State of Alaska
Department of Transportation & Public Facilities
Northern Region Construction

Engineering Technician Training Guide

Wage Group 57 and Wage Group 55 / 54 Problems and Solutions

Edited & Revised
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Useful Conversion Factors and Formulae

CONVERSION FACTORS

1 meter = 39.37 inches (exact) or	1m = 39.37"
1 foot = 0.3048006096 meters	1' = 0.3048006096 m
1 station = 100 feet	1 sta. = 100'
1 square yard = 9 square feet	$1 yd^2 = 9 ft^2$
1 acre = 43560 square feet= 0.404687261 hectares	1 acre = 43560 ft^2 = 0.404687261 ha
1 hectare = 10000 square meters	1 ha = 10000 m^2 (A 100 meter square)
1 cubic yard = 27 cubic feet = 0.764559 cubic meters	$1 yd^3 = 27 ft^3 = 0.764559 m^3$
1 pound = 453.59237 grams	1 # = 453.59237 g
1 ton = 2000 pounds = 0.90718474 megagrams	1 T = 2000# = 0.90718474 Mg
1 megagram = 1000 kilograms	1Mg = 1000 kg
1 cubic centimeter of water† = 1 milliliter = 1 gram	1 cm^3 H_2O† = 1 mL = 1 g
1 liter of water† = 1 kilogram	1 L H_2O† = 1 kg
1 gallon of water‡ = 8.33 pounds	1 gal. H_2O‡ = 8.33 #
1 gallon = 3.785412 liters	1 gal. = 3.785412 L
1 cubic foot of water† = 7.48052 gallons	1 ft^3 H_2O† = 7.48052 gal.
1 cubic foot of water† = 62.428335 pounds	1 ft^3 H_2O† = 62.428335 #
1 cubic meter of water† = 1 kiloliter = 1 megagram	1 m^3 H_2O† = 1 kL = 1 Mg
1 megagram per cubic meter = 62.428335 pounds per cubic foot	1 Mg / m^3 = 62.428335 # / ft^3

‡Water at 20C (68 deg F)

† Water at 4C (39.2 deg F) (pure water at its most dense)

FORMULAS

Area & Volume

Area of a Rectangle = length x width	A = l w
Area of a Parallelogram = base x height	A = b h
Area of a Triangle = ½ base x height	A = ½ b h
Area of a Trapezoid = [(top + base)/2] x height (top and base parallel)	A = [(t + b)/2] h
Volume of a rectangular solid (V) = length x width x height (l x w x h)	V = l w h
Volume of a Trapezoidal solid = Trapezoid Area x Length (L)	V = [(t + b)/2] h L

Circles

radius = r

diameter = d

π = Pi = 3.14159 (approx.)

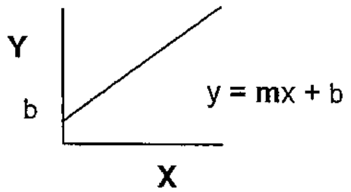
circumference = C = π d

Area = A = πr^2

Volume of a circular cylinder = circular area x length (L) $V = \pi r^2 L$

Slope

Algebraic Slope of a Line: The change in the value of the y coordinate associated with the change in the value of the x coordinate. An equation for a line always takes the format of : $y = mx + b$ where y is the y coordinate, x is the x coordinate, b is the y coordinate where the line crosses the y axis and **m is the "slope of the line"**.



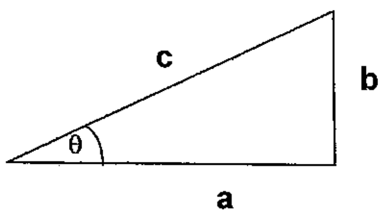
Slope Ratio: In the English system, horizontal to vertical ratio, H : V. For example, 4:1 means four horizontal units for each vertical unit. (The vertical component is always 1)
(The algebraic slope will be the vertical divided by horizontal or 1 / 4 = 0.25)

Percent Slope: An expression of slope describing the vertical rise or fall in a horizontal distance of one hundred feet. If it is fall, the percent will be negative. For example, 5 feet of vertical rise in 100 horizontal feet will be 5%. (The algebraic slope (not percent) will be 5 feet / 100 feet = 0.05 ft / ft., also called the Rate per foot, 0.05 feet per foot)

Horizontal Distance = Slope Ratio x Vertical Distance or Vertical Distance/Rate per Foot

Triangles & Trigonometry

For a **right** triangle where a = adjacent, b = opposite, c = hypotenuse, and θ (theta) = angle



Pythagorean Theorem: $a^2 + b^2 = c^2$ For any **right** triangle, the area of the square on the hypotenuse (i.e. the area of a square having the hypotenuse as one of its sides) equals the sum of the areas of the squares on the legs.
Trigonometry Functions: For any **right** triangle:
Sin θ = b/c = the ratio of the side opposite the angle θ to the hypotenuse.
Cos θ = a/c = the ratio of the side adjacent to the angle θ to the hypotenuse.
Tan θ = b/a = the ratio of the side opposite the angle θ to the side adjacent to the angle

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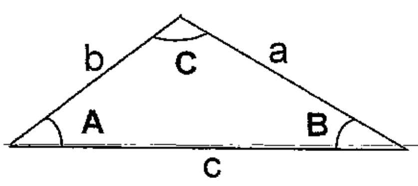
A + B + C = 180° (see figure below) The sum of the angles of **any** triangle equals 180 degrees.

Sine Law: a / sin A = b / sin B = c / sin C
The **Sine Law** applies to **any** triangle. Given any angle and the side opposite it, plus one more side or angle, and **all** of the sides and angles of the triangle can be found using this law and the sum of angles equation above.



Vertical Curves

VC = Vertical Curve

VPI = Vertical Point of Intersection of the tangents to a vertical curve.

VPC = Vertical Point of Curvature, where a vertical curve begins.

VPT = Vertical Point of Tangency, where a vertical curve ends.

El_d = elevation on the VC at d

El_{VPC} = elevation at the VPC

L = Length of the VC

d = distance from VPC

G = grade or slope of a tangent, positive if rising, negative if falling

These equations will work either using stations and percent grades, or using feet and decimal grades. Be very careful carrying the signs through these equations.

$VPC = VPI - L/2$

$El_{VPC} = El_{VPI} - [(G_1)(L/2)]$

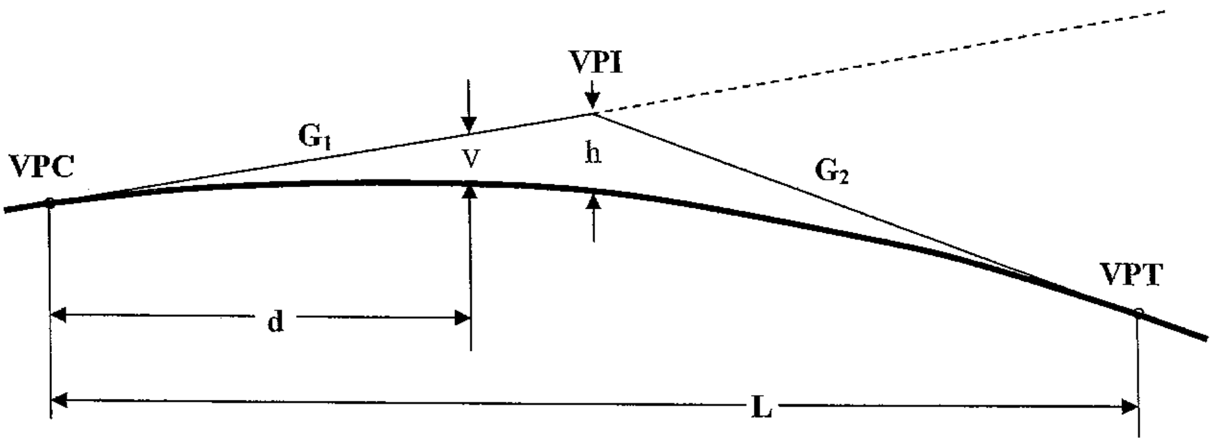
$VPT = VPI + L/2$

$El_{VPT} = El_{VPI} + [(G_2)(L/2)]$

$El_d = [(G_2 - G_1) / 2L]\, d^2 + (G_1)\, d + El_{VPC}$

Location of high or low point on the vertical curve

$HiLo = VPC - [(G_1)\, L / (G_2 - G_1)]$



Horizontal Curves

PC = Point of Curve (or Curvature) = the point on ℄ where a horizontal curve begins.

PT = Point of Tangent (or Tangency) = the point on ℄ where a horizontal curve ends.

PI = Point of Intersection (**not π**) = the point where the tangents on either end of a horizontal curve will intersect if extended. This point will be outside the middle of the curve.

T = Tangent = the length of the extended tangent from the PC to the PI and of the extended tangent from the PT to the PI (which are equal). (This is not the trigonometry definition, see formulae below for that.)

L = the Arc Length of a horizontal curve.

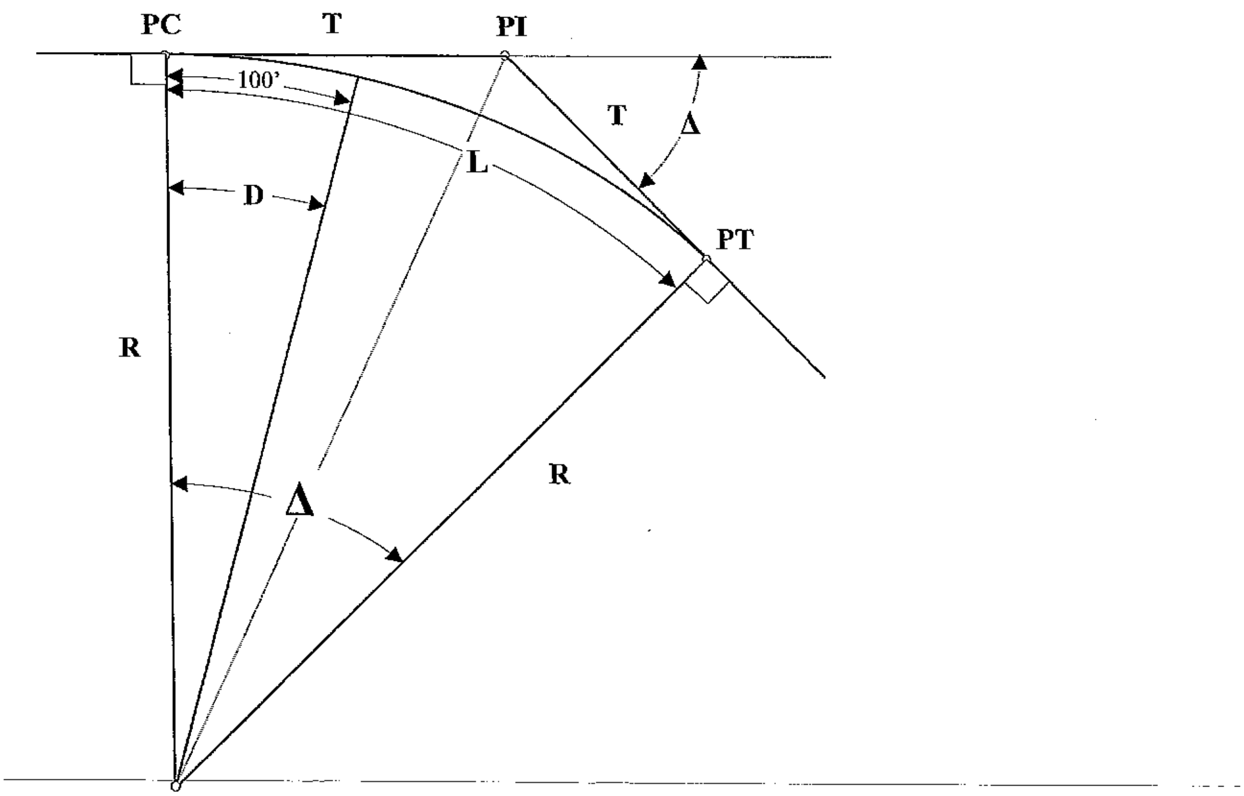
R = Radius of a curve = a measure of how sharp a horizontal curve is. A small radius means a sharp curve. The radii to both the PC and PT will always be perpendicular to the adjacent tangents (hence the curve itself is tangent to both tangents).

D = Degree of curve = another measure of how sharp a horizontal curve is. It is the angular change in direction of a curve in 100 arc feet, expressed in degrees. A larger number means a sharper curve.

Δ = Delta = the total change of direction of a horizontal curve, expressed as an angle. So if a curve begins northbound and ends eastbound, $\Delta = 90^\circ$ Rt, the tangent deflection angle. It is also (by perpendicular geometry) the included angle between the radii to the PC and the PT.

tan θ = opposite side / adjacent side (for a right triangle) so
$\tan(\Delta/2) = T / R$

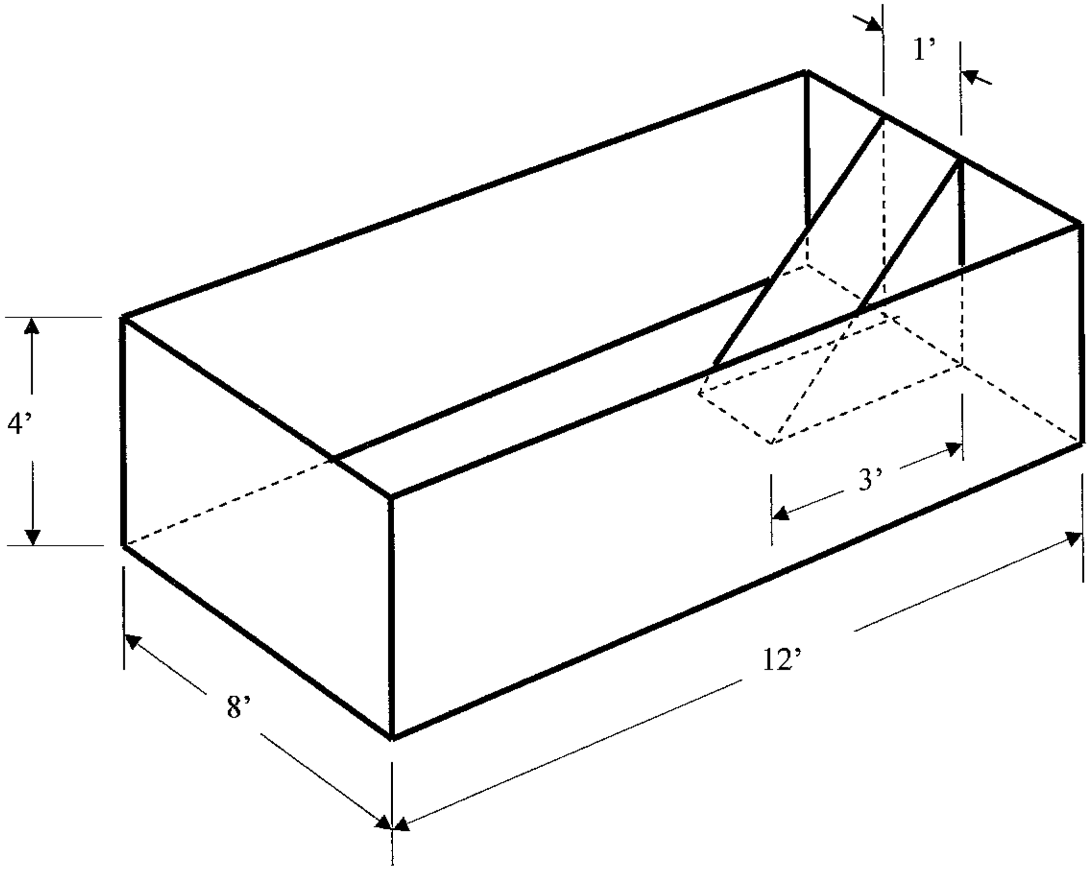
$2\pi R / 360^\circ$ (full circle) = $100' / D(^\circ) = L / \Delta(^\circ)$ This is a simple proportion of curve length to angle circumference of a full circle : 360° = given length around the circumference: included angle = 100' : D = L : Δ



Wage Group 57 Problems and Solutions

Problem #1

Given: The end dump bed shown below:



A. Find the volume of the end dump bed in cubic yards.

The volume of the rectangular box is V = L x W x H = 12' x 8' x 4' = 384 ft^3

(Whenever volume is paid by truck measure, the measure is a level load.)

The volume of the hydraulic ram housing equals the area of the triangle times its width.

V = (½ B x H) x W = (½ x 3' x 4') x 1' = 6 ft^3

Total V = 384 ft^3 – 6 ft^3 = 378 ft^3

Converting to cubic yards

V = 378 ~~ft~~^{3} x (1 yd^3 / 27 ~~ft~~^{3}) = **14.0 yd^3**

B. If the truck is filled level full with borrow which weighs 2 tons per cubic yard, what will the net weight of the truck be?

Net weight is the weight of the truck's cargo, so the weight of the borrow.

So **Net Wt** = 14.0 ~~yd~~^{3} x (2 T / ~~yd~~^{3}) = **28.0 Tons**

Problem #2

Given:

A cylindrical water tank with a length of 35’ and a diameter of 8’.

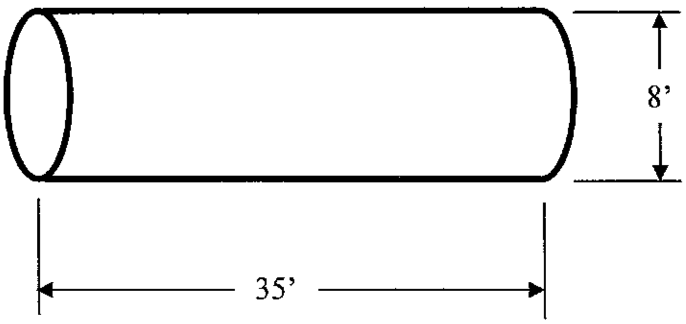
Formulae:

1 gallon of water = 8.34 pounds or 1 gal. H_2O = 8.34 #

1 cubic foot of water = 62.4 pounds or 1 ft^3 H_2O = 62.4 #

$\pi = 3.14159$

Volume of a circular cylinder = circular end area x length = $V = \pi r^2 L$,
where r = radius and L = length of the cylinder



Find the capacity of the tank in gallons

First find the volume of the tank in cubic feet. Remember, the radius is half the diameter.

$V = \pi r^2 L = 3.14159 \times (8'/2)^2 \times 35' = 3.14159 \times 16\ ft^2 \times 35' = 1759.29\ ft^3$

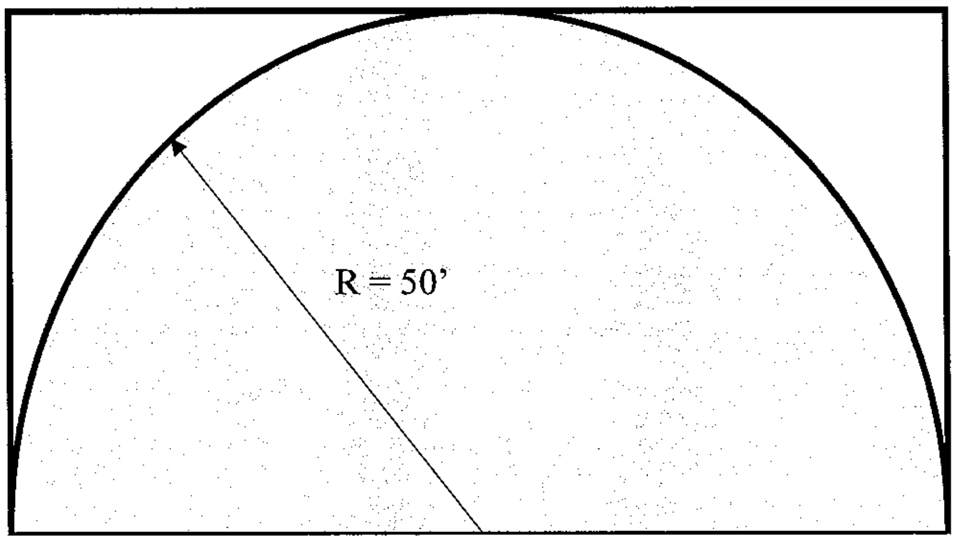
Then convert this to gallons. This requires first converting to pounds of water, then on to gallons of water. (Note that we can find the capacity in gallons using the parameters of water even if it is a fuel tank, though the weight of the contents will be different than our intermediate calculation.)

$1759.29\ ft^3 \times (62.4\# / 1\ ft^3\ H_2O) = 109779.7\#$

$109779.7\# \times (1\ gal.\ H_2O / 8.34\#)$ = **13,163 gallons = Tank capacity**

Problem #3

Calculate the area of the unshaded portions (fillets) of the drawing.



There is no formula given for the area of unshaded portions of this drawing. However, the area of the shaded portion is the area of a half circle (A_{hc}) and the area of the whole drawing is the area of a rectangle (A_r). So by finding the area in the rectangle that is not in the half circle, which is the difference between these two areas, the area of the unshaded portion can be derived.

The area of a circle = πR^2 so the area of the half circle is

$A_{hc} = \pi R^2 / 2 = 3.14159 \times 50'^2 / 2 = 3927.0 \text{ ft}^2$

The area of the rectangle is 2R wide times R high.

$A_r = bh = 100' \times 50' = 5000 \text{ ft}^2$

So the area of the unshaded portions (A_u) is:

$\mathbf{A_u} = A_r - A_{hc} = 5000.0 \text{ ft}^2 - 3927.0 \text{ ft}^2 = \mathbf{1073.0 \text{ ft}^2}$

Problem #4

Given:

A subcut starts abruptly at station 52+19. The excavation is from 5' left of centerline to 9' right. It is 3.5' deep. The subcut ends abruptly at station 53+12.

Compute the cubic yards removed from this subcut.

A subcut is an unplanned excavation, usually to remove poor material. In order to pay for this work, it is usually measured and then paid for by the cubic yard. Above is a description of such an excavation.

In a problem like this, it is usually helpful to draw a picture, in this case, of the excavated hole.

V = L x W x D

The length L = 5312 – 5219 = 93'

(Stations are 100 feet long, and are designated by the number to the left of the plus sign (52 & 53). The intermediate feet are represented by the number to the right of the plus sign. By removing the plus sign, a number results that represents a location in feet, so 5312 feet. If the plus sign is replaced with a decimal point, the result is in stations, so 52.19 stations. Stations are measured along centerline, usually from an arbitrary point that is off the project; the project almost never starts at 0+00 and stations are never negative. An exact station can be represented **53~** = 53+00 and the intermediate feet are can be represented without the station, +12, if it is clear to which station they belong.)

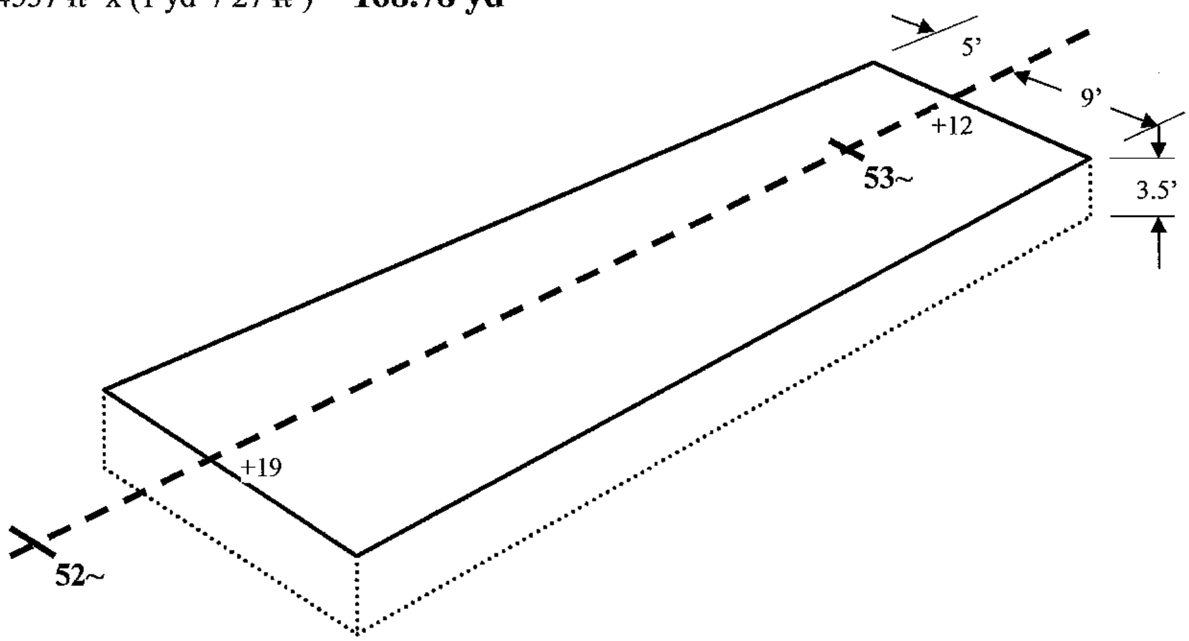
The width W = 5' + 9' = 14'

And depth D = 3.5'

So V = 93' x 14' x 3.5' = 4557 ft^3

Converting this to cubic yards

V = 4557 ft^3 x (1 yd^3 / 27 ft^3) = **168.78 yd^3**



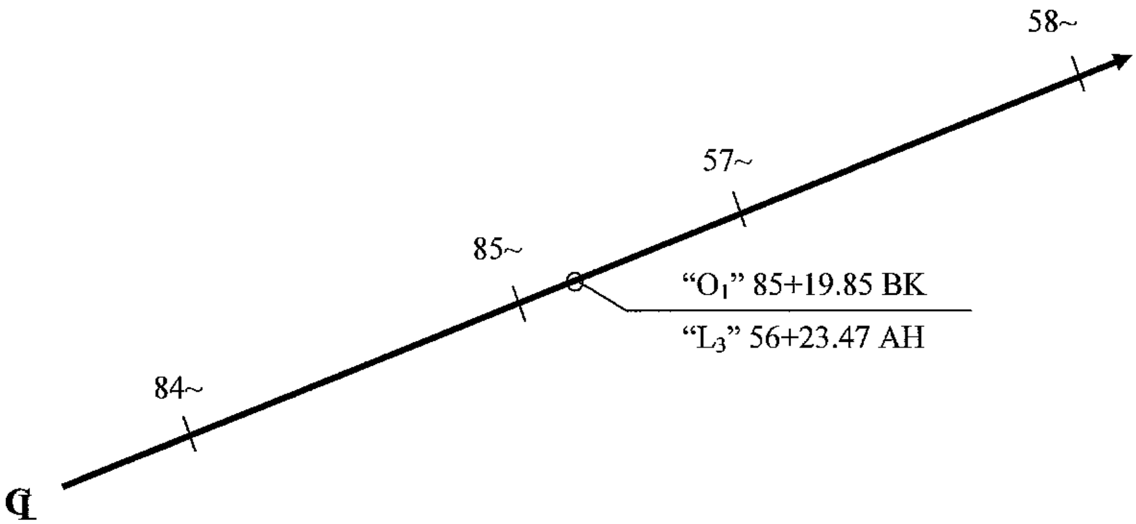
Given: Equation "O_1" 85+19.85 BK / "L_3" 56+23.47 AH

Notice that in this case, the stations from 56+24 to 85+19 (again in round numbers) may **exist on both lines**, so care must be taken to include the line name ("O_1" or "L_3") in order to specify any point in this range.

What is the distance from "O_1" 85+00 to "L_3" 60+00?

"O_1" 85+00	to "O_1" 85+19.85	= 19.85'
"L_3" 56+23.47	to "L_3" 60+00	= 376.53'
		396.38'

The distance from "O_1" 85+00 to "L_3" 60+00 = 19.85' + 376.53' **= 396.38'**



Problem #5

Given: Equation "O_1" 75+19.25 BK / "L_3" 96+29.48 AH

What is the distance from station "O_1" 75+00 to "L_3" 97+00?

An equation is a **point**, usually on centerline, where one line ("O_1") ends and another line ("L_3") begins, so the point has stationing for both lines. So from this equation, if you travel back station, BK, you begin counting backwards from "O_1" 75+19.25, and if you move ahead, AH, you begin counting forward from "L_3" 96+29.48. Notice that for this example, stationing from 75+20 to 96+29 (in round numbers) **does not exist** on either line; it is skipped over. Hence these omitted stations are not part of the distance between "O_1" 75+00 to "L_3" 97+00.

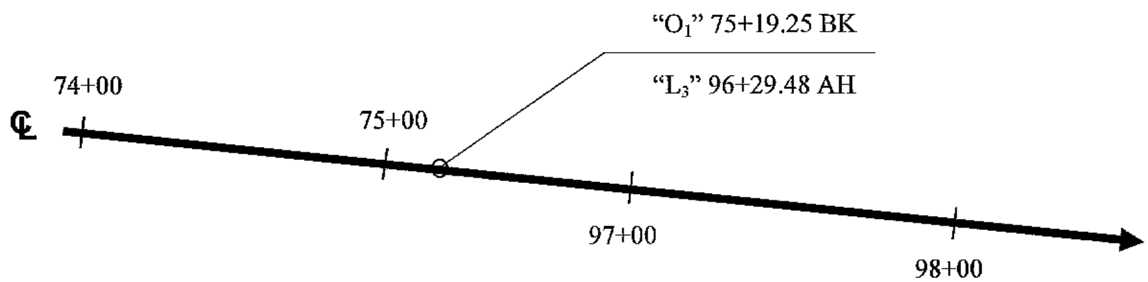
Equations are produced in design to merge two lines together, or to make adjustments on a line late in the design process. For instance, the designer wants to blend two adjacent projects together so that the original stationing on each project can still be used, which could be the case in this problem.

Or he adjusts the length of a curve and now the stationing at the end of the curve doesn't match the stationing beyond the curve. Rather than change the stationing for the whole rest of the project, it is simpler to insert an equation to make the stationing match. Usually, the curve line will be renamed to reduce confusion, so if the mainline is "L", perhaps the curve will be "O_1". (This will result in two equations, one at the beginning of the curve which will change the name of the line, normally without changing the station ("L_3" 60+25 BK = "O_1" 60+25), and one at the end of the curve to make the adjustment and change back to the original line, as in this problem.)

So, in this problem, if you begin at "O_1" 75+00 and move ahead, you reach the equation at "O_1" 75+19.25, a distance of 19.25'. Then you continue on from "L_3" 96+29.48 to "L_3" 97+00, a distance of 70.52' more.

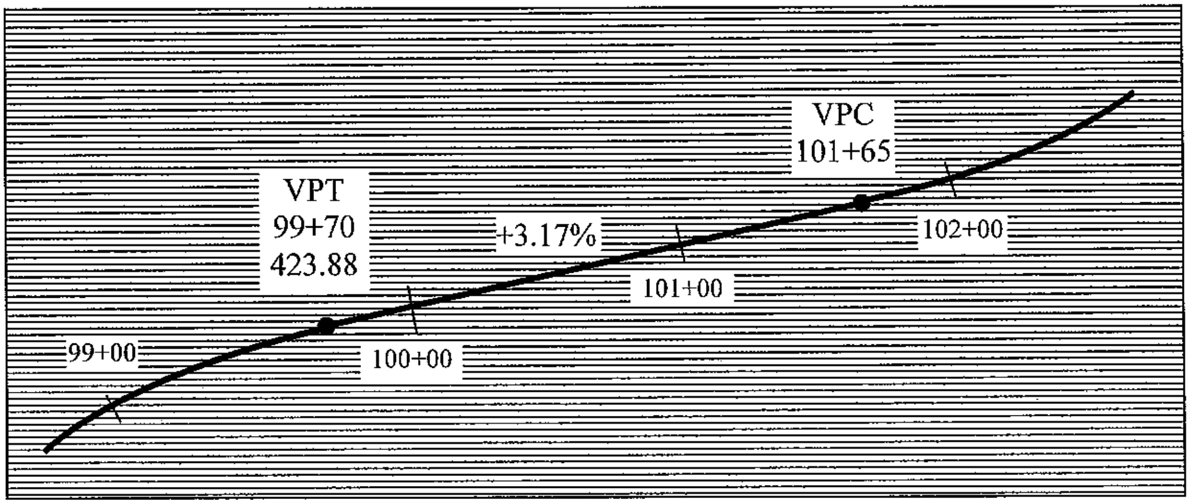
75+00	to	75+19.25	=	19.25'
96+29.48	to	97+00	=	70.52'
				89.77'

The distance from station "O_1" 75+00 to "L_3" 97+00 = 19.25 + 70.52 = **89.77** feet.



Problem #6

Given the profile view below:



Calculate the elevation of the VPC at 101+65.

A profile view of a roadway is a view that shows elevation, so the hills and valleys may be seen. In this drawing, the road is going uphill. There is a vertical curve that ends at 99+70 (VPT = Vertical Point of Tangency), then a vertical tangent (straight line) with a grade of 3.17% to 101+65, which is the beginning of another vertical curve (VPC = Vertical Point of Curvature). The 3.17% grade means that the road climbs 3.17' in every hundred feet. This grade begins at the end of the vertical curve at 99+70 at an elevation of 423.88 feet, and continues to 101+65.

Step 1: Calculate the horizontal distance from the known elevation to the point where the elevation is to be determined.
Distance = 10165 – 9970 = 195 feet
(See problem 4 for an explanation of how to convert stations into feet.)

Step 2: Change the per cent grade to a decimal, +3.17 / 100 = +0.0317. This decimal represents the feet the road rises in one foot, or ft / ft.
(If the grade is negative, it represents the amount the road descends or falls in one foot.)

Step 3: Calculate the difference in elevation between the VPT and the VPC.
Elevation difference = 195' x 0.0317 ft /ft = 6.18'

Step 4: Add this difference to the elevation at 99+70.
423.88' + 6.18' = **430.06' = $\mathbf{VPC_{el}}$**

Alternatively, you may calculate the horizontal distance in stations
Dist = 101.65 – 99.70 = 1.95 Sta.

Calculate the difference in elevation
E_{diff} = 1.95 ~~sta~~ x 3.17' / ~~sta~~ = 6.18'

Calculate the VPC elevation
$\mathbf{VPC_{el}}$ = 423.88' + 6.18' = **430.06'**

Calculate the centerline elevation at 101+00.

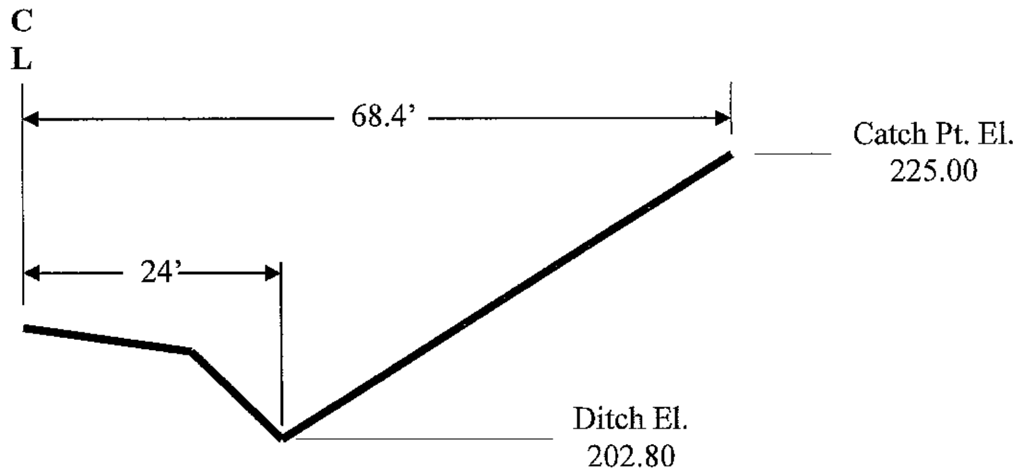
10100 – 9970 = 130 ft

130' x .0317 = 4.12 ft

423.88 + 4.12 = **428.00 = Elevation at 101~**

Problem #7

Given the partial cross section below:



Find the slope of the back slope.

A cross section is a view of the roadway perpendicular to the centerline. In this case, centerline is on the left, and moving to the right, the roadway surface right of centerline, the fore slope down to the ditch bottom, and the back slope up to original ground at the catch point. This is a cut section. In a fill section, the fore slope is the slope down from the shoulder to original ground, and there is no back slope.

Slope (in the English system for roadways) is expressed as a ratio of the horizontal distance corresponding to the vertical distance of one, so

The horizontal distance = 68.4 – 24 = 44.4

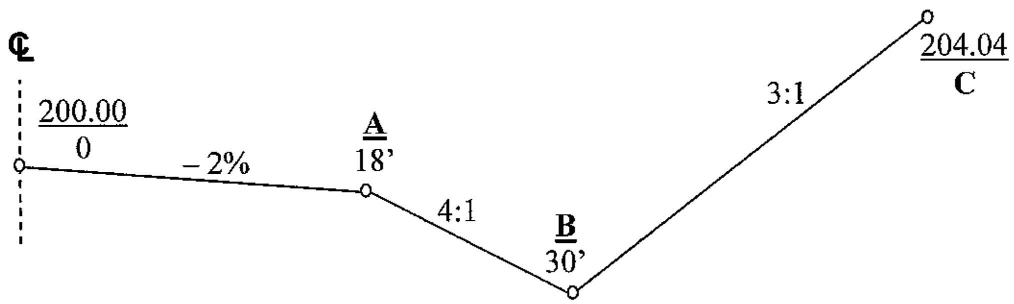
The vertical distance = 225.00 – 202.80 = 22.2

And the **slope** = 44.4 : 22.2 **= 2 : 1**

Problem #8

Given:

The cross sectional drawing below:



Solve for A, B, & C

Each of the number sets (they look like, but are not fractions) above represent elevation over distance from centerline for the adjacent point. Again, they are **not** fractions. So the centerline (0') is at an elevation of 200.00', and A is the elevation 18' right of centerline, etc. To calculate A, the change in elevation needs to be computed along the 2% crown, and subtracted from the elevation at centerline, 200.00'.

A = 200.00 – 2% x 18' = 200.00 – 0.02 x 18 = 200.00 – 0.36 = **199.64 = A**

Or using a ratio, 2% means 2' vertical in 100' horizontal and using the proportion
2' is to 100' as the elevation difference from ℄ to A (200.00' – A) is to 18'
2' / 100' = (200.00' – A) / 18'
18' x 2' / 100' = 200.00' – A
0.36 = 200.00' – A
200' – 0.36' = **199.64 = A**

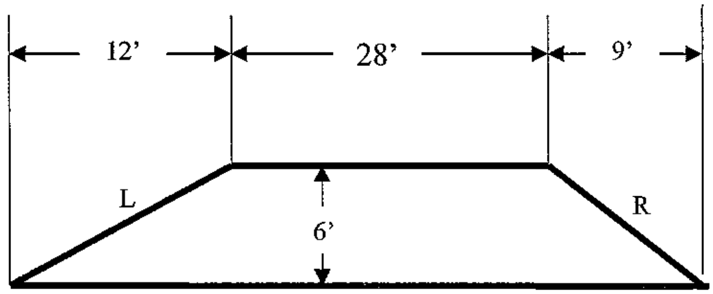
Then the elevation at B can be calculated by computing the distance from the shoulder to the ditch bottom, and using the 4:1 slope ratio to compute the change in elevation between these two points, which will then be subtracted from A. In the slope ratio the 1 always represents the vertical component of the ratio. (Note that this is the inverse of an algebraic slope. Metric slopes are turned around so that they do represent algebraic slopes. So an English 4:1 becomes a metric 1:4, with 1 still representing the vertical.) For every unit of vertical change, there will be 4 units of horizontal change. Since the ditch is lower than the shoulder the slope will be negative.
–4 / 1 = (30 – 18) / (B – A)
Solving for B
–4 x (B – A) = 12
B – A = 12 / (–4) = –3
B = A – 3 = 199.64 – 3 = **196.64 = B**

Solving for C is similar, but finding the distance rather than the elevation. So using the proportion
3 / 1 = (C – 30) / (204.04 – 196.64) = (C – 30) / 7.40
3 x 7.40 = C – 30
C = 22.2 + 30 = **52.2 = C**

Problem #9

Given:

The cross section below:



Solve for the slopes L & R of the fore slopes

The fore slope is the slope from the shoulder to the natural ground or the ditch bottom.
The slope is the ratio of the horizontal to the vertical, with the vertical being one.

Left slope horizontal : vertical ratio
L = 12' : 6' which needs to be reduced so that the vertical is one.
12' : 6' = 12'/6' : 6'/6' = **2:1 = the left fore slope.**

Right slope ratio:
R = 9' : 6' = 9'/6': 6'/6' = **1½ : 1 = the right fore slope**.

Find the area of the cross section

A cross section of a road is a view of the road when cut perpendicular to centerline. It can show the different layers of construction such as excavation, borrow, base course, and asphalt, though this one does not have that much detail.

The shape of this cross section is a trapezoid.

Area of a Trapezoid = [(top + base)/2] x height, where the top and base are parallel

$$Area = \left[\frac{28' + (12' + 28' + 9')}{2}\right] \times 6' = \left[\frac{28' + 49'}{2}\right] \times 6' = \frac{77'}{2} \times 6' = 231 ft^2 = Area$$

231 ft² = cross sectional area

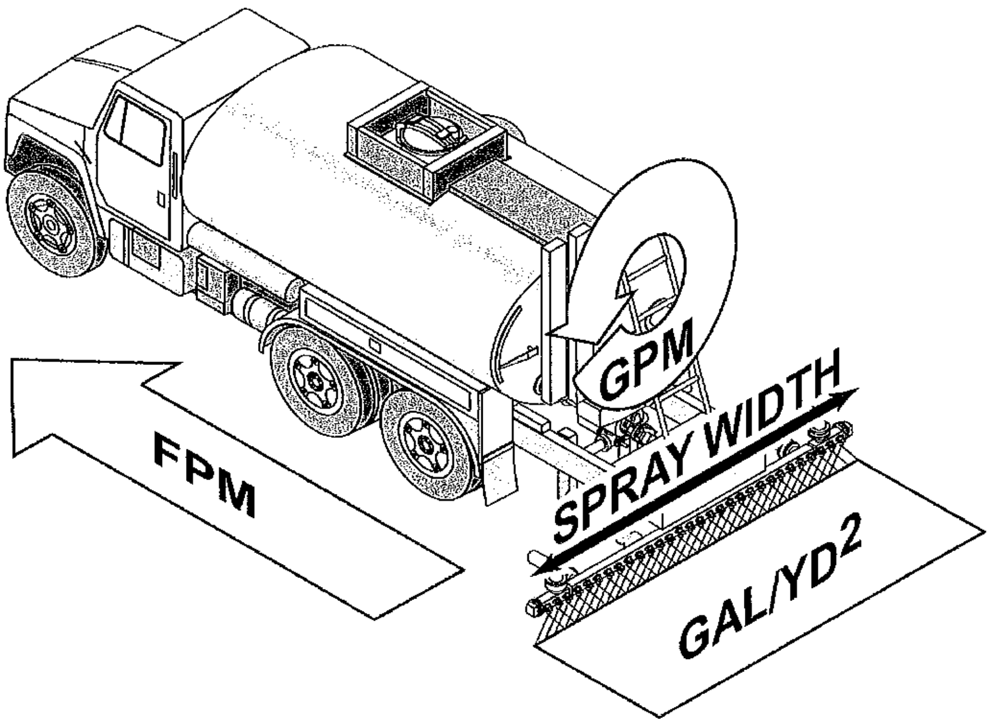
Problem #10

Given:

A distributor sprays tack from 134+44 to 52+18, 15 feet wide, and uses 11,220 pounds of material.
Tack Coat STE-1 weighs 8.40 pounds / gallon.
The plan application rate is 0.10 gallons per square yard.

Calculate the yield in gallons per square yard and the per cent of plan quantity.

This is a distributor (truck) spraying an asphalt material on a roadway (with dimensions shown than are not required for this problem). Tack is a liquefied asphalt material sprayed onto a roadway to prepare it for paving.



http://www.etnyre.com/images/centennialtruckthing.pdf

First calculate the number of gallons used.

11,220 # x (1 gal / 8.4 #) = 1335.7 gallons

Then calculate the area covered (in square yards).

(13444' – 5218') x 15' x (1 yd^2 / 9 ft^2) = 13,710.0 yd^2

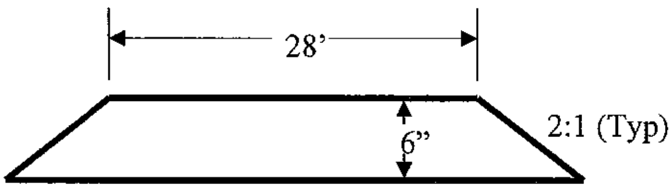
Then the yield is

1335.7 gal / 13,710.0 yd^2 = **0.0974 gal / yd^2 = yield**
(0.0974 gal / yd^2) / (0.10 gal / yd^2) = 0.974 which is **97.4% of plan quantity**.

Problem #11

Given:

Base course compacted to the required density weighs 138 pounds per cubic foot.
The typical section for base course is shown below.
1 station = 100 feet



How many tons of base course will be required to fill one station?

A Typical Section is the planned cross section for a particular length of road.

In order to determine the answer, the volume in cubic feet of one station of base course needs to be computed, and then converted into a weight. The volume is found by calculating the area at each end, averaging the two areas, and multiplying that average by the length between the two areas. This volume can then be multiplied by the unit weight and converted to tons.

The area of the typical section is the area of a trapezoid, which requires the top and bottom dimensions and the depth. The bottom is calculated using the slopes to determine how much wider it is than the top. The (Typ) = typical, and means this 2:1 slope applies to all similar slopes, so it applies to both sides. So for a 2:1 slope, and a 6" vertical measure, the horizontal measure is 12" <u>on each end.</u>

2 : 1 :: H : 6" so [2 / 1 = H / 6"] = [2 x 6" / 1 = H x (~~6"~~ / ~~6"~~)] = 12" = Horizontal

(Note that if the roadway had a crown or super, the 12" dimension would have to be determined using the formula in Problem 17.) So the bottom of base course is 28' + 12" + 12" wide.

Converting these dimensions all into feet, the bottom = 28' + 1'+ 1' = 30'.

The area of the trapezoid = A = [(top + base)/2] x height (where the height is in the same dimensions as the top and base, feet)

A = ((28' + 30') / 2) x (6 ~~in~~ x (1' / 12 ~~in~~)) = 14.5 ft^2

Since both ends are the same (they have the same Typical Section), the average end area will also be 14.5 ft^2.

Then the volume will be V = Ave. end area x length.

V = 14.5 ft^2 x (1 ~~sta~~ x (100 ft / 1 ~~sta~~)) = 1450 ft^3

Total weight is then

W = 1450 ~~ft^3~~ x 138 # / ~~ft^3~~ = 200,100 #

The answer is required in tons, so

200,100 ~~#~~ (per station) x (1 T / 2000 ~~#~~) = **100.05 T (per station)**

Problem #12

Given:

The contractor placed 362,220 # of hot mix asphalt from 'NW' 25+76 to 'NW' 35+90, 12' wide.

The asphalt is supposed to be 2" thick, and the theoretical yield is 220 # / yd^2 (that is, a square yard of asphalt, 2" thick will weigh 220#).

What is the actual yield, and what is the percent over or under run?

Area of paving = (3590' – 2576') x 12' x (1 yd^2 / 9 ft^2) = 1352 yd^2

Actual Yield = 362,220 # / 1352 yd^2 = **267.9 # / yd^2**

% Yield = (267.9 # / yd^2) / (220 # / yd^2) = 1.218 = 121.8%

So the **Over Run = 21.8%**

Note that once the % yield is calculated, the actual depth is easily calculated using the ratio

2" / 100% = Act. depth / % yield = Act. depth / 121.8%

Actual Depth = 2" x 121.8% / 100% = 2.44 inches

Actual tons per station or pounds per foot (other methods of computing a yield) can also be found this way if you calculate or know the theoretical yield in these units first.

Problem #13

Given:

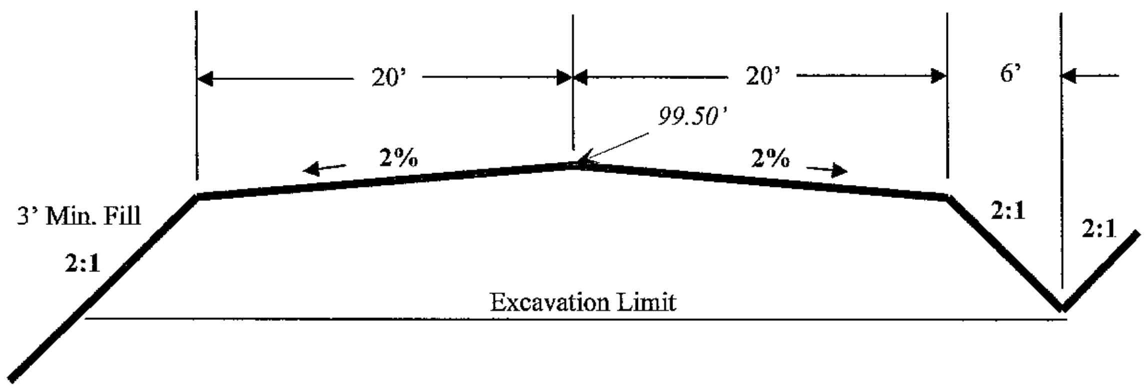
The following original ground survey information, typical section, and the finish centerline elevation for Station 105+00 (in italics).

Plot the cross section for 105+00 on the attached graph paper using a scale 1" = 1' vertically and 1" = 20' horizontally.

OG Survey @ 105+00

HI = 100.00

99.5	99.0	94.2	97.4	97.9	97.7	94.6	98.8	93.1
0.5	*1.0*	*5.8*	*2.6*	*2.1*	*2.3*	*5.4*	*1.2*	*6.9*
50	*30*	*18*	*12*	*0*	*12*	*18*	*28*	*50*



Typical Section

100+00 to 155+00

First, some explanation. The original ground (OG) survey is to establish what existed before work began. It depicts what the ground would look like if sliced perpendicular to centerline at the station 105+00. It is written up in a field book much as shown above. The bottom number is the distance right or left of centerline. (Centerline will be 0). The middle number is the rod shot at that point. The top number is the elevation calculated (using the rod shot & HI) of that same point. So, at 105+00, 30' left, the rod shot was 1.0'. Using the given height of instrument (HI) of 100.00', the elevation is then 100.00 – 1.0 = 99.0'.

The typical section is the planned cross section of the new road, usually for a range of stations (100+00 to 155+00). It shows the widths and slopes needed to construct the roadway. Usually, one side of centerline will depict a cut section with a ditch and back slope (on the right here) and the other side a fill section. However, either side can be either if the new road is symmetric, and the mirror image is used as needed. The lines on either edge extend until they intercept the original ground.

The elevation of the centerline has been given for this particular station, and is *99.50'*.

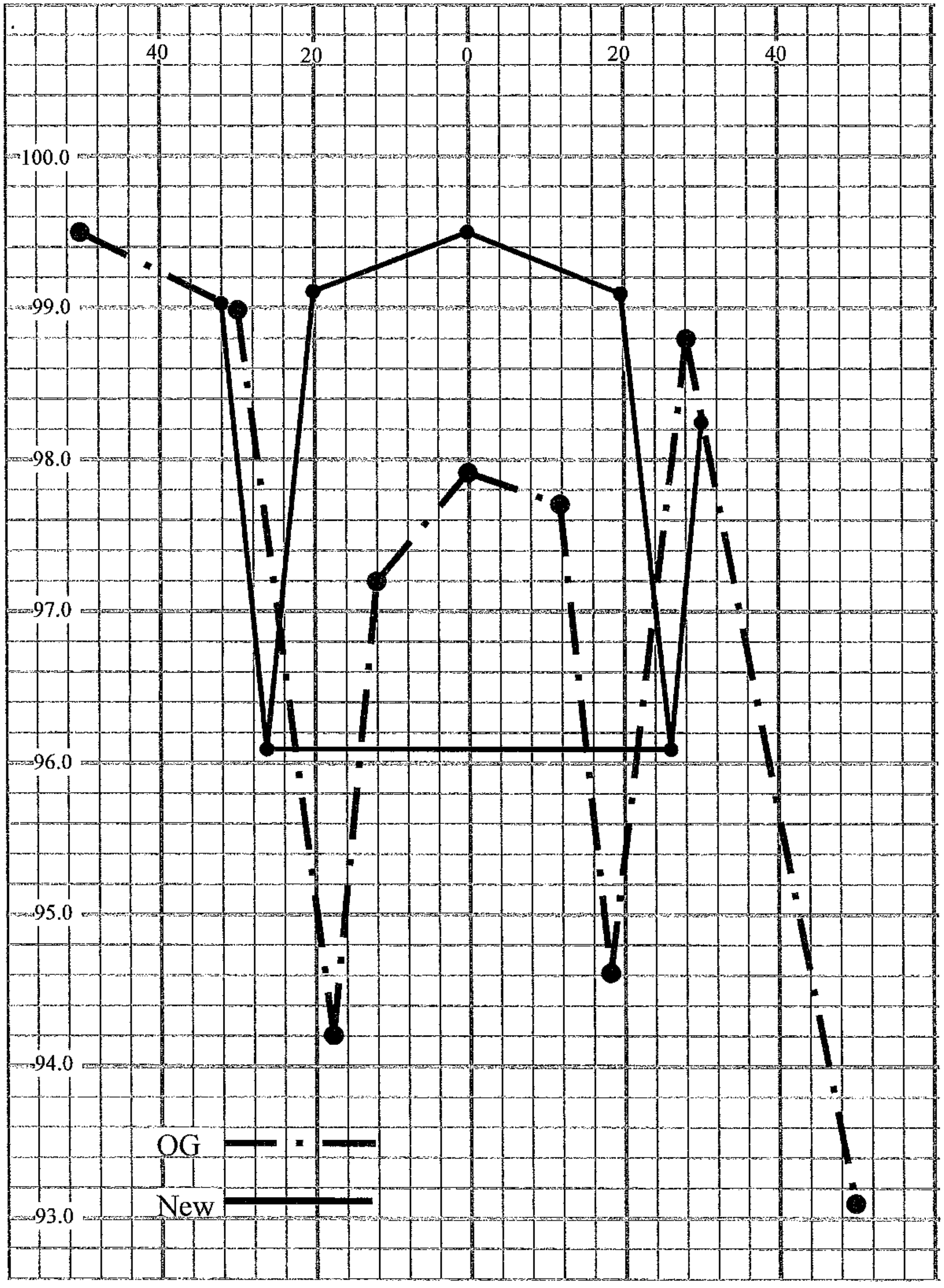
In order to plot this information, first set up the graph paper with distances right and left of centerline along the top or bottom and elevations along the side, using the scales specified. This graph paper has five small squares per inch in each direction. So horizontally, if 1" = 20', then one small square is 4'. Vertically, if 1" = 1', then one small square is 0.2'. Make sure that the plot will fit. The largest distances are 50' right and left. The elevations range from 93.1' (far right OG) to 99.5' (centerline of new road and far left OG).

Plot the OG points and connect the dots. Note that the vertical dimensions are extremely exaggerated.

Then plot the typical section, beginning at centerline, which is the only known elevation. Calculate the elevation of the shoulders, 99.5' + (-0.02 x 20') = 99.1', and plot these. Then calculate ditch bottom, 99.1 – (6' / 2) = 96.1, and plot these. Since the minimum fill is 3', which is the same as the ditch bottom, if either of these is in the air, continue the 2:1 line down until it intersects with OG, and the plot on that side is complete. Since neither of these was in the air, (they are both below the orignal ground line) plot a 2:1 back up from the ditch bottom to original ground.

Usually two different color pencils are used as in the plot below. And usually the individual points are labeled on the drawing so area calculations can be made easily from the drawing. So the ditch bottoms would have 96.1 / 26 (elevation over distance from centerline) and the original ground point 30' left would have 99.0 / 30 over or under it.

See the solution graph on the following page.

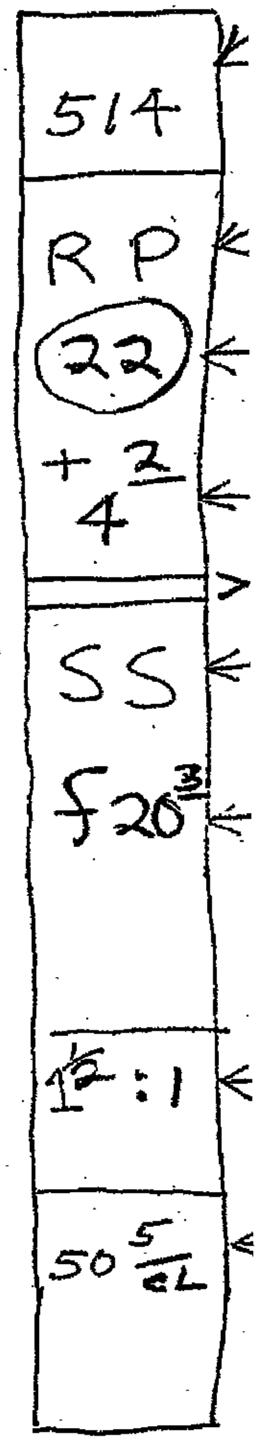

40
20
0
20
40
100.0
99.0
98.0
97.0
96.0
95.0
94.0
93.0
OG
New

Wage Group 55/54 Problems and Solutions

Problem #14

Given the survey stake shown, explain each item on it.

Stake **Explanation**



This number is the station at which the stake is set, 514+00.

RP = Reference Point. So this stake is a reference point for some other stake or point. The actual reference point is a hub (a square stake usually pounded flush with the ground) set directly in front of this stake.

This circled number, 22, is the distance in feet from the hub to the point being referenced, in the direction this stake is facing.

This is the difference in elevation from the hub to the point being referenced, so that point is 4.2 feet higher than this reference point. (The underlined portion is the tenths of a foot.)

This double line separates the RP information above from the information on the stake being referenced.

SS = Slope Stake. So the point being referenced is a slope stake. The slope stake itself will have the station at the top, and all of the information below the double line on it, with all of the RP info omitted.

F = Fill (C = Cut) The slope stake says Fill 20.3 feet (vertically). Fills are usually to the shoulder. Cuts are usually to the ditch bottom.

The fill slope will be 1½ : 1. So 1½ feet horizontally for every 1 foot vertically. The horizontal measure of this slope will then be 20.3' x 1½ = 30.45 feet.

This is the distance from the slope stake to the centerline. If the distance of the slope is subtracted from it, the width of half the roadway can be determined. 50.5' – 30.45' = 20.05' (Most likely 20 feet with a small rounding error, since slope stake info is usually only to the nearest tenth.) (If this calculation doesn't result in half the roadway width, the slope stake is probably in error, which is called a bust.)

Problem #15

Given:

New shoulder elevation and offset at 43+00 will be 93.7 @ 32'
Fill Slope = 2:1
HI = 97.21
Rod reading at the catch = 8.2

Calculate the offset from centerline and the fill required at the catch.

The shoulder elevation and offset are for the new road, not yet built. The first step is to calculate the grade rod (GR), which is the theoretical rod reading one would get if the rod was placed on the new shoulder. This is calculated by subtracting the shoulder elevation from the Height of Instrument, HI.

GR = 97.21 – 93.7 = 3.51 = GR or 3.5 if rounded.

If the rod reading at the catch point is 8.2 and the new shoulder will be 3.5, the difference will be the fill required, since the catch is lower than the shoulder.

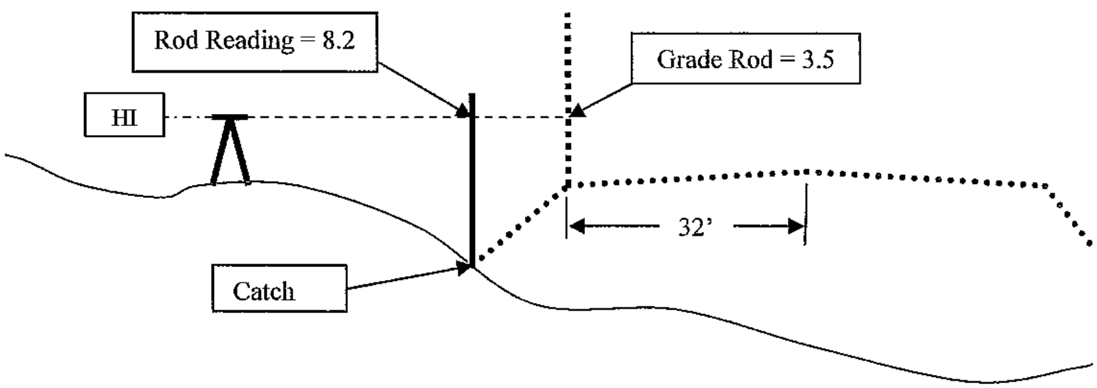
Fill (at the catch) = 8.2 – 3.5 = **4.7' (to the shoulder)**

This is the vertical difference between the new shoulder and the catch. Since the new slope is 2:1, the horizontal dimension will be twice the vertical or
Hor. = 4.7 x 2 = 9.4'
This must be added to the shoulder offset to get the catch offset.

Catch Offset = 9.4' + 32' = **41.4' from centerline.**

So the slope stake, which is placed at the catch will read ------------------------------

43~
SS
F
4.7
2:1
41.4



Problem #16

Given:

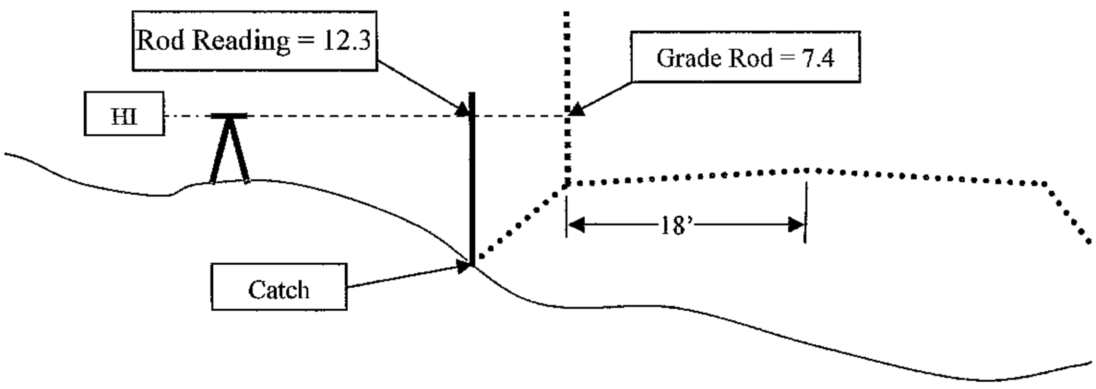
Shoulder distance from centerline = 18 feet
Grade rod = 7.4 feet
Fill slope = 2:1
Rod shot = 12.3 feet at 9.8' left of the new shoulder

Is this a catch for the left slope stake?

The catch or catch point is where the new slope will intercept the original ground, and is where the slope stake is placed.
The grade rod is the theoretical rod shot on the finished shoulder (on a fill).
The difference between the rod shot at the catch (which is also the toe of slope) and the finished shoulder grade rod is the height of the fill. In this case the difference is 12.3' – 7.4' = 4.9' below the new shoulder. The horizontal distance from the shoulder is twice that height on a 2:1 slope (2 x 4.9' = 9.8') which agrees with the given distance so **this is a catch**. If it didn't agree, another rod shot would be taken at another distance, and by trial and error, a catch would be found.

> In this example a first rod shot of 13.2 may have been taken 8.0' left of the new shoulder at the given station.
> 13.2 – 7.4 = 5.8
> 5.8 x 2 = 11.6' left, considerably farther than the 8.0' left that the shot was taken.
> This would mean that the catch is farther left, but since the ground is rising, it won't be as far as 11.6' left.
> So next try 10.0' left, and the rod shot is 12.0
> 12.0 – 7.4 = 4.6
> 4.6 x 2 = 9.2' left, not as far as we guessed (10.0 left). We now know that the catch is between 8' and 10' left, and most likely between 9.2' and 10' left, since the ground is rising fairly consistently. A skilled surveyor at this point would probably know where the catch is and put his rod at 9.8' from the new shoulder, getting the above catch rod reading of 12.3.

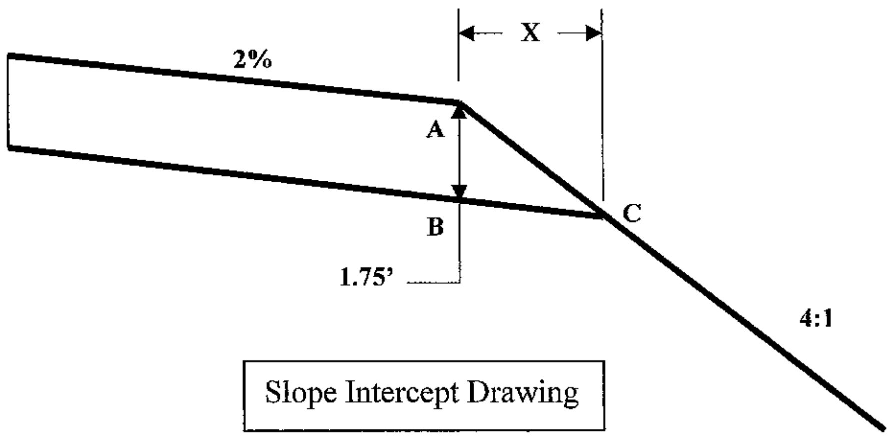
The slope stake would be placed at this location. The fill will be 4.9' and the distance from centerline will be 9.8' + 18' = 27.8'.



Problem #17

Given:

Slope Intercept drawing of the right half of a roadway.



Formula:

$$X = \frac{A - B}{S_1 - S_2}$$

Where S = the algebraic slope (rise / run).

Find X and the difference in elevation between A and C.

This is basically a line – line intercept problem, where both lines are sloped.
So $S_1 = -2' / 100' = -0.02$
and $S_2 = -1 / 4 = -0.25$
(Both are negative because they are going downhill, left to right.)

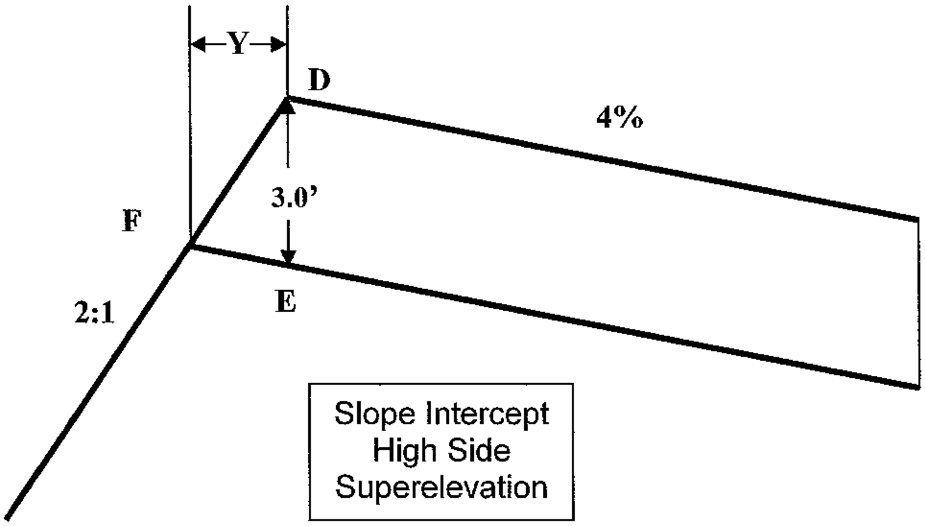
Then X = 1.75' / [–0.02 – (–0.25)] = 1.75' / 0.23 = **7.61'**

(Note that this distance X is from the finish shoulder to the lower grade shoulder. To get the distance from centerline, the width of the roadway from centerline to the finish shoulder will need to be added.)
The difference in elevation from A to C can be now calculated in two different ways. If the results are equal, the calculations check.

Straight down from the shoulder to the lower level, then out on the 2% slope
E_{diff} = 1.75' + (0.02 x 7.61') = **1.90'**
Or down the 4:1 slope
E_{diff} = 7.61 x 0.25 = **1.90'**

Continued

Given:
Slope Intercept drawing showing the high side superelevation on the left half of a roadway.



Find Y and the difference in elevation between D and F.

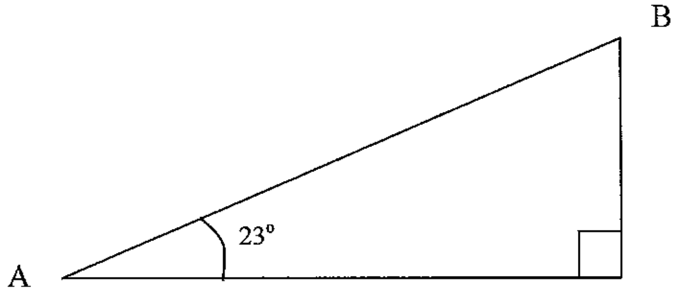
Superelevation is used on curves to aid traffic traveling around them. The roadway is banked like some racetracks, but to a lesser degree.
$S_1 = +4 / 100 = .04$ (moving right to left)
$S_2 = -1 / 2 = -0.5$

Y = 3.0 / (0.04 – (–0.5) = 3.0 / 0.54) = **5.56'**

E_{diff} = 3.0 – 0.04 x 5.56 = **2.78'**
and
E_{diff} = 5.56 / 2 = **2.78'**
In this case, the difference in elevation is less than the depth of the layer of material (3.0')

Problem #18

Given the triangle below and the slope distance from A to B of 351.23 feet.



Calculate Angle B and the horizontal and vertical distances from A to B.

There are a total of 180° in a triangle. The square in the lower right side angle denotes a 90° or right angle. So
$23^\circ + 90^\circ + B = 180^\circ$
Solving for B
B $= 180^\circ - 23^\circ - 90^\circ =$ **67°**

The rest is a simple trigonometry problem.
Line AB is the hypotenuse, the long side of a right triangle, and the side opposite the right angle. (Again, the square in the lower right side angle denotes a 90° or right angle which makes the triangle a right triangle)
Using the definitions for sine (sin) and cosine (cos) in a right triangle

cos 23° = adjacent side / hypotenuse (Adjacent side is the side (not the hypotenuse) next to the 23° angle)

sin 23° = opposite side / hypotenuse (Opposite side is the side opposite the 23° angle)

And solving these two equations for the horizontal and vertical sides
cos 23° x hypotenuse = adjacent (horizontal) side
sin 23° x hypotenuse = opposite (vertical) side
The values for both sin 23° and cos 23° can be found using any scientific calculator.
So the horizontal distance is

$\mathbf{D_H} = (\cos 23^\circ) \times 351.23' = 0.92050 \times 351.23' =$ **323.31 feet**

and the vertical distance is

$\mathbf{D_V} = (\sin 23^\circ) \times 351.23' = 0.39073 \times 351.23' =$ **137.24 feet**

This work can be checked using the Pythagorean Theorem for a right triangle.
$a^2 + b^2 = c^2$ where a is the opposite side, b is the adjacent side and c is the hypotenuse.

$137.24^2 + 323.31^2 = 351.23^2$

18,835 + 104,529 = 123,363

123364 = 123363, which is close enough to check the work, considering rounding errors.

Problem #19

Given:

Table 1.1

A. How much would 8 - #22 (metric) reinforcing bars 33' 2½" long weigh (in pounds)?
B. What is the equivalent English size of these reinforcing bars?

Doing B. first, using Table 1.1, **the English equivalent to metric #22 bar is #7.**
To convert without the Table, change the metric size, which is diameter in millimeters, into eighths of an inch in diameter, which is what the English sizes represent up to an inch (they vary a bit above an inch).

$$22\,\text{mm} \times \frac{1\,\text{in}}{25.4\,\text{mm}} \times \frac{8\text{ eighths of an inch}}{1\,\text{in}} = 6.92\text{ eighths of an inch,}$$

which rounds to 7 eighths of an inch, so **#7.**

Note that metric sizes are not exact; they are adjusted slightly to match English sizes. Metric sizes are mm in diameter; English sizes are eighths of an inch in diameter (so #7 (English) = 7/8"). The English sizes depart slightly from this rule above #8.
Today almost all rebar have metric markings, even though DOT&PF plans designate their sizes in English. If in doubt, measure the rebar diameter to see which marking system is being used.

Now A:
First convert the bar length to decimal feet so the weight per foot chart can be used. So the inch part of the measure is converted to decimal feet, and added to the 33 feet.

2½ ~~in~~ x (1ft / 12 ~~in~~) = 0.21 ft so each bar is 33.21' long and the total length is 33.21' x 8 = 265.68'

Then from the chart, determine the weight per foot for #22 (metric) bar = 2.044 # /ft
Then the weight of these bars = 2.044 # / ~~ft~~ x 265.68~~ft~~ = **543.0 #**

ASTM Standard Reinforcing Bars
Table 1.1

Soft Metric Size	Nom Diam (mm)	Area (mm2)	Weight Factors kg/m	Weight Factors kg/ft	English Size #	Nom Diam (inches)	Area in^2	Weight Factors lb/ft
10	9.5	71	0.560	0.171	3	0.375	0.11	0.376
13	12.7	129	0.994	0.303	4	0.500	0.20	0.668
16	15.9	199	1.552	0.473	5	0.625	0.31	1.043
19	19.1	284	2.235	0.681	6	0.750	0.44	1.502
22	22.2	387	3.042	0.927	7	0.875	0.60	2.044
25	25.4	510	3.973	1.211	8	1.000	0.79	2.670
29	28.7	645	5.060	1.542	9	1.128	1.00	3.400
32	32.3	819	6.404	1.952	10	1.270	1.27	4.303
36	35.8	1006	7.907	2.410	11	1.410	1.56	5.313
43	43.0	1452	11.384	3.470	14	1.693	2.25	7.650
57	57.3	2581	20.239	6.169	18	2.257	4.00	13.600

Problem #20

Given:
Tank diameter = 60 inches
Tank length = 6.81 feet
1 cubic foot = 7.48 gallons

What is the volume of the tank in gallons?

The formula for the volume of a cylinder is
$V = \pi r^2 L$
The radius is half the diameter
r = 60" / 2 = 30"
The length and radius both need to be in feet in order to get cubic feet.
r = 30 ~~in~~ x (1 ft / 12 ~~in~~) = 2.5 ft
V = 3.14159 x 2.5'^{2} x 6.81' = 133.71 cubic feet

V = 133.71 ~~ft^3~~ x (7.48 gal / 1 ~~ft^3~~) **= 1000 gallons**

Problem #21

Given:

Table A-6 and
the tank in Problem #20, horizontal and filled with asphalt cement 15 inches deep

How many gallons of asphalt cement does it contain?

The Table A-6 is based on percentage of depth filled and percentage of capacity.

% of depth = 15" / 60" = 0.25 = 25% of depth

From the chart, 25% of the depth = 19.55% of the capacity of 1000 gallons.

Using the proportion

$$\frac{19.55\%}{100\%} = \frac{\text{gallons}_{15\ in}}{1000\ \text{gallons}_{full}}$$

And solving

(19.55~~%~~ / 100~~%~~) x 1000 gal = **195.5 gallons**

Table A-6
Quantities for Various Depths
Cylindrical Tanks in Horizontal Positions

% of depth filled	% of capacity	% of depth filled	% of capacity	% of depth filled	% of capacity	% of depth filled	% of capacity
1	0.17	26	20.66	51	51.27	76	81.55
2	0.48	27	21.78	52	52.55	77	82.62
3	0.87	28	22.92	53	53.82	78	83.69
4	1.34	29	24.07	54	55.09	79	84.73
5	1.87	30	25.23	55	56.36	80	85.76
6	2.45	31	26.40	56	57.62	81	86.77
7	3.08	32	27.59	57	58.88	82	87.76
8	3.75	33	28.78	58	60.14	83	88.73
9	4.46	34	29.98	59	61.40	84	89.67
10	5.20	35	31.19	60	62.65	85	90.59
11	5.98	36	32.41	61	63.89	86	91.49
12	6.80	37	33.64	62	65.13	87	92.36
13	7.64	38	34.87	63	66.36	88	93.20
14	8.51	39	36.11	64	67.59	89	94.02
15	9.41	40	37.35	65	68.81	90	94.80
16	10.33	41	38.60	66	70.02	91	95.54
17	11.27	42	39.86	67	71.22	92	96.25
18	12.24	43	41.12	68	72.41	93	96.92
19	13.23	44	42.38	69	73.60	94	97.55
20	14.24	45	43.64	70	74.77	95	98.13
21	15.27	46	44.91	71	75.93	96	98.66
22	16.31	47	46.18	72	77.08	97	99.13
23	17.38	48	47.45	73	78.22	98	99.52
24	18.45	49	48.73	74	79.34	99	99.83
25	19.55	50	50.00	75	80.45	100	100.00

Problem #22

Given:

The tank in Problem #21 partially filled with asphalt cement.
The cement has a specific gravity (sp. gr.) of 0.967 at 60° F.
The cement has a measured temperature of 300° F.
Table A-1a.
1 cubic foot of water = 62.4 pounds
1 cubic foot = 7.48 gallons

Find the weight of the asphalt cement in the tank.

So from Problem #21, there are 195.5 gallons in the tank.
Convert this to gallons at the standard temperature using the multiplier from the chart.

$195.5\ gal_{300F} \times 0.9187 = 179.6\ gallons_{60F}$

This then needs to be converted to a weight. Specific gravity gives a comparative weight to a equal volume of water; in this case the asphalt cement at standard temperature weighs 0.967 of an equal volume of water. So if this was water it would weigh

179.6 ~~gal~~ of H_2O x (1 ~~ft~~^{3} / 7.48 ~~gal~~) x (62.4 # / ~~ft~~^{3}) = 1498.3 # of H_2O

and the asphalt will weigh

1498.3 # x 0.967 = **1448.9 # of asphalt cement**

Table A-1a

TEMPERATURE-VOLUME CORRECTIONS FOR ASPHALTIC MATERIALS (CUSTOMARY UNITS)
SPECIFIC GRAVITY AT 60°F ABOVE 0.966
t = Observed Temperature in Degrees Fahrenheit
M = Multiplier for Correcting Oil Volumes to the Basis of 60°F

t	M	t	M	t	M	t	M	t	M
0	1.0211	50	1.0035	100	0.9861	150	0.9689	200	0.9520
1	1.0208	51	1.0031	101	0.9857	151	0.9686	201	0.9516
2	1.0204	52	1.0028	102	0.9854	152	0.9682	202	0.9513
3	1.0201	53	1.0024	103	0.9851	153	0.9679	203	0.9509
4	1.0197	54	1.0021	104	0.9847	154	0.9675	204	0.9506
5	1.0194	55	1.0017	105	0.9844	155	0.9672	205	0.9503
6	1.0190	56	1.0014	106	0.9840	156	0.9669	206	0.9499
7	1.0186	57	1.0010	107	0.9837	157	0.9665	207	0.9496
8	1.0183	58	1.0007	108	0.9833	158	0.9662	208	0.9493
9	1.0179	59	1.0003	109	0.9830	159	0.9658	209	0.9489
10	1.0176	60	1.0000	110	0.9826	160	0.9655	210	0.9486
11	1.0172	61	0.9997	111	0.9823	161	0.9652	211	0.9483
12	1.0169	62	0.9993	112	0.9819	162	0.9648	212	0.9479
13	1.0165	63	0.9990	113	0.9816	163	0.9645	213	0.9476
14	1.0162	64	0.9986	114	0.9813	164	0.9641	214	0.9472
15	1.0158	65	0.9983	115	0.9809	165	0.9638	215	0.9469
16	1.0155	66	0.9979	116	0.9806	166	0.9635	216	0.9466
17	1.0151	67	0.9976	117	0.9802	167	0.9631	217	0.9462
18	1.0148	68	0.9972	118	0.9799	168	0.9628	218	0.9459
19	1.0144	69	0.9969	119	0.9795	169	0.9624	219	0.9456
20	1.0141	70	0.9965	120	0.9792	170	0.9621	220	0.9452
21	1.0137	71	0.9962	121	0.9788	171	0.9618	221	0.9449
22	1.0133	72	0.9958	122	0.9785	172	0.9614	222	0.9446
23	1.0130	73	0.9955	123	0.9782	173	0.9611	223	0.9442
24	1.0126	74	0.9951	124	0.9778	174	0.9607	224	0.9439
25	1.0123	75	0.9948	125	0.9775	175	0.9604	225	0.9436
26	1.0119	76	0.9944	126	0.9771	176	0.9601	226	0.9432
27	1.0116	77	0.9941	127	0.9768	177	0.9597	227	0.9429
28	1.0112	78	0.9937	128	0.9764	178	0.9594	228	0.9426
29	1.0109	79	0.9934	129	0.9761	179	0.9590	229	0.9422
30	1.0105	80	0.9930	130	0.9758	180	0.9587	230	0.9419
31	1.0102	81	0.9927	131	0.9754	181	0.9584	231	0.9416
32	1.0098	82	0.9923	132	0.9751	182	0.9580	232	0.9412
33	1.0095	83	0.9920	133	0.9747	183	0.9577	233	0.9409
34	1.0091	84	0.9916	134	0.9744	184	0.9574	234	0.9405
35	1.0088	85	0.9913	135	0.9740	185	0.9570	235	0.9402
36	1.0084	86	0.9909	136	0.9737	186	0.9567	236	0.9399
37	1.0081	87	0.9906	137	0.9734	187	0.9563	237	0.9395
38	1.0077	88	0.9902	138	0.9730	188	0.9560	238	0.9392
39	1.0074	89	0.9899	139	0.9727	189	0.9557	239	0.9389
40	1.0070	90	0.9896	140	0.9723	190	0.9553	240	0.9385
41	1.0067	91	0.9892	141	0.9720	191	0.9550	241	0.9382
42	1.0063	92	0.9889	142	0.9716	192	0.9547	242	0.9379
43	1.0060	93	0.9885	143	0.9713	193	0.9543	243	0.9375
44	1.0056	94	0.9882	144	0.9710	194	0.9540	244	0.9372
45	1.0053	95	0.9878	145	0.9706	195	0.9536	245	0.9369
46	1.0049	96	0.9875	146	0.9703	196	0.9533	246	0.9365
47	1.0046	97	0.9871	147	0.9699	197	0.9530	247	0.9362
48	1.0042	98	0.9868	148	0.9696	198	0.9526	248	0.9359
49	1.0038	99	0.9864	149	0.9693	199	0.9523	249	0.9356

t	M	t	M	t	M	t	M	t	M
250	0.9352	300	0.9187	350	0.9024	400	0.8864	450	0.8705
251	0.9349	301	0.9184	351	0.9021	401	0.8861	451	0.8702
252	0.9346	302	0.9181	352	0.9018	402	0.8857	452	0.8699
253	0.9342	303	0.9177	353	0.9015	403	0.8854	453	0.8696
254	0.9339	304	0.9174	354	0.9011	404	0.8851	454	0.8693
255	0.9336	305	0.9171	355	0.9008	405	0.8848	455	0.8690
256	0.9332	306	0.9167	356	0.9005	406	0.8845	456	0.8687
257	0.9329	307	0.9164	357	0.9002	407	0.8841	457	0.8683
258	0.9326	308	0.9161	358	0.8998	408	0.8838	458	0.8680
259	0.9322	309	0.9158	359	0.8995	409	0.8835	459	0.8677
260	0.9319	310	0.9154	360	0.8992	410	0.8832	460	0.8674
261	0.9316	311	0.9151	361	0.8989	411	0.8829	461	0.8671
262	0.9312	312	0.9148	362	0.8986	412	0.8826	462	0.8668
263	0.9309	313	0.9145	363	0.8982	413	0.8822	463	0.8665
264	0.9306	314	0.9141	364	0.8979	414	0.8819	464	0.8661
265	0.9302	315	0.9138	365	0.8976	415	0.8816	465	0.8658
266	0.9299	316	0.9135	366	0.8973	416	0.8813	466	0.8655
267	0.9296	317	0.9132	367	0.8969	417	0.8810	467	0.8652
268	0.9293	318	0.9128	368	0.8966	418	0.8806	468	0.8649
269	0.9289	319	0.9125	369	0.8963	419	0.8803	469	0.8646
270	0.9286	320	0.9122	370	0.8960	420	0.8800	470	0.8643
271	0.9283	321	0.9118	371	0.8957	421	0.8797	471	0.8640
272	0.9279	322	0.9115	372	0.8953	422	0.8794	472	0.8636
273	0.9276	323	0.9112	373	0.8950	423	0.8791	473	0.8633
274	0.9273	324	0.9109	374	0.8947	424	0.8787	474	0.8630
275	0.9269	325	0.9105	375	0.8944	425	0.8784	475	0.8827
276	0.9266	326	0.9102	376	0.8941	426	0.8781	476	0.8624
277	0.9263	327	0.9099	377	0.8937	427	0.8778	477	0.8621
278	0.9259	328	0.9096	378	0.8934	428	0.8775	478	0.8618
279	0.9256	329	0.9092	379	0.8931	429	0.8772	479	0.8615
280	0.9253	330	0.9089	380	0.8928	430	0.8768	480	0.8611
281	0.9250	331	0.9086	381	0.8924	431	0.8765	481	0.8608
282	0.9246	332	0.9083	382	0.8921	432	0.8762	482	0.8605
283	0.9243	333	0.9079	383	0.8918	433	0.8759	483	0.8602
284	0.9240	334	0.9076	384	0.8915	434	0.8756	484	0.8599
285	0.9236	335	0.9073	385	0.8912	435	0.8753	485	0.8596
286	0.9233	336	0.9070	386	0.8908	436	0.8749	486	0.8593
287	0.9230	337	0.9066	387	0.8905	437	0.8746	487	0.8590
288	0.9227	338	0.9063	388	0.8902	438	0.8743	488	0.8587
289	0.9223	339	0.9060	389	0.8899	439	0.8740	489	0.8583
290	0.9220	340	0.9057	390	0.8896	440	0.8737	490	0.8580
291	0.9217	341	0.9053	391	0.8892	441	0.8734	491	0.8577
292	0.9213	342	0.9050	392	0.8889	442	0.8731	492	0.8574
293	0.9210	343	0.9047	393	0.8886	443	0.8727	493	0.8571
294	0.9207	344	0.9044	394	0.8883	444	0.8724	494	0.8568
295	0.9204	345	0.9040	395	0.8880	445	0.8721	495	0.8565
296	0.9200	346	0.9037	396	0.8876	446	0.8718	496	0.8562
297	0.9197	347	0.9034	397	0.8873	447	0.8715	497	0.8559
298	0.9194	348	0.9031	398	0.8870	448	0.8712	498	0.8556
299	0.9190	349	0.9028	399	0.8867	449	0.8709	499	0.8552

Problem #23

Given: An open field level book that shows level loop data and the top, back of curb plan elevations.

Calculate the grade rods for the three top, back of curb elevations.

Also calculate the error of closure for the level loop.

	Item 609(2) Curb & Gutter				*27-Jun-03*				15
					Clear & Sunny, +65			*Crew PC*	*I.M. Swift*
								Λ	*R.V. Sore*
Sta.	+	HI	-	Elev.	TBM			Φ	*D.O. Wright*
TBM #1	*4.72*	*94.05*		*489.33*	TBM #1, 489.33, 276+75, 75'Lt				
TP #1			*2.79*	*91.26*					
	5.63	*96.89*							
								Grade Rod	
279+00 Rt				93.79	Top, Back of Curb				
279+25 Rt				93.66	Top, Back of Curb				
279+50 Rt				93.52	Top, Back of Curb				
TBM #2			*9.23*	*87.66*	TBM #2, 487.65, 281+10, 50'Rt				

First a bit of explanation about the field book format. The + and – columns are for rod shots taken during the course of the survey. The + shots establish the height of the instrument, HI, (a level) which will always be higher than the elevation used to establish this height, and the – shots establish the height of points being surveyed which are always lower than the instrument. On the first row of shots (TBM #1) the **Height of the Instrument, HI**, is established by taking a plus rod shot 4.72 on the **TBM - Temporary Bench Mark**, a previously established elevation marker on which the rod can be placed. The instrument must be above the TBM in order to get a rod shot, so the rod shot must be added to the elevation of the TBM, 489.33. Thus, the HI = 89.33 + 4.72 = 94.05. (Note that the (4) hundreds are dropped, since they are all the same.)

Then the level can then be moved ahead using a Turning Point, TP. The elevation of this arbitrary turning point is established by taking a minus shot (the turning point must be lower than the HI to get a rod shot) first. (94.05 – 2.79 = 91.26) Then the level is moved forward and the new HI is established by taking a plus shot with the rod on the same turning point. (91.26 + 5.63 = 96.89)

This new HI will be used to set grade for the new curb on the right. Then the loop will be closed by taking a minus shot on another TBM (or returning to the starting TBM) and calculating its elevation. (96.89 – 9.23 = 87.66)

If the calculated elevation is the same as the previously established elevation for this TBM, the loop is closed without error, a check on the level work. If the two numbers are not the same, the error of closure, e, is the difference between them (known – calculated).

e = 487.65 – 487.66 = **-0.01**

Grade rod is the **theoretical** rod reading that would be taken on a finished surface of the new roadway. So in this problem, it is the expected rod reading on the top back of the new (but not yet constructed) curb. This depends on the HI, 96.89. The grade rod will be the HI minus the plan elevation of the top back of curb.

Once this is calculated, a hub can be set at the given grade rod or the cut or fill is an easy calculation of the difference between the rod reading and the grade rod.

At 279+00, GR = 96.89 – 93.79 = **3.10**

At 279+25, GR = 96.89 – 93.66 = **3.23**

At 279+50, GR = 96.89 – 93.52 = **3.37**

Problem #24

Given: An open field survey book. The left page gives the level loop data and the plan excavation templates. The right page gives the actual measured depths of a sub-excavated area.

Calculate the volume of the sub-excavation.

	Item 203(3) Unclassified Exc.					27-Jun-03				14
						Clear & Sunny, +65			Crew PC	I.M. Swift
									Λ	R.V. Sore
Sta.	+	HI	-	Elev.	TBM				Φ	D.O. Wright
TBM #1	5.37	94.13		88.76	TBM #1					
					75'Lt, 100+75					
		Excavation Templates					Sub-ex Cross Sections			
100+50		75.30	75.96	75.30			75.3	76.0	75.3	
		38	0	38			18.8	18.1	18.8	
							38	0	38	
101+00		75.80	76.46	75.80		75.8	76.5	75.0	74.3	75.8
		38	0	38		18.3	17.6	19.1	19.8	18.3
						38	0	0	38	38
TP	19.27	94.96	18.44							
101+50		76.30	76.96	76.30			76.3	77.0	76.3	
		38	0	38			18.7	18.0	18.7	
							38	0	38	
TBM #1			6.20	88.76	TBM #1					
					75'Lt, 100+75					

See Problem 23 for a similar field book problem. First a bit of explanation about the field book format. The + and – columns are rod shots taken during the course of the survey. The first line (TBM #1) of shots establishes the height of the instrument, HI, by taking a rod shot 5.37 on the TBM, which is at the given elevation of 88.76. So the HI = 88.76 + 5.37 = 94.13. This HI is used for 100+50 and 101~ sub-excavation shots.

Then the instrument is moved ahead using a turning point, TP. The elevation of this arbitrary point is established with the minus shot from the old HI, then the level is moved forward and the new HI is established using the plus shot on the same point. Since the elevation of the TP is not needed, the new HI is calculated without actually determining it. (94.13 - 18.44 + 19.27 = 94.96) This new HI is used for 101+50. Finally, the loop is closed by taking another shot on the original TBM and calculating its elevation. If the calculated elevation is the same as the given elevation, the loop is closed without error, a check on the level work. (94.96 – 6.20 = 88.76)

The 'fractions' appearing on the left page represent the planned excavation. They have the elevation over the distance rt. or lt. of centerline. On the right page, they represent what was actually excavated.

They have a rod shot in between the elevation and the distance from centerline, which was used to calculate the elevation. So for 101+00, 38' Lt.: 94.13 (HI) – 18.3 (Rod Shot) = 75.8(3).
See Problem 9 for a simpler cross section problem. Sub-excavation is excavation below the planned cut, usually done as needed to remove unanticipated poor material. There was no sub-excavation at either 100+50 or 101+50, since the measured elevations are roughly equal to the excavation template (which is confirmation that the planned excavation was accomplished). These would be assumed the end limits of this sub-excavation, since the surveyors included them in this sub-ex record. The end area of each of them will be 0 ft^2.

At 101~, there is no sub-exc. on the left side either. At centerline, two elevations are given, which indicates that a vertical cut was made on centerline (so one shot is for the top of the subcut and one for the bottom. The same is true at 38 feet right.

The depth of the subcut at centerline is
76.46 – 75.0 = 1.46'

The depth of the subcut at 38' Rt. is
75.80 – 74.3 = 1.50'

The end area (cross section) of this subcut at 101~ is then the area of a trapezoid with the vertical sides parallel
38'(wide) x (1.46' +1.5')/2 (the ave. depth) = 56.24 ft^2

Using average end area to calculate the volume, one end being zero and the other 56.24
$A = (56.24_{101\sim} + 0_{100+50})/2 = 28.12\ ft^2$

and the length between these two areas is 50', so the volume of the subcut between them is
$V = 50' \times 28.12\ ft^2 = 1406\ ft^3$

This same volume exists between 101~ and 101+50, so the total volume $V = 2 \times 1406\ ft^3 = 2812\ ft^3$

Converting to cubic yards,
$\mathbf{V} = 2812\ ft^3 \times (1\ yd^3 / 27\ ft^3) = \mathbf{104.1\ yd^3}$

So the total volume of sub-excavation = 104.1 cubic yards

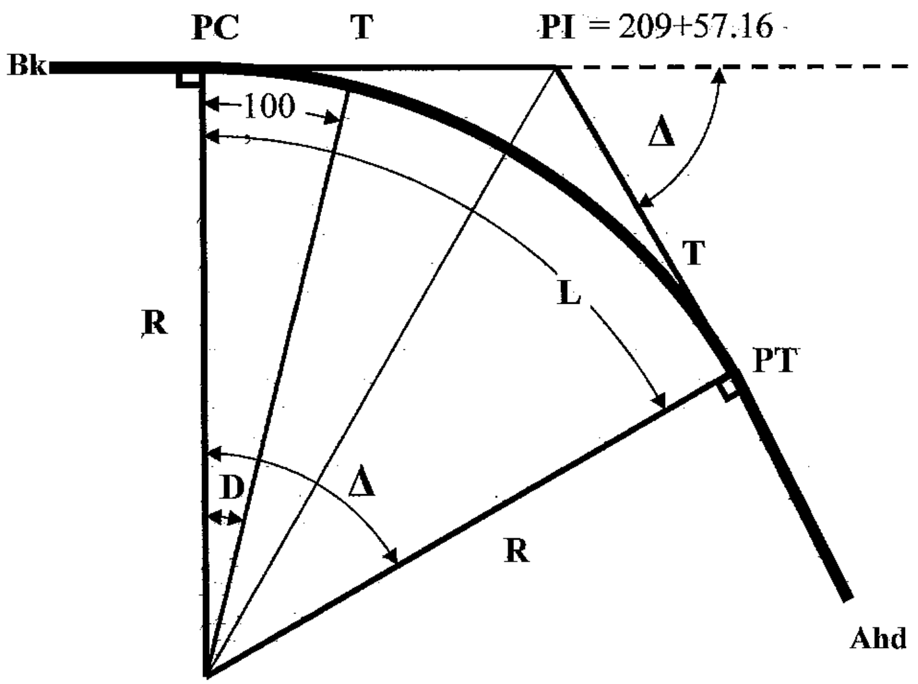
Problem #25

Given: A horizontal curve with
PI = 209+57.16
Δ (delta) = 48° 32' 24" Rt.
R = 381.97'

Formulae: tan θ = opposite / adjacent (for a right triangle)
$2\pi R / 360^{o} = 100' / D(^{o}) = L / \Delta(^{o})$
This is a simple proportion of
circumference of a full circle : 360° :: 100' : D :: L : Δ

Find: T
D
L
Station of PC
Station of PT

Horizontal curve drawing



Definitions:

PC = Point of Curve (or Curvature) = the point on ℄ where a horizontal curve begins.

PT = Point of Tangent (or Tangency) = the point on ℄ where a horizontal curve ends.

PI = Point of Intersection (**not π**) = the point where the tangents on either end of a horizontal curve will intersect if extended. This point will be outside the middle of the curve.

T = Tangent = the length of the extended tangent from the PC to the PI and of the extended tangent from the PT to the PI (which are equal). (This is not the trigonometry definition; see the formula above for that.)

L = the Arc Length of a horizontal curve.

R = Radius of a curve = a measure of how sharp a horizontal curve is. A small radius means a sharp curve. The radii to both the PC and PT will always be perpendicular to the adjacent tangents (hence the curve itself is tangent to both tangents).

D = Degree of curve = another measure of how sharp a horizontal curve is. It is the angular change in direction that a curve makes in 100 arc feet, expressed in degrees, so a larger angle means a sharper curve.

Δ = Delta = the total change of direction of a horizontal curve, expressed as an angle. So if a curve begins northbound and ends eastbound, $\Delta = 90^o$ Rt, the tangent deflection angle. It is also (by perpendicular geometry) the included angle between the radii to the PC and the PT.

Solutions:

First, solve T using the trigonometry tangent formula: tangent = opposite side over adjacent side of a right triangle. In the right triangle T is opposite side and R (radius to the PC) is adjacent side. The line from the PI to the radius point is the hypotenuse and it bisects delta (since both T's are equal). So the angle θ will be half of delta, and $\tan(\Delta/2) = T / R$

In order to solve this, delta (48^o 32' 24" = 42 degrees, 32 minutes, 24 seconds) needs to be converted from <u>degrees, minutes, seconds</u> to decimal degrees (unless your calculator will handle angles in this format. Some calculators do this with a button labeled DMS to DD.) If not, simply divide the seconds by 60 to get decimal minutes and add this decimal to the minutes, then divide these decimal minutes by 60 again to get decimal degrees, which are added to the degrees.
24" x (1'/60") = 0.4'. Add this to the minutes and convert them
32.4' x (1^o/60') = 0.54^o, so delta in decimal degrees is 48.54^o.

Solve for T:
T = R x tan (Δ/2) = 381.97' x tan (48.54^o / 2) = 381.97' x tan 24.27^o = 381.97' x 0.450887 =
172.23' = T
Then the PC will be this distance back from the PI, so
PC = PI – T = 209+57.16 – 172.23' = **207+84.93 = PC**

Next find L, the length of the curve, using the proportion:
$2\pi R / 360^o = L / \Delta$ (Circumference is to 360^o as L is to Δ.)
Solve for L:
$L = 2\pi R\Delta / 360^o$ = 2 x 3.1415926 x 381.97' x 48.54^o / 360^o = **323.60' = L**

Note that this will be a bit less that twice the tangent length, since it is a shorter distance.

Now the PT station can be found by adding this length to the PC.
PT = PC + L = 207+84.93 + 323.60' = **211+08.53 = PT**

Note that the **PT cannot be found** by adding T to the PI.

The remaining value, degree of curve, again uses a proportion (inverted to simplify the solution):
$360^o / 2\pi R$ = D / 100' (360^o is to circumference as D is to 100')
Solving for D:
D = 100' x 360^o / $2\pi R$ = 100' x 360^o / (2 x 3.1415926 x 381.97') = **15^o = D**

Problem #26

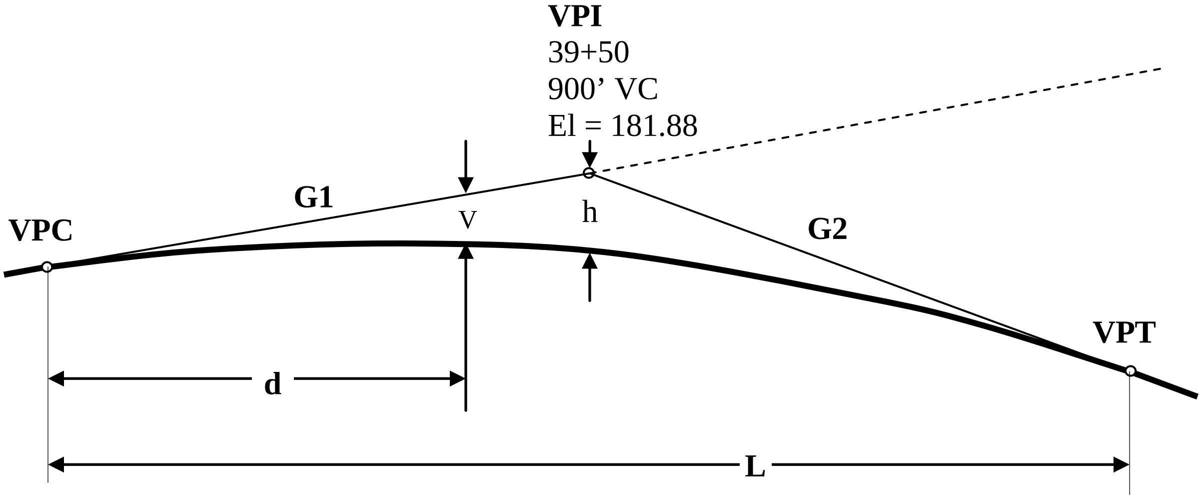
Given: A 900' vertical curve with
VPI = 39+50 and with
Elevation = 181.88
G1 = 0.0200 ft/ft (or 2.00 %)
G2 = -0.0300 ft/ft (or -3.00 %)

Formulae: $h = (G2 - G1)L / 8$

$V = h\,(2d / L)^2$

$s = (Y_1 - Y_2) / (X_1 - X_2)$

Find: VPC and VPT station and elevation
Elevation at 39+50, 38+00 and 42+00



Definitions:

VC = Vertical Curve = how ℄ changes Grade (or slope) if a curve is used. Instead of specifying the two ends of the vertical curve, it will usually have a given (horizontal) length (900' VC), half of which will be each direction from the VPI.

VPI = Vertical Point of Intersection of the tangents to a vertical curve. This point will be in the middle of the curve.

VPC = Vertical Point of Curve, the point on ℄ where a vertical curve begins

VPT = Vertical Point of Tangent, the point on ℄ where a vertical curve ends

L = Horizontal **Length** of the vertical curve (not the arc length).

h = the **vertical distance** from the VPI to the curve (at the midpoint)

G1 & **G2** are the **grades** (slopes) of the two tangents that intersect at the VPI

V is the **vertical offset** from one of the tangents at a given distance **d** on the curve

Solutions:

First find the stations of both ends of the curve. Stations are always measured on the horizontal plane, not along the slope of the roadway.

VPC = VPI – L / 2 = 39+50 – 900’ / 2 = 3950 – 450’ = **35+00 = VPC**

VPT = VPI + L / 2 = 39+50 + 450’ = **44+00 = VPT**

Then find the elevations of both ends of the curve using the slope formula, working forward and backward along the tangents from the VPI, using the definition, slope equals change in elevation over change in distance.

s = 0.02 = (El_{VPI} – El_{VPC}) / (VPI – VPC) = (181.88’ – El_{VPC}) / (39+50 – 35+00), so
0.02 x 450’ = 181.88’ – El_{VPC}, and
El_{VPC} = 181.88’ – 0.02 x 450’ = 181.88’ – 9.00’ = **172.88’ = El_{VPC}**

s = – 0.03 = (El_{VPT} – El_{VPI}) / (VPT – VPI) = (El_{VPT} – 181.88’) / (44+00 – 39+50) =
– 0.03 = (El_{VPT} – 181.88’) / 450’, and
El_{VPT} = 181.88’ –0.03 x 450’ = 181.88’ – 13.5’ = **168.38’ = El_{VPT}**

Note: Check these two elevations to make sure that they are correctly above or below the VPI.

Next, find h.
h = (G2 – G1)L / 8 = (–0.03 – 0.02) x 900 / 8 = –0.05 x 900 / 8 = **–5.625 = h**
So the elevation of the curve at 39+50 = 181.88 – 5.625 = **176.255 = El_{39+50}**

Now find the elevations at the other required points, 38+00 and 42+00.
First find V
V = h (2d / L)^2 = –5.625 x (2 x (3800 –3500) / 900)^2 = –5.625 x (2 x 300 / 900)^2 =
–5.625 x (600 / 900)^2 = **–2.50 = $V_{38\sim}$**
This is the distance below the 2% tangent, so the elevation on this tangent at 38+00 must be determined.
El_{VPC} + G1 x (3800 – 3500) = Tangent El @ 38+00 = 172.88 + 0.02 x 300 = 172.88 + 6.00 =
178.88 = Tangent $El_{38\sim}$
Then V is added to this, so
El @ 38+00 = 178.88 + (– 2.50) = **176.38 = $El_{38\sim}$**

Similarly at 42+00
V = h (2d / L)^2 = –5.625 x (2 x (4200-3500) / 900)^2 = –5.625 x (1400 / 900)^2 = **–13.611 = $V_{42\sim}$**
El_{VPC} + G1 x (4200 – 3500) = Tangent El @ 42+00 = 172.88 + 0.02 x 700 = 172.88 + 14.000 =
186.88 = Tangent $El_{42\sim}$
And El @ 42+00 = 186.88 + (– 13.61) = **173.27 = $El_{42\sim}$**

Note that both stations were solved from the VPC. They may also be solved from the VPT, using G2 as the line being calculated from.

So for 42+00

V = h (2d / L)^2 = –5.625 x (2 x (4400-4200) / 900)^2 = –5.625 x (400 / 900)^2 = **-1.11 = $V_{42\sim}$**
El_{VPT} - G2 x (4400 – 4200) = Tangent El @ 42+00 = 168.38 – (–0.03) x 200 =
168.38 + 0.03 x 200 = 168.38 + 6.00 = **174.38 = Tangent $El_{42\sim}$**
And El @ 42+00 = 174.38 + (– 1.11) = **173.27 = $El_{42\sim}$**

This actually is a good way to check the elevation, by calculating it from both ends.