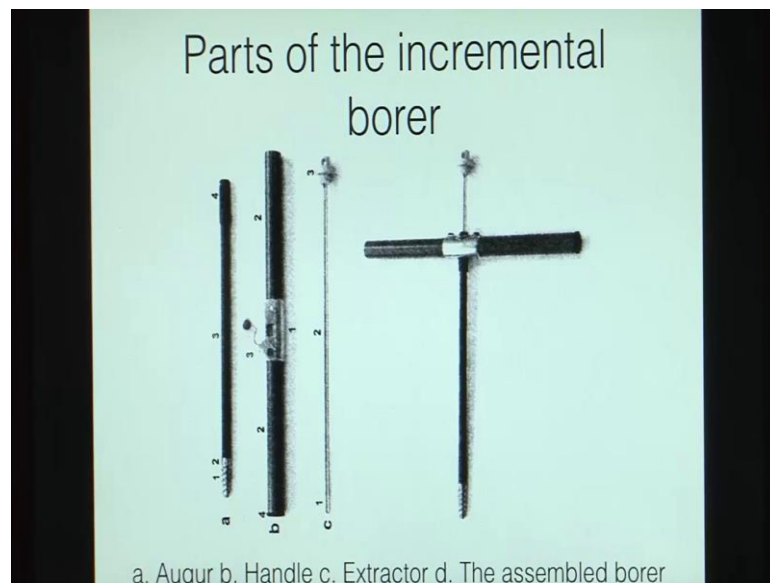
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Table of bark relationship for *Pinus radiata*

dbh _{ob} (cm)	2BT (cm)	%	dbh _{ob} (cm)	2BT (cm)	%
12	1.5	12.5	30	4.7	16
14	2.0	14	32	4.9	15
16	2.4	15	34	5.1	15
18	2.8	16	36	5.4	15
20	3.1	15.5	38	5.6	15
22	3.5	16	40	5.8	14.5
24	3.8	16	42	6.0	14
26	4.1	16	44	6.2	14
28	4.4	16	46	6.4	14

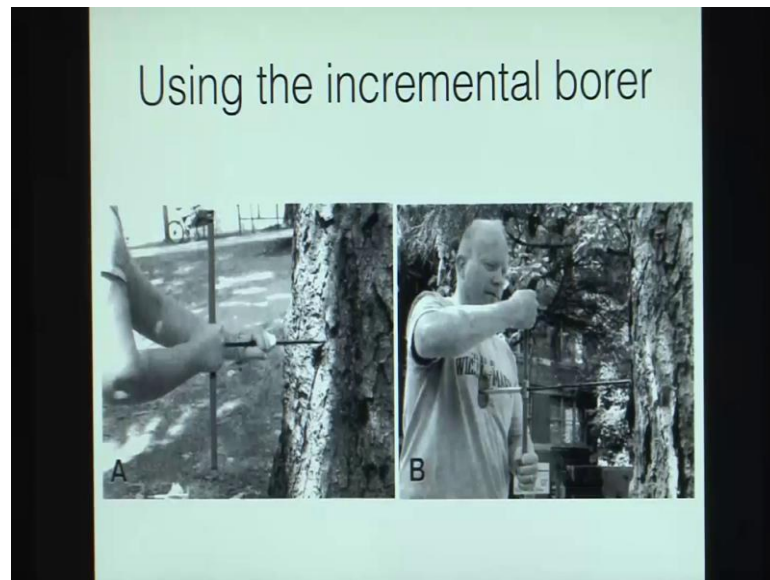
Then next we looked at an incremental borer.

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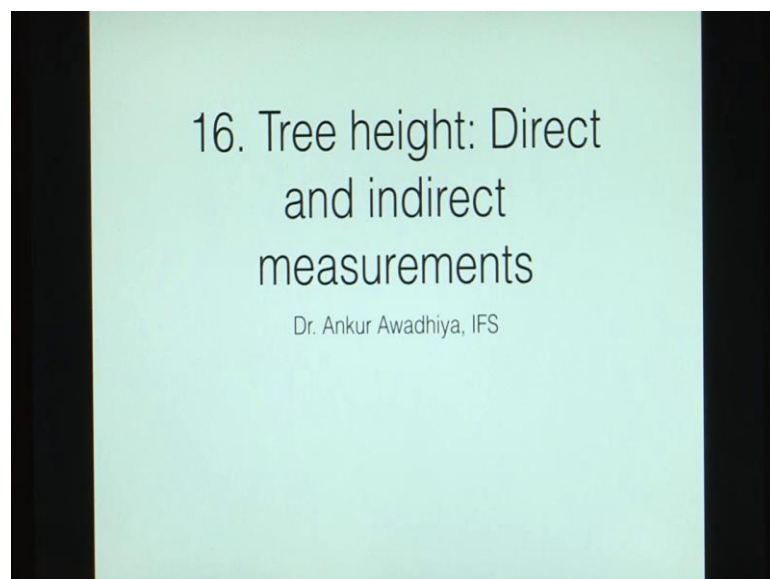
That has these three parts augur handle and the extractor and all these three can be join together to get your assembled borer.

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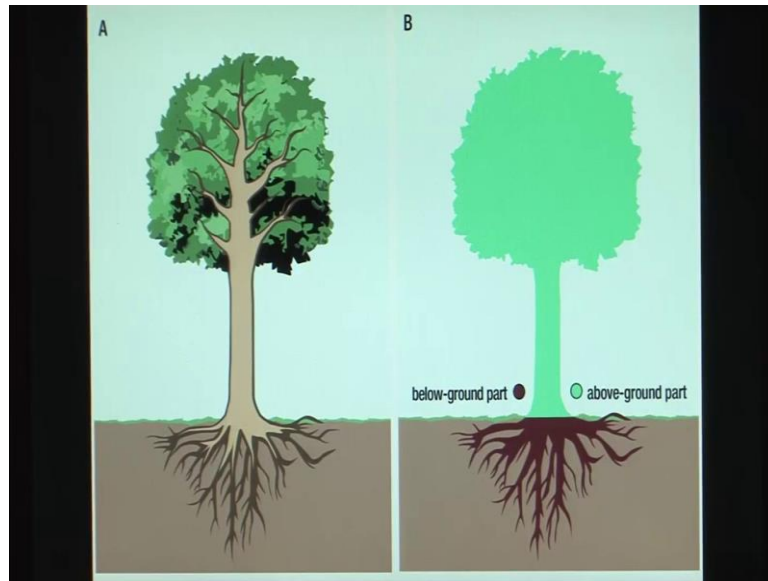
This is how an incremental borer is used and when you get your sample outside from the incremental borer, you can very easily measure the rings that is used in dendrochronology.

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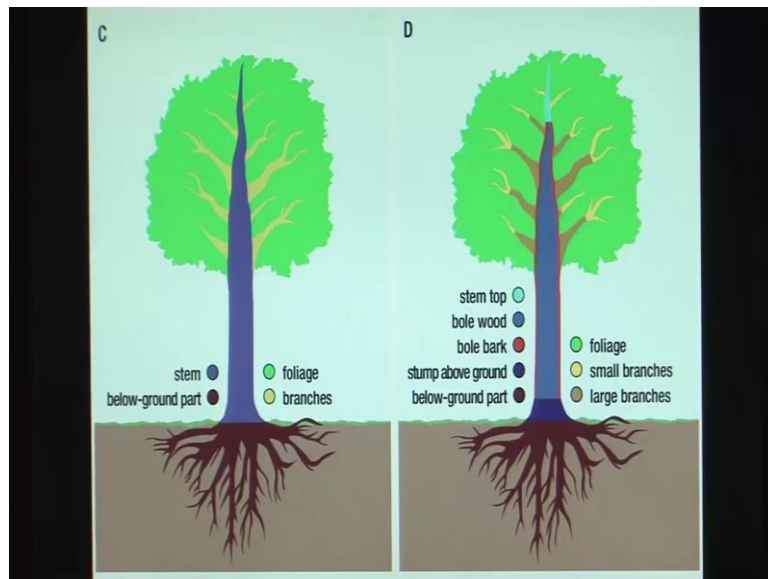
Next we looked at the tree height the direct and indirect measurements. So, we looked at how.

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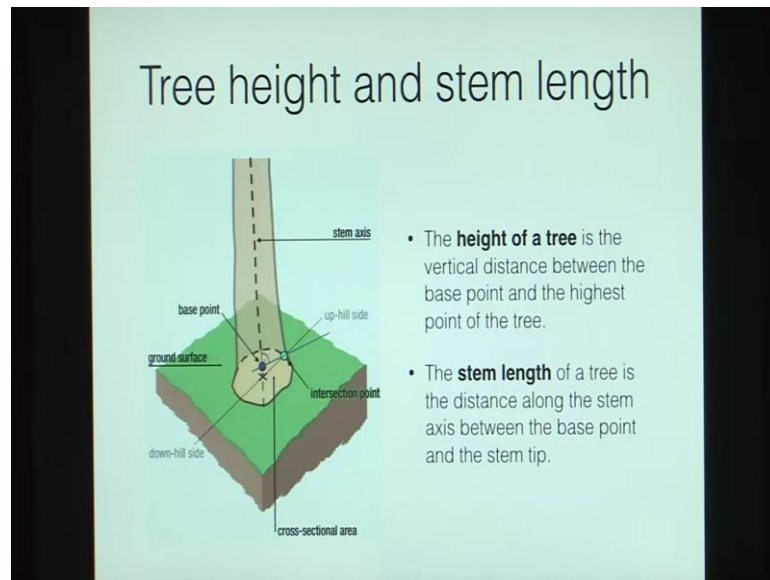
A tree is divided into various portions, the above ground part the below ground part.

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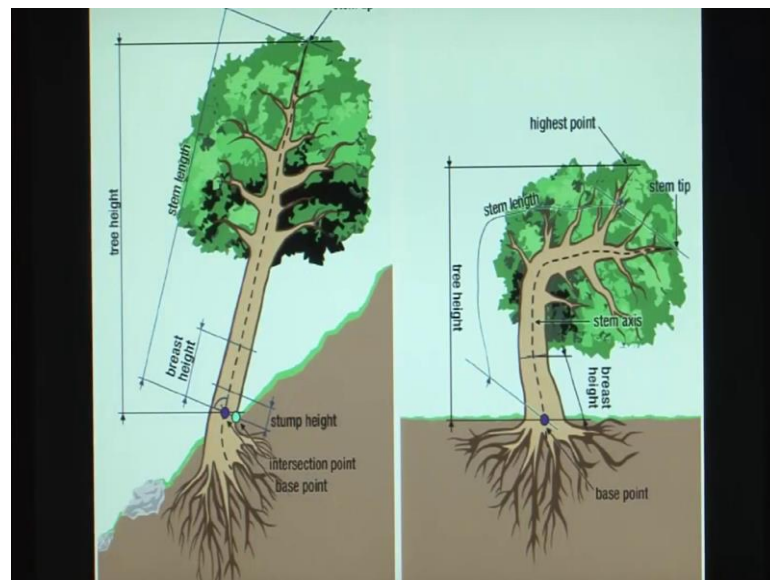
The main stem the branches and so on.

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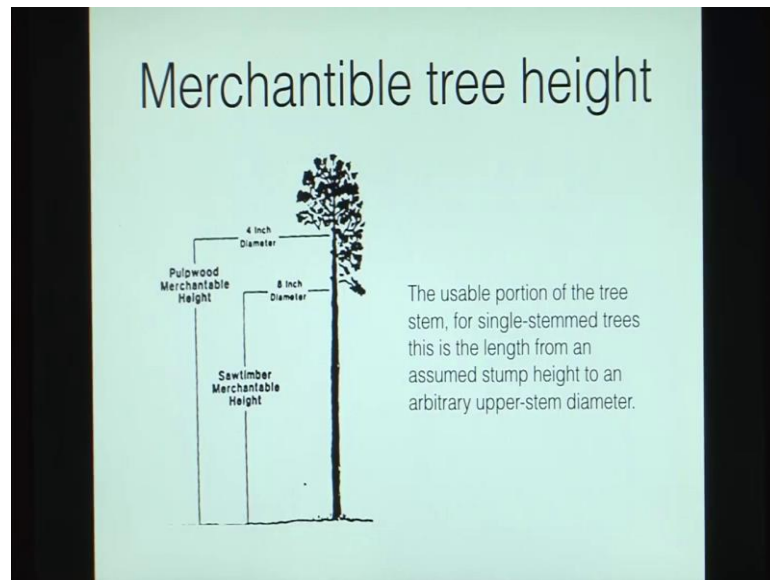
We looked at the difference between the tree height and the stem length and different situations.

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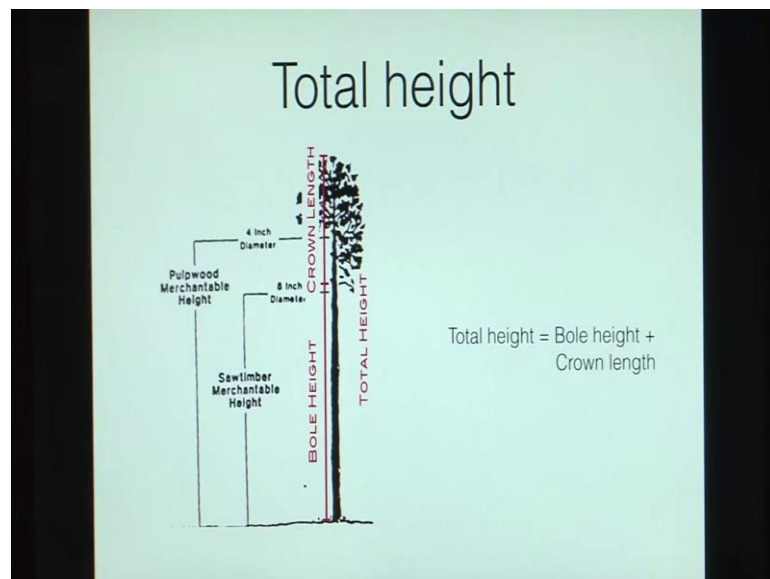
Then we also looked at the merchantable tree height.

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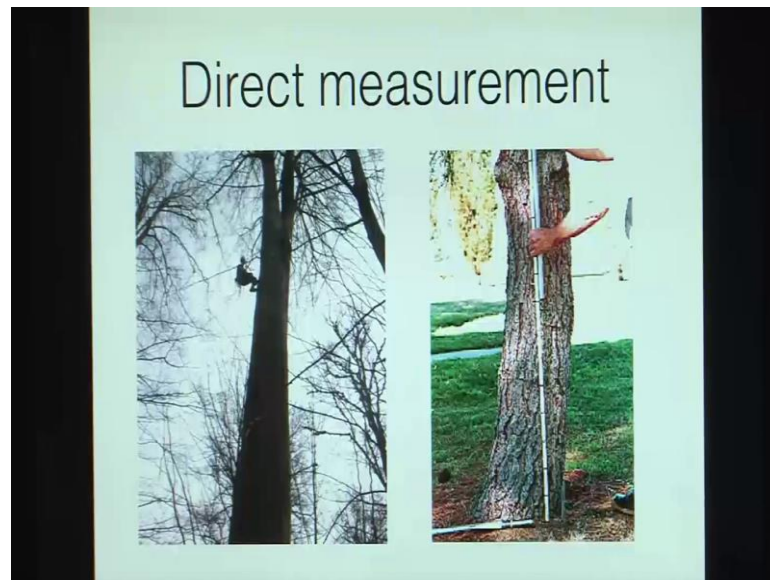


Then things like bole height, total height and the canopy length.

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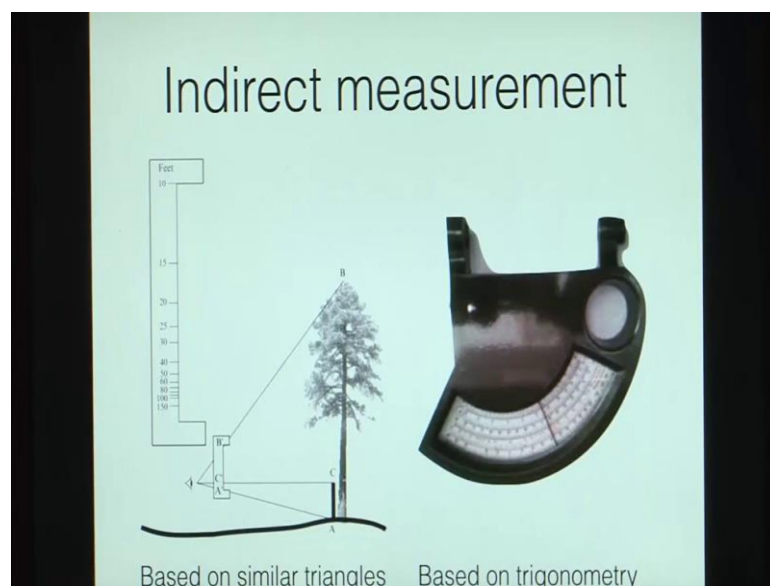


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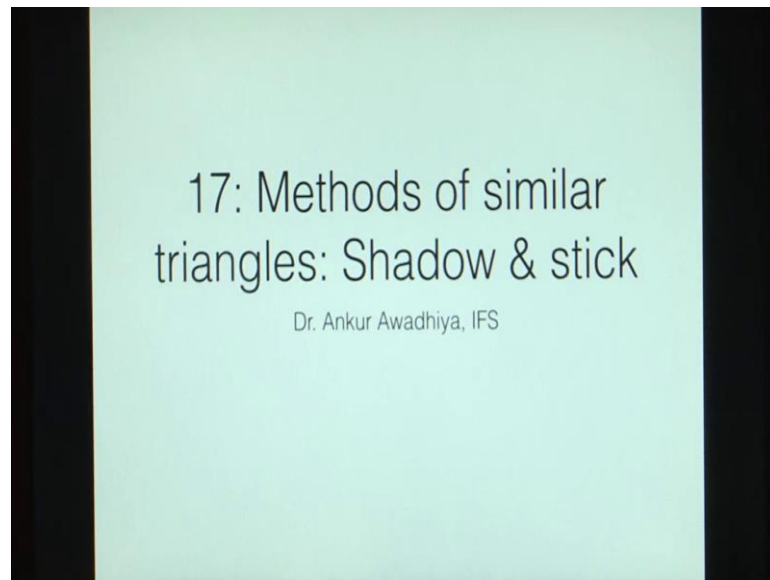
Then in the case of direct measurement you can go on top of a tree and then throw a string with some beta directs to it, and the length of this string when it when the weight is touching the ground and this string is (Refer Time:28:29). So, length of the string will give you the measurement of the tree or you can use a scale directly along the tree to get a direct measurement.

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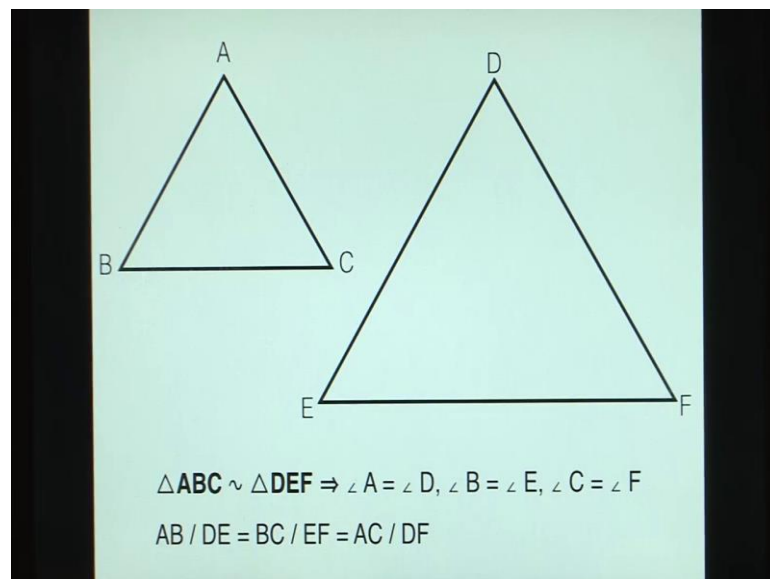
In the case of indirect measurement you can use your principles of similar triangles or principles of trigonometry to measure the heights of the trees.

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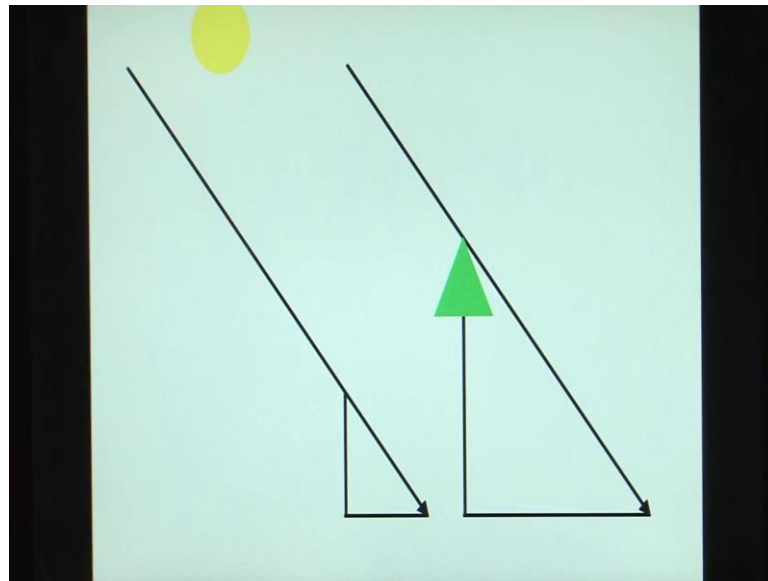
Next we looked at the methods of similar triangles the shadow and the stick method.

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So, in the case of similar triangles there the lengths of the corresponding sides maintain a constant ratio.

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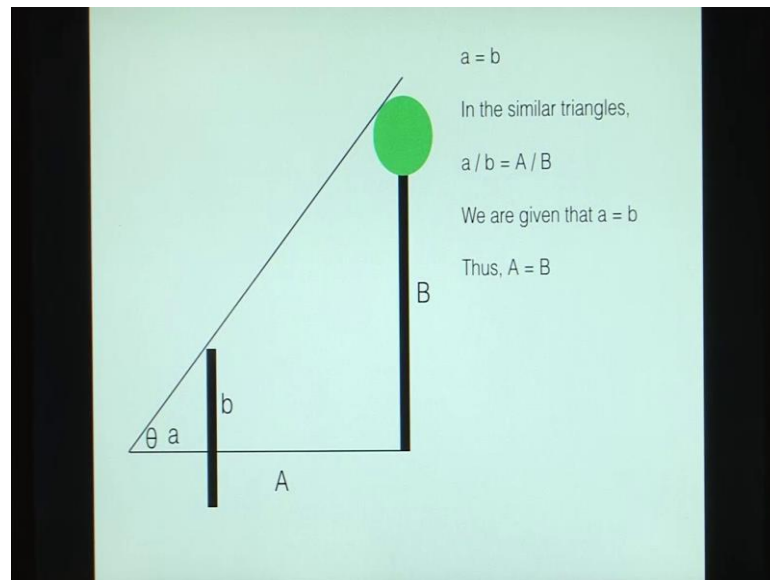
So, we look at this single Pole method which your observer holds a pole and that is it makes this these two similar triangles.

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Single pole method

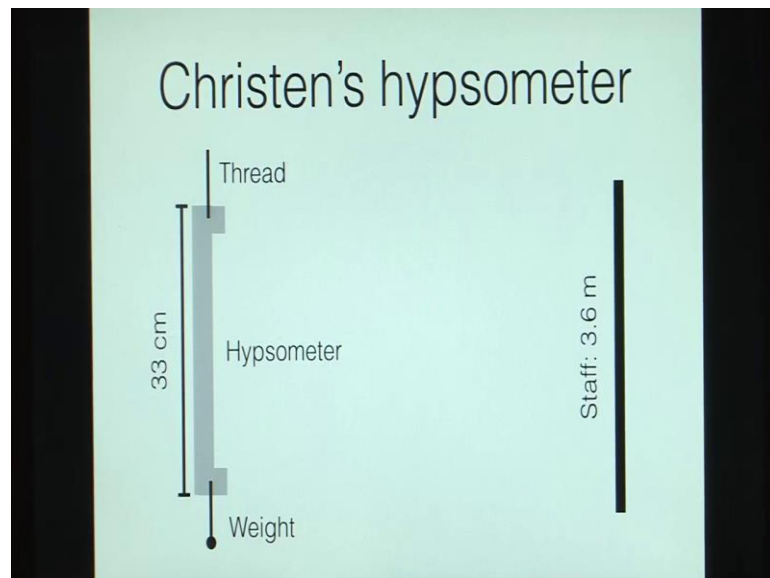
- Observer holds a pole (1.5 m long) vertically at arm's length such that the portion of the pole above the hand is equal in length to the distance of the pole from the eye.
- The observer moves forward and backward till the line of sight from the tip of the tree passes through the tip of the pole and that to the base of the tree through the point where the pole is held by the hand.
- Then height of the tree = distance of base from eye

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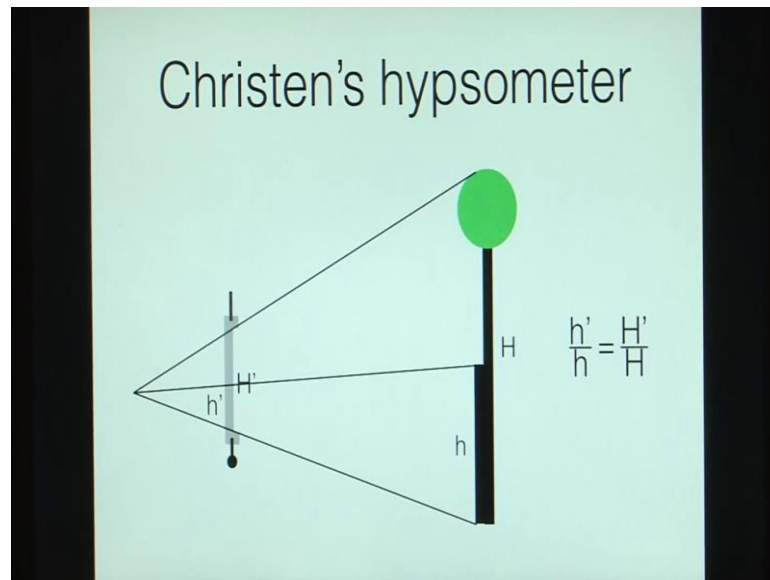
So, you can get the height of the tree as a constant ratio of the sides of the triangles and when a and b are the same. So, capital A and capital B will also be the same.

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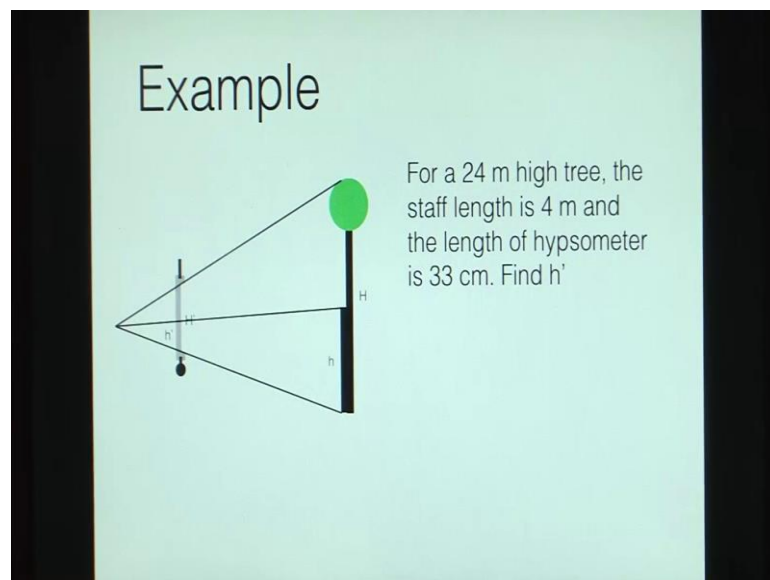
We also looked at this instrument called christens hypsometer is a which is which can be made out of any material even card board.

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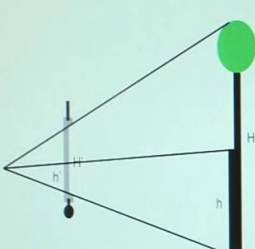
So, in this case we use it with a pole and we get the readings for h and H prime and we can use this equation to get the height of the tree.

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Solution

$$\frac{h'}{h} = \frac{H'}{H}$$


Here,
 $H = 24 \text{ m}$
 $h = 4 \text{ m}$
 $H' = 33 \text{ cm}$
 $h' = ?$

$$\begin{aligned} h' &= H' / H \times h \\ &= 33 / 24 \times 4 \\ &= 33 / 6 \\ &= 5.5 \text{ cm} \end{aligned}$$

Next we looked at its advantages.

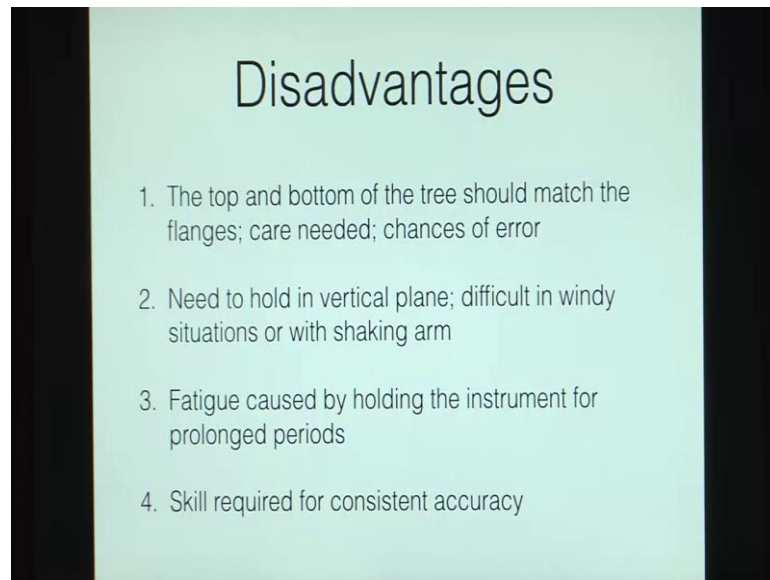
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Advantages

1. Light, easy to transport
2. Simple, easy to make
3. Quick to use
4. No need to measure distance from tree

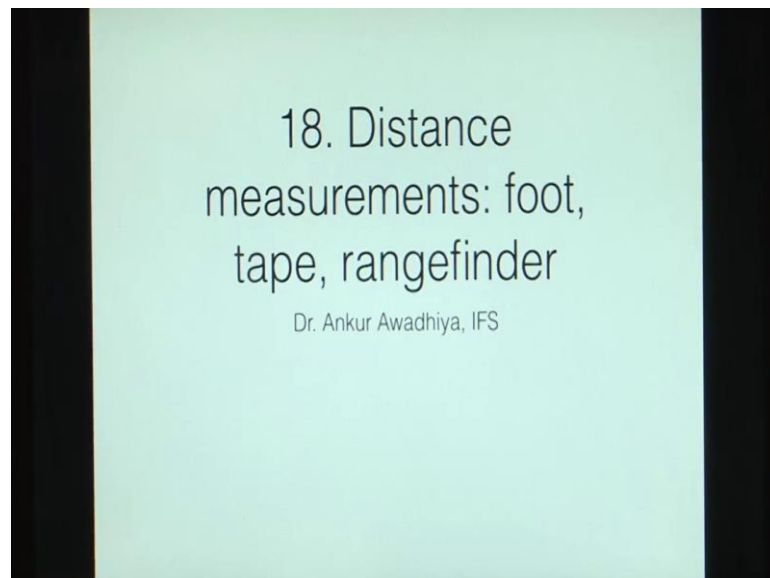
It is light and easy to transport simple and easy to make quick to use and there is no need to measure the distance from the tree.

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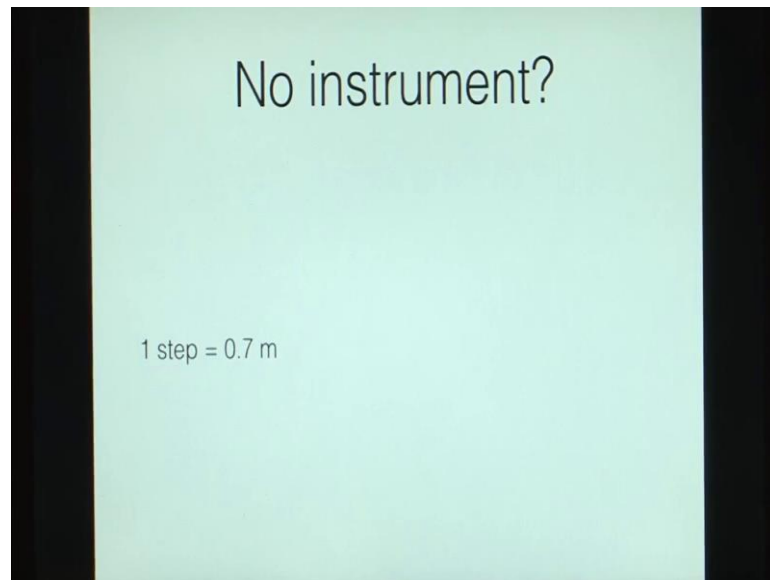
But at the same time you require quite a lot of skill and you need to keep it steady and vertical even in the case of windy situations.

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Next we looked at distance measurements with foot tap and range finder. So, if you do not have any instrument.

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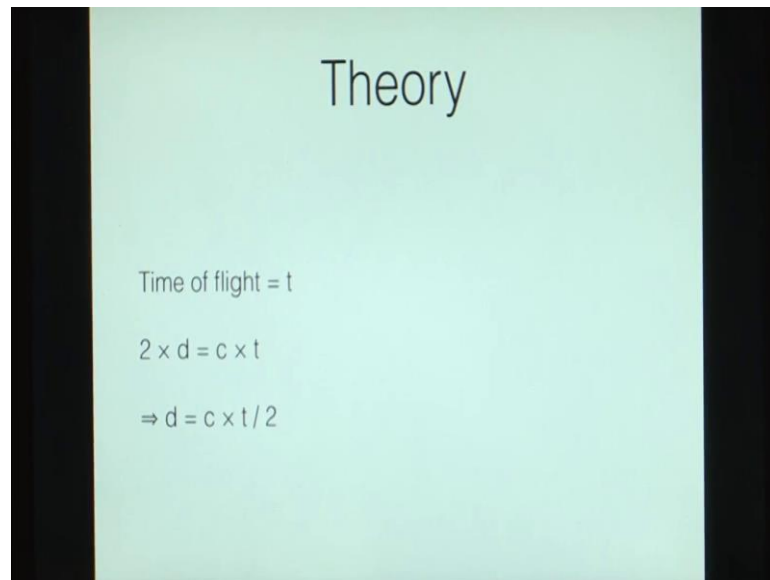
Then you can approximate one step to be equal to 0.7 meters, you can use a tape to measure horizontal distances or you can.

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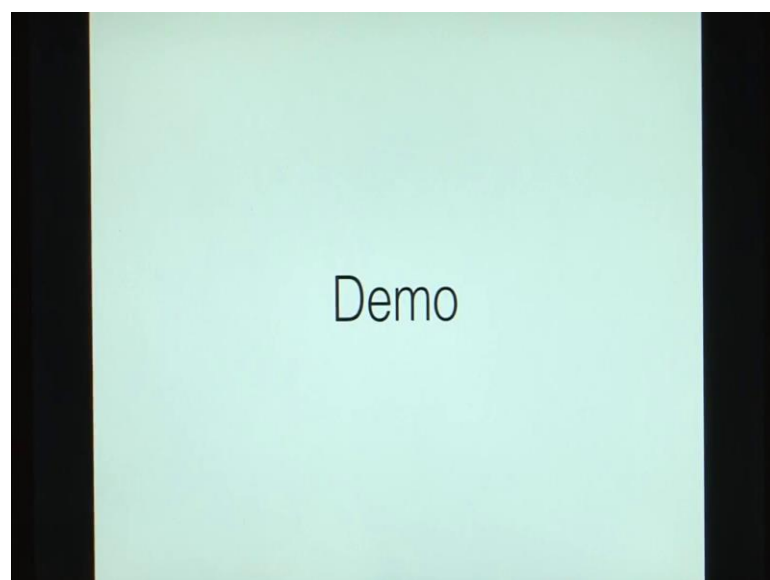
Use a range finder to measure the horizontal distance.

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We looked at its theory. So, twice of distance is equal to the time of flight multiplied by the speed of the wave that you are using. So, you can either be using light rays as in the case of a laser range finder. So, in that case your speed is equal to the speed of light that is 299792458 meters per second or you can go for an ultrasonic range finder in which your speed is equal to the speed of sound that is 340 meters per second.

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We also looked at a demonstration of how these range finders work next we also saw how we can measure.

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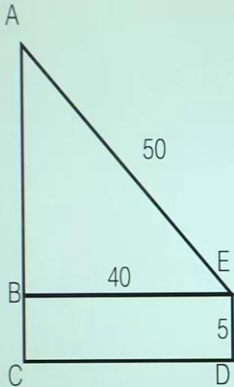
Example

The top of a tree is at a distance of 50 ft and the tree itself is at a distance of 40 ft.

If the instrument is kept at a height of 5 ft, find the height of the tree.

The height of a tree just by using a range finder and pythagoras theorem.

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The diagram shows a right-angled triangle ABE where A is the top of the tree, B is the base of the tree, and E is the instrument. The horizontal distance BE is 40 ft, and the hypotenuse AE is 50 ft. A rectangle BCDE is formed by extending the base BC and the instrument height ED, where ED is 5 ft.

Solution

Using Pythagoras theorem,

$$AB = \sqrt{AE^2 - BE^2}$$
$$\Rightarrow AB = \sqrt{2500 - 1600}$$
$$\Rightarrow AB = \sqrt{900} = 30 \text{ m}$$

Height of tree, $AC = AB + BC$
 $= AB + ED = 30 + 5 = 35 \text{ ft.}$

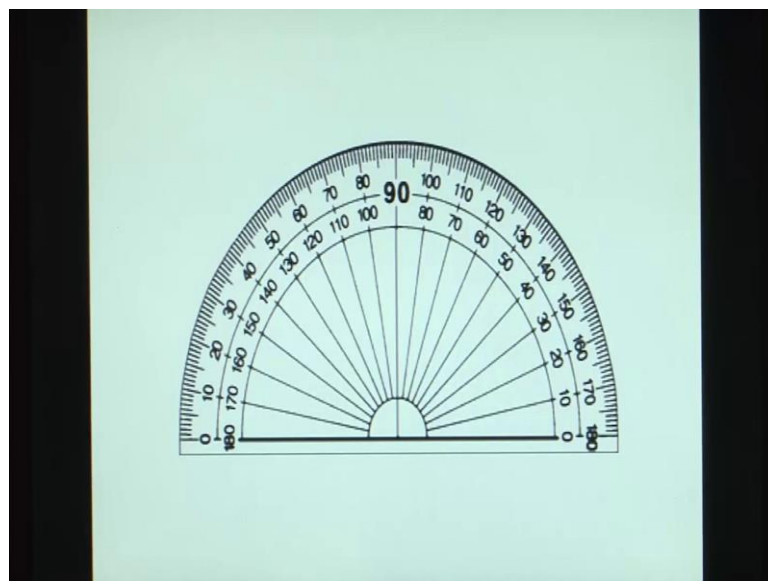
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19. Angular measurements

Dr. Ankur Awadhiya, IFS

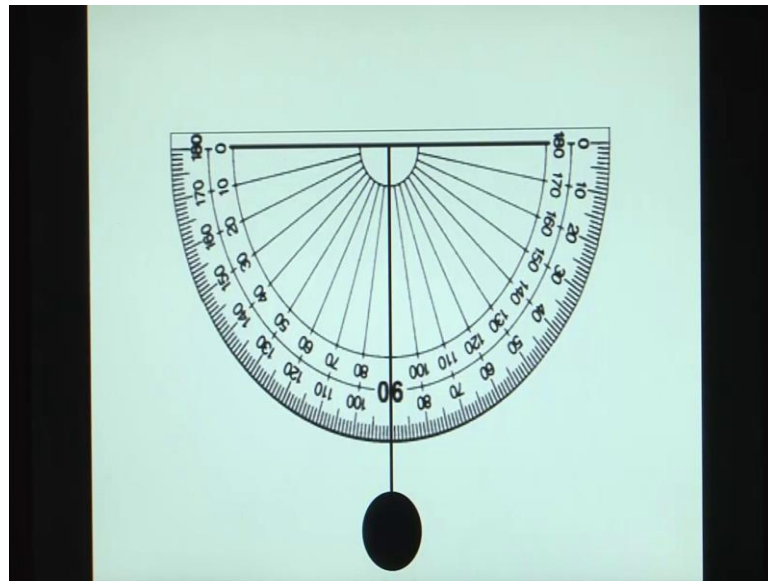
Next we looked at angular measurements.

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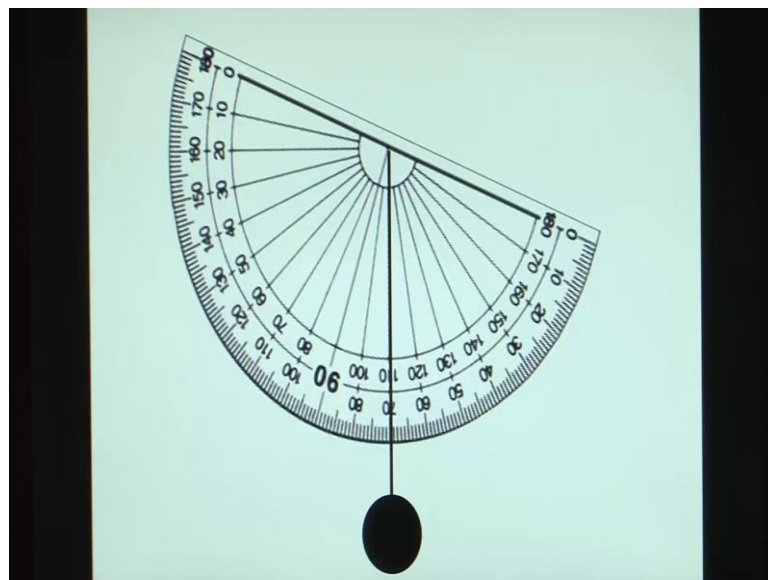
So, we saw that we can use a protector for angular measurements, and if you want to get the angle of elevation or depression then we can attach string to our protector.

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And a weight below which can keep our string tightened and in this case the angle that we measure is the angle of elevation or the angle of depression.

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Then we also looked at some problems in which we saw that when you have a tree that has a lean.

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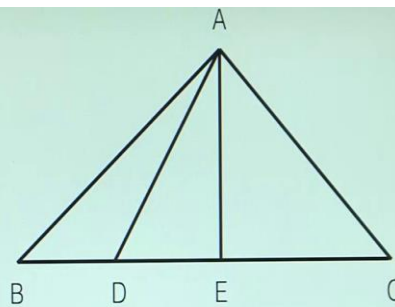
Example

A logger measures the height of a tree leaning away from him by lying on the ground at a distance of 25 m from the base of the tree. The angle to the tip is measured to be 30° . The logger then walks to the diametrically opposite point on the other side of the tree, again at a distance of 25 m from the base of the tree. The tree now leans towards him, and the angle to the tip is measured to be 60° .

To estimate the height of the tree, the logger obtains the two heights, assuming no lean, and takes the average. Is he correct? Assume that the inclination of the tree to the vertical is 30° .

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Solution

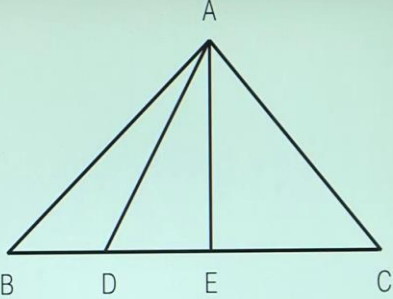


$$\begin{aligned}\angle ADE &= 60^\circ, \angle ABC = 30^\circ, \angle ACB = 60^\circ \\ BD &= 25 \text{ m}, CD = 25 \text{ m} \\ \text{Let } DE &= x \text{ m; then } EC = (25 - x) \text{ m} \\ \text{In } \triangle AEC, AE / EC &= \tan \angle ACE = \tan 60^\circ = \sqrt{3} \\ \Rightarrow EC &= AE / \sqrt{3}\end{aligned}$$

So, in that case you cannot take the readings from both the sides and then average them out, but you need to use principles of trigonometry to find out the correct height of the tree.

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Solution



In $\triangle ADE$, $AE / ED = \tan \angle ADE = \tan 60^\circ = \sqrt{3}$
 $\Rightarrow ED = AE / \sqrt{3}$
 $EC + ED = CD = 25 \text{ m}$
 $\Rightarrow 2 \times AE / \sqrt{3} = 25 \Rightarrow AE = 12.5 \sqrt{3}$

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Then we also looked at this instrument called Haga altimeter that makes measurement of these distances heights and angles very easy.

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So, you measure distance along the ground.

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And then you use this instrument to look at the top of the tree and then you can use these two buttons two either keep your pointer in a freely moving condition or you can fix your pointers.

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So, that you can get the angle and it also gives you $\tan \theta$ multiplied by your distance for two or three different distances, in which you can directly get the height of the tree. So, that is all for today and will have another recap session in the next lecture.

Thank you for your attention [FL].