MODULE 4 - VOLUME MEASUREMENTS

Slide 1 WELCOME

Welcome to the Florida Department of Transportation's computer-based training series on Final Estimates, Level 1 Training. This is Module 4, Volume Measurements. This CBT contains audio and interactive elements. An alternate version is available on the resources page. To begin, select the start button or press Shift+N on your keyboard.

Slide 2 INTRODUCTION

Volume measurements are needed for two categories of pay items:

- Earthwork: items such as borrow excavation and subsoil excavation
- Concrete: the various classes of concrete used in bridges and other structures

Each category is calculated differently in the field.

Slide 3 UNITS OF MEASUREMENTS

The pay item unit of measurement for volume is usually by the cubic yard (CY). It is important to keep certain relationships in mind when calculating volumes. From the previous module, we remember that 12 inches equal 1 foot and Pi is equal to 3.1416. We now must remember that one cubic yard is equal to 27 cubic feet.

Slide 4 METHODS FOR COMPUTING VOLUMES

There are various methods used to compute volumes of earthwork and concrete pay items. These include:

1 Cross Sections
2. Truck Measurements
3. Geometric Shapes

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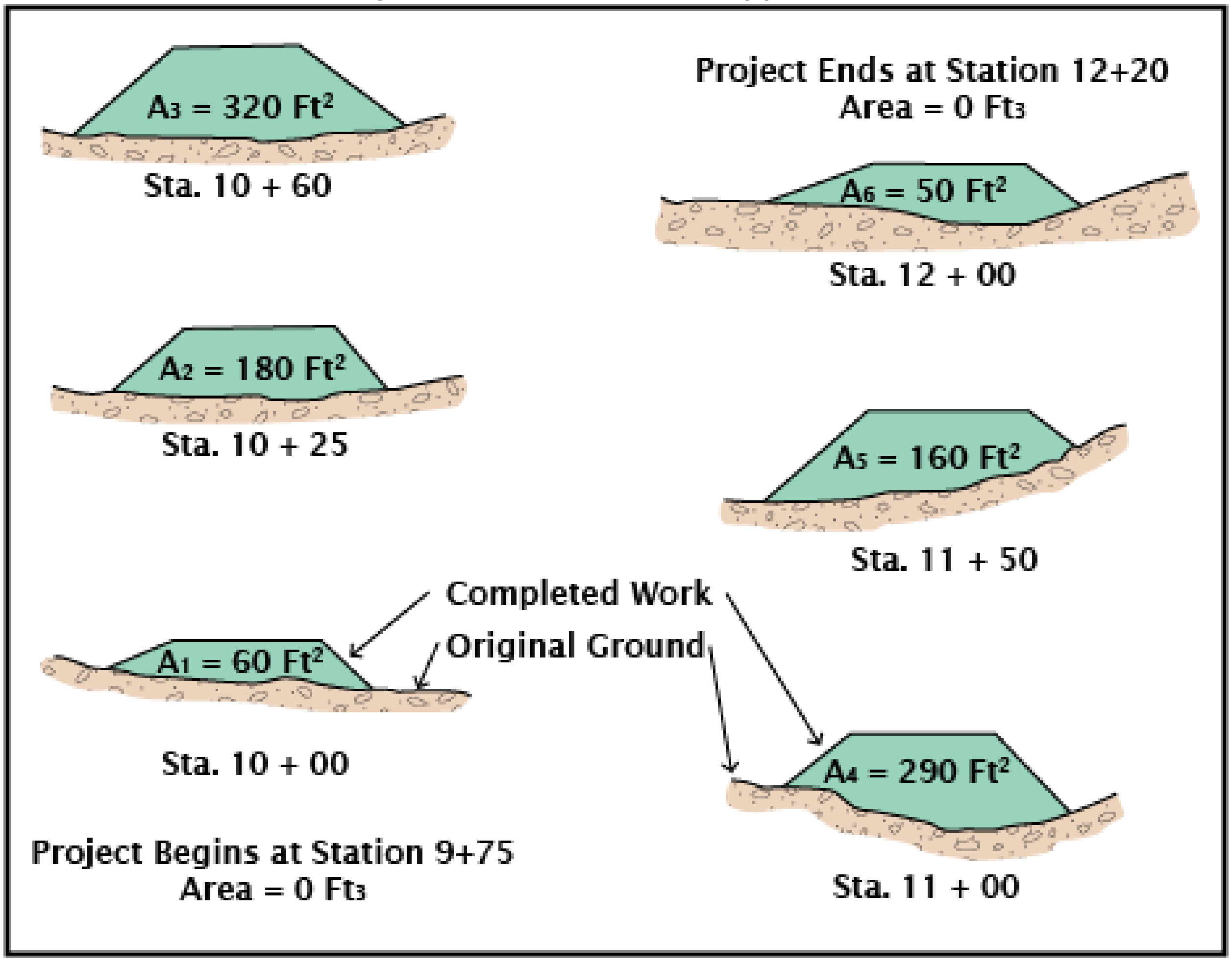
Earthwork can utilize two different methods: the use of cross sections and the use of truck measurements. For example, the Subsoil Excavation pay item compares areas surveyed before and after excavation to calculate the volume of earthwork removed. Whereas the Borrow Excavation pay item is paid by truck quantity.
The method used to calculate the volume of concrete in structures is geometric shapes. Concrete structures such as pilings and bridge decks can closely resemble geometric shapes such as cylinders and rectangular solids.

These volumes are fairly simple to calculate and can easily be related to the volume within the concrete structure.

Slide 6 CROSS SECTIONS

In Module 2, we talked about cross section notes and how they shall be recorded in field books. In this module, we will learn how to use cross sections for measuring volumes of earthwork. The figure shown illustrates typical earthwork cross sections.



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A common method of determining volumes from cross sections is that of average end area. It assumes that the volume between successive cross sections is the average of their end areas multiplied by the distance between them. This is expressed in the formula:

$$\text{Volume (ft.}^3\text{)} = \left(\frac{\text{Area 1 (ft.}^2\text{)} + \text{Area 2 (ft.}^2\text{)}}{2}\right) \text{ x Length (ft.)}$$

In which Area 1 and Area 2 are the end areas in square feet of successive cross sections and L is the length in feet between the sections.

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It should be noted that the average end area method is only approximate in calculating volumes due to the lack of survey between stations; however, it is generally accepted as sufficient for computing earthwork volumes. The area end method can be calculated manually and using less survey information. There are other methods of calculating earthwork volumes more precisely.

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Survey technology, such as LIDAR and photogrammetry, has advanced rapidly over the past years and is becoming more widely used. It is a more accurate means of calculating volumes since it obtains more survey information but requires computer software to calculate volumes using surface to surface comparison. Cross section and average end areas are being discussed in this course since they can be used in the field to quickly estimate volume quantities without computer software.

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Using the examples of cross sections shown, let's see if we can compute the volume of earthwork by applying the formula shown.

First, we must compute the volume between each pair of cross sections. Once these are calculated we can then calculate a total summation for the entire project.

Our final answer should be in cubic yards, so we will divide by 27.

$$\text{Volume (Yd}^3\text{)} = \left\{\left(\frac{\text{Area 1 (ft.}^2\text{)} + \text{Area 2 (ft.}^2\text{)}}{2}\right) \text{ x Length (ft.)}\right\}\left(\frac{\text{1 Yd.}^3}{\text{27 ft.}^3}\right)$$

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The formula will now be:

$$\text{Volume (Yd.}^3\text{)} = \left(\frac{\text{Area 1 (ft.}^2\text{)} + \text{Area 2 (ft.}^2\text{)}}{\text{54 ft.}^3 \text{ / Yd.}^3}\right) \text{ x Length (ft.)}$$

Volume equals the average of Area 1 and Area 2 multiplied by the length. The simplified formula equals sum of Area 1 and Area 2 divided by 54 multiplied by the length. If this is repeated for each interval between the cross sections, the following volumes shown in the table will be obtained.

Limits	Area (ft.^{2})	Volume (ft.^{3})
Station 9+75 – 10+00	Station 9+75 Area = 0 Station 10+00 Area = 60	$\left(\frac{0\text{ ft.}^2+60\text{ ft.}^2}{54}\right)$ x 25' = 27.78 CY
Station 10+00 – 10+25	Station 10+00 Area = 60 Station 10+25 Area = 180	$\left(\frac{60\text{ ft.}^2+180\text{ ft.}^2}{54}\right)$ x 25' = 111.11 CY
Station 10+25 – 10+60	Station 10+25 Area = 180 Station 10+60 Area = 320	$\left(\frac{180\text{ ft.}^2+320\text{ ft.}^2}{54}\right)$ x 35' = 324.07 CY
Station 10+60 – 11+00	Station 10+60 Area = 320 Station 11+00 Area = 290	$\left(\frac{320\text{ ft.}^2+290\text{ ft.}^2}{54}\right)$ x 40' = 451.85 CY
Station 11+00 – 11+50	Station 11+00 Area = 290 Station 11+50 Area = 160	$\left(\frac{290\text{ ft.}^2+160\text{ ft.}^2}{54}\right)$ x 50' = 416.67 CY
Station 11+50 – 12+00	Station 11+50 Area = 160 Station 12+00 Area = 50	$\left(\frac{160\text{ ft.}^2+50\text{ ft.}^2}{54}\right)$ x 50' = 194.44 CY
Station 12+00 – 12+20	Station 12+00 Area = 50 Station 12+20 Area = 0	$\left(\frac{50\text{ ft.}^2+0\text{ ft.}^2}{54}\right)$ x 20' = 18.52 CY
	TOTAL =	1,544.44 CY **1,544 CY (Rounded Accurately)**

Slide 12 KNOWLEDGE CHECK

Now let's test your knowledge.

1) Volume measurements are needed for which different categories of pay items?
   A. Subsoil and Borrow Excavation
   B. Pilings and Bridge Decks
   C. Fencing and Slope Pavement
   D. Both A and B
   E. None of the above

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2) Based on the areas determined for the Stations shown, what is the total volume of earthwork between Station 71+25 and 72+75, to the nearest cubic yard?

A. 1,406 CY
B. 2,828 CY
C. 1,916 CY
D. 1,666 CY

Station	Area	Volume
71+25	308.0 Ft^2	
71+48	287.0 Ft^2	
71+81	291.5 Ft^2	
72+23	304.0 Ft^2	
72+75	315.3 Ft^2	
	Total	_______

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3) The table shows the end areas determined for the indicated cross sections. Which of the following is the total volume of earthwork between stations 408+00 and 410+10, to the nearest cubic yard?

A. 2,925 CY
B. 2,332 CY
C. 1,927 CY
D. 1,513 CY

Station	Area (S.F.)	Volume (CY)
408+00	244	
408+62	263	
409+25	212	
409+81	259	
410+10	303	
	Total =	

Slide 15 TRUCK MEASUREMENTS

The secondary method for calculating earthwork includes measuring truck quantities. The Borrow Excavation pay item is an example of this. Each truck contains a manufacturer's certification or permanent decal showing the truck's capacity. This will need to be recorded on a department issued form and spot checked. The Department's field personnel will confirm the manufacturer's information matches the truck measurements.

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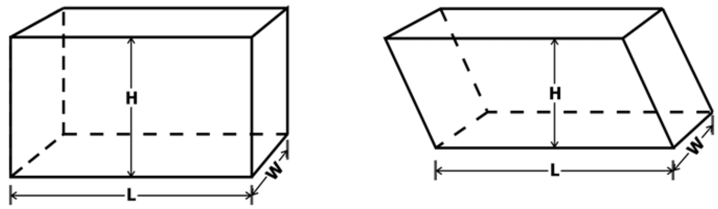
Once confirmed, the field technicians can simply count the number of loads delivered and multiply by the capacity of each truck to obtain the total volume hauled on-site. It is important to note that only certain pay items can be measured in this manner. The Standard Specifications will detail how an earthwork item can be paid.

Slide 17 GEOMETRIC SHAPES

Cross sections do not work well for computing the volumes of some pay items such as reinforced concrete. For these items, it is much better to measure the dimensions of the construction and use conventional formulas to compute geometric shapes. The Construction Mathematics CBT training course provides a good background in the use of formulas for calculating volumes. Let's take a quick look at some of the formulas we will be using. The simplest geometric shape is the rectangular solid with opposite sides parallel. Two examples are shown.



Volume = Length x Width x Height

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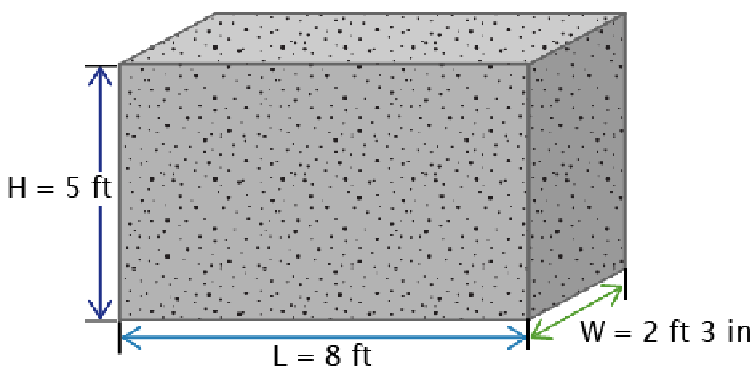
In both cases, Volume equals Length times Width times Height.

Let's work a problem. We will find the volume of the concrete block shown, to the nearest cubic yard.

First, we must make sure all the measurements have the same units of measurements. The height and length are measured in feet. The width is measured in feet and inches. We will convert the inches into feet. 3 inches divided by 12 equals 0.25 feet.

So, our width now equals 2.25 feet.



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Volume equals length time width times height. Our equation will be 8 times 2.25 times 5, which equals 90 cubic feet. To find the answer in cubic yards, use the cubic feet to cubic yard relationship mentioned earlier and divide by 27, so the volume equals 3.33 cubic yards. Rounding to the nearest cubic yards, we have a final answer of 3 cubic yards.

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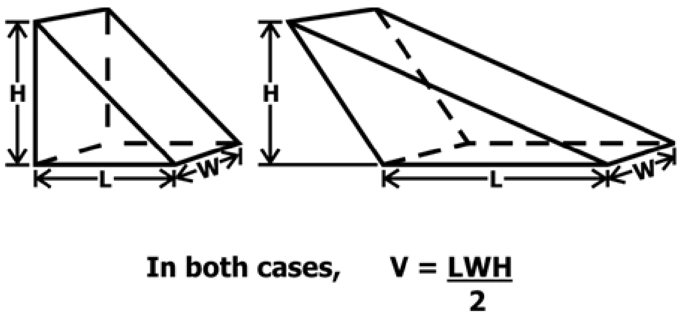
Now that we've learned how to calculate volumes for rectangular and parallelogram shapes, let's discuss triangular shapes. Since a triangle is half of a rectangle, this same concept will apply to volumes as well.



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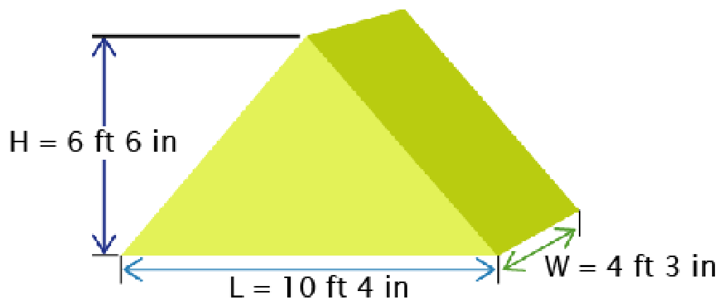
Let's calculate the volume of the triangle shown to the nearest cubic yard.



H = 6' 6" and $\frac{6"}{12"/foot}$ = 0.5' → H = 6.5 ft.

L = 10' 4" and $\frac{4"}{12"/foot}$ = 0.33' → L = 10.33 ft.

W = 4' 3" and $\frac{3"}{12"/foot}$ = 0.25' → W = 4.25 ft.

First, we must convert inches into feet to make sure all of our measurements have the same units of measurement. Height equals 6 feet and 6 inches. We take the 6 inches and divide by 12 to arrive at 0.5 feet. Height now equals 6.5 feet.

Length equals 10 feet and 4 inches. We take the 4 inches and divide by 12 to arrive at 0.33 feet. Length now equals 10.33 feet. Width equals 4 feet and 3 inches. We take the 3 inches and divide by 12 to arrive at 0.25 feet. Width now equals 4.25 feet.

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V = ½ x (Length x Width x Height)
= ½ x (6.5" x 10.33" x 4.25")
= 142.68 CF

$V = \frac{142.68\ CF}{27\ CF/CY} = 5.28 = 5\ CY$

The volume of our shape will equal 10.33 times 6.5 times 4.25 divided by 2. This gives us an answer of 142.68 cubic feet. However, we are looking for cubic yards. We will divide 142.68 by 27, which is 5.28 cubic yards. Our example said to calculate to the nearest cubic yard so our final answer will be 5 cubic yards.

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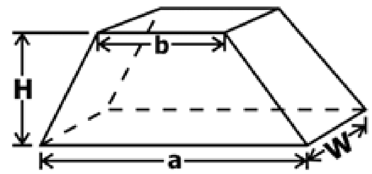
Now how about trapezoidal solids?

$$V = \frac{a + b}{2} \times HW$$



Do these formulas look familiar? When you stop to think about it, we are really computing an end area and then multiplying by a third dimension to find the volume.

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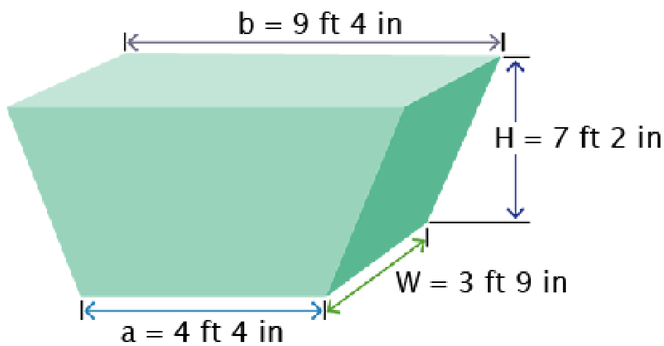
Let's calculate the volume of the trapezoid shown, to the nearest cubic foot.



First be sure that all units of measurement match. We will convert each to feet.

Length A equals 4 feet and 4 inches. We take the 4 inches and divide by 12 to arrive at 0.33 feet. Length A now equals 4.33 feet.

Length B equals 9 feet and 4 inches. We take the 4 inches and divide by 12 to arrive at 0.33 feet. Length B now equals 9.33 feet.

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Height equals 7 feet and 2 inches. We take the 2 inches and divide by 12 to arrive at 0.17 feet. Height now equals 7.17 feet.

Width equals 3 feet and 9 inches. We take the 9 inches and divide by 12 to arrive at .75 feet. Width now equals 3.75 feet.

Volume then equals a plus b divided by 2 times the height times the width, we take 4.33 plus 9.33 which equals 13.66 and divide by 2 which equals 6.83.

Multiply 6.83 by 7.17 by 3.75 to arrive at 183.64. Rounded our final answer is 184 cubic feet.

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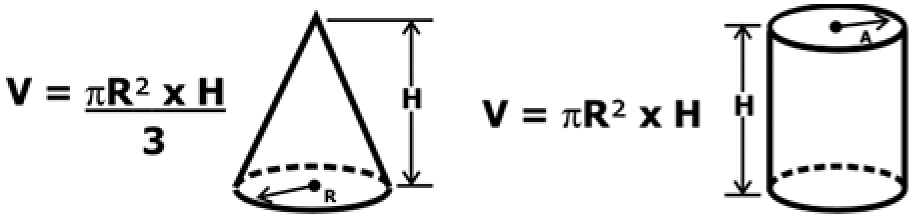
Let’s try it with a cylindrical solid and a cone:



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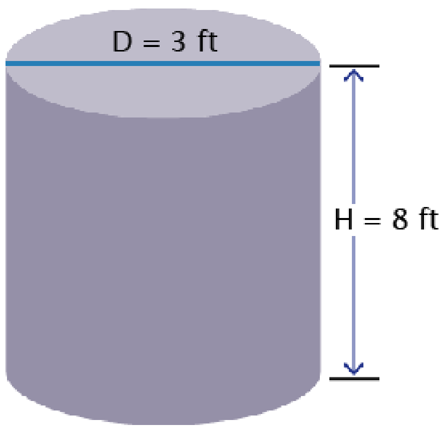
Using the equations given, let’s solve some examples together.



$$\mathbf{V = \pi R^2 \times H}$$

$$R = \tfrac{1}{2} \times (\text{Diameter}) = \tfrac{1}{2}\,(3') = 1.5'$$

$$\begin{aligned} V &= \pi R^2 \times H \\ &= 3.1416 \times (1.5')^2 \times 8' \\ &= \frac{56.5\ \text{CF}}{27\ \text{CF/CY}} \\ &= 2.1 = 2\ \text{CY} \end{aligned}$$

Calculate the volume of this cylinder to the nearest cubic yard. The formula for the volume of a cylinder states that volume is equal to Pi times the radius squared times height. We must remember that Pi is equal to 3.1416. Knowing that the diameter is 3 feet, we can divide this by 2 to find the radius.

Next we multiply 3.1416 by 1.5 squared by 8 (the height). This is equal to 56.5 cubic feet. Our problem asks for the answer in cubic yards. We will divide 56.5 by 27 to arrive at 2.1 cubic yards.

Lastly, we will round to the nearest cubic yard making the final answer 2 cubic yards.

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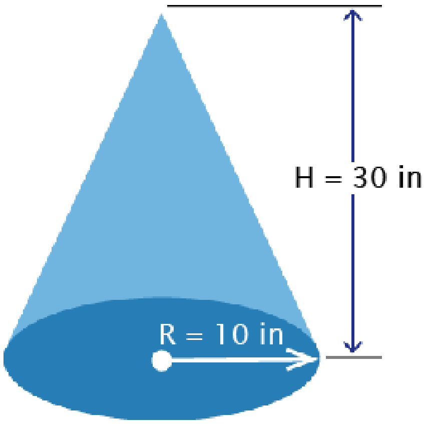
Now let’s calculate the volume of this cone to the nearest cubic foot. The cone formula states that Volume equals Pi times Radius squared divided by 3 times the height. Do you recognize this formula? You should; it is the formula for calculating volume of a cylinder divided by 3. This tells us that a cone is exactly one-third the volume of a cylinder.



$$V = \frac{\pi R^2 \times H}{3}$$

$$H = \frac{30 \text{ in.}}{12 \text{ in./ft.}} = 2.5 \text{ ft.}$$

$$R = \frac{10 \text{ in.}}{12 \text{ in./ft.}} = 0.83 \text{ ft.}$$

$$V = \frac{\pi R^2 \times H}{3} = \frac{((3.1416)(0.83')^2) \times 2.5'}{3} = 1.8 \text{ CF} = 2 \text{ CF}$$

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To solve this problem, we will first need to convert the measurements from inches to feet. 30 divided by 12 equals 2.5 feet. 10 divided by 12 equals 0.83 feet. Remember that for this course we will use 3.1416 as Pi, though in practice you should use the fullest capability of your machine to calculate values of Pi. So, 3.1416 times 0.83 squared divided by 3 times 2.5 equals 1.8. Round to the nearest cubic foot and our final answer is 2 cubic feet.

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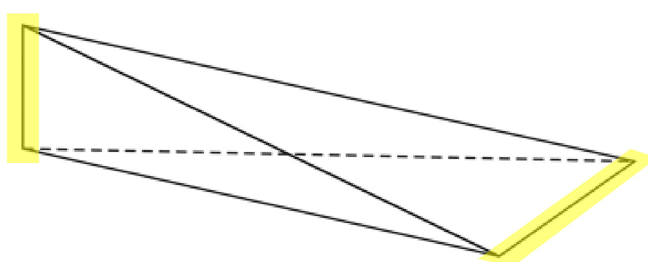
What if we have an odd irregular shaped object? For these instances, the prismoidal formula can be used.

When the side planes of an object taper in or out in relationship to one another, the average-end-area method is not accurate. For instance, in the shape shown, both end areas are zero, and yet the figure does have volume.



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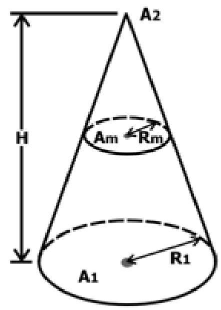
By using the prismoidal formula, the figure's volume can be computed accurately using the following formula:

$$\boldsymbol{V = \frac{(A1 + A2 + 4Am)}{6} H}$$

A1 and A2 correspond to the end areas of the object. However, A_m (or the mean area) corresponds to the cross sectional area located in the middle of the object.



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You will see many applications of prismoidal formulas in your work, especially in retaining wall, truck body and concrete structure calculations. The prismoidal formula should always be used for concrete volume computations when the average of the end areas does not equal the area located in the center of the object.

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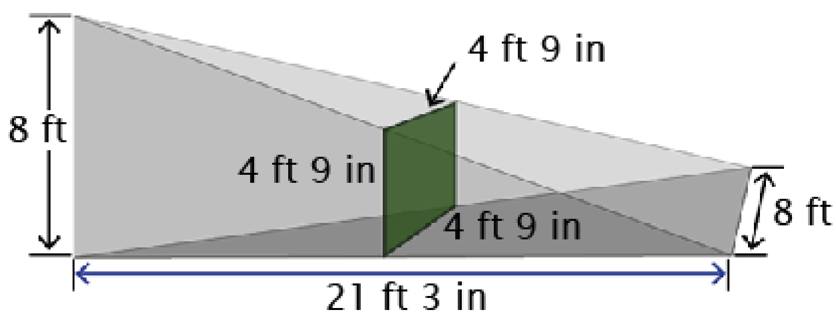
Let’s go through an example of an odd shaped concrete block with an average area:



Calculate the volume for the odd shape concrete using the prismoidal formula. Round the answer to the nearest cubic yard.

Volume equals A1 plus A2 plus 4 Am all divided by 6 times the height. A1 equals zero. A2 also equals zero.

The middle area equals 4, the area of the square, and 4 feet 9 inches equals 4.75 feet.

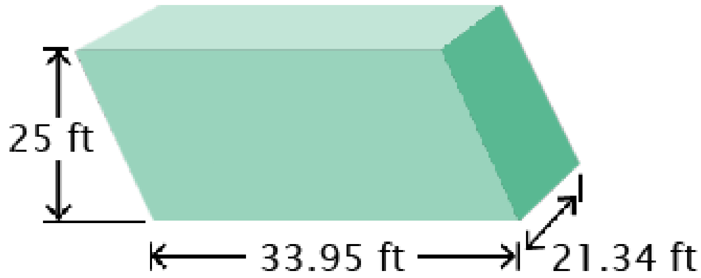
The Height (H) equals 21 feet and 3 inches, or 21.25 feet.

Total Volume equals 4 times 4.75 times 4.75 all divided by six, times 21.25 which equals 319.64 cubic feet. Divide that by 27 gives you 11.83, rounded to the nearest cubic yard is 12 cubic yards.

Slide 34 KNOWLEDGE CHECK

1) Which of the following is the volume of the shape shown to the nearest cubic yard?

A. 671 CY
B. 8,754 CY
C. 11,784 CY
D. 18,112 CY
E. None of the above



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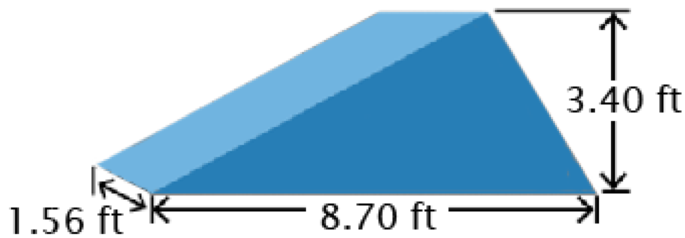
2) Which of the following is the volume of the shape shown to the nearest 10th of a cubic yard?

A. 0.86 CY
B. 0.9 CY
C. 1.3 CY
D. 2.8 CY
E. None of the above



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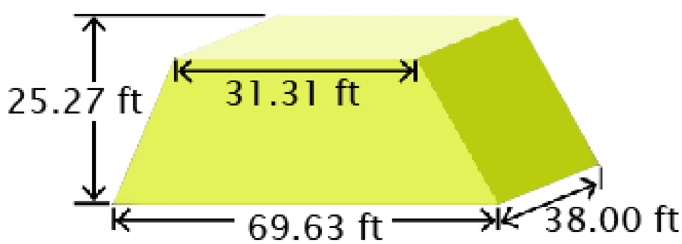
3) Which of the following is the volume of the shape shown to the nearest cubic yard?

A. 1,795 CY
B. 1,884 CY
C. 1,978 CY
D. 2,077 CY
E. None of the above



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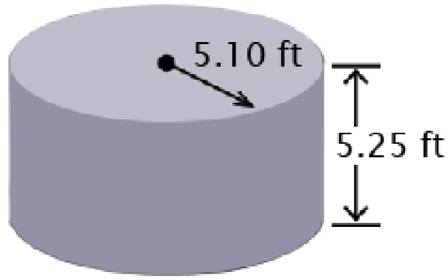
4) Which of the following is the volume of the shape shown to the nearest tenth of a cubic yard?

A. 19.3 CY
B. 17.5 CY
C. 18.4 CY
D. 15.9 CY
E. None of the above



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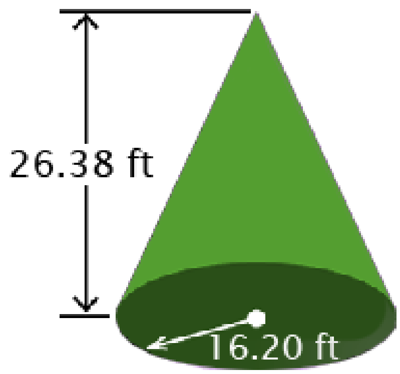
5) Which of the following is the volume of the shape shown to the nearest tenth of a cubic yard?

A. 282.0 CY
B. 296.8 CY
C. 268.5 CY
D. 326.4 CY
E. None of the above



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6) The prismoidal formula should always be used for concrete volume computations when the mean area:
A. Is less than 50 square feet
B. Is equal to the average end areas.
C. Is not the average of the two end areas
D. Is greater than 50 square feet.
E. None of the above

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7) True or False. The prismoidal formula is: $\boldsymbol{V} = \frac{(A1+A2+4Am)}{6}\boldsymbol{H}$

A. True
B. False

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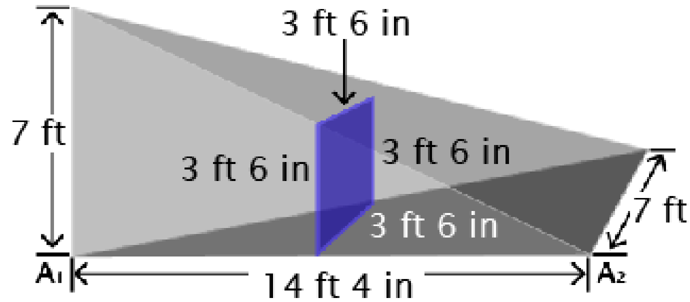
8) Which of the following is the volume of the figure shown to the nearest cubic foot?

A. 129 Cubic Feet
B. 117 Cubic Feet
C. 136 Cubic Feet
D. 157 Cubic Feet
E. None of the above



Slide 42 **CONCLUSION**

This is the end of Module 4. Thank you for your time and attention.