Chapter 13: Solving Geometry Problems Using DCALC

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February 2014

13.1 Introduction:

It can be difficult to get a sense of how much engineering has changed since the introduction of CAD. Prior to CAD, everything was drafted, and it was necessary for engineers to compute geometry mathematically. It was a tedious job, requiring expertise in bridge layout and an aptitude for mathematics.

The need to compute geometry radically changed when the engineering industry transitioned from traditional drafting to CAD. Today, we automatically make measurements that are computed internally by the CAD software. What was once tedious is now effortless.

Although CAD seems to make our jobs easier, our responsibility to produce buildable documents has not changed. We have an obligation to make sure that the dimensions shown in our drawings are correct. New checking issues have evolved due to CAD:

- Sometimes different CAD systems produce dimensions which differ. Then we are faced with a question of which CAD is giving the correct result or is more accurate.
- A project's QA/QC documentation may require that CAD produced dimensions be checked independently. This may involve verifying a few dimensions using hand calculations, by spreadsheet or by using another piece of software.
- Engineers who are reviewing/checking plans produced by others typically must check plan dimensions without the benefit of or access to the CAD model
- Similarly, steel detailer must be able to verify or check a consultant's framing

13.2 DCALC Program "GEOMETRY"

The DCALC program "GEOMETRY" is a collection of simple geometry solving routines intended for checking plans. GEOMETRY can also be very useful for engineers laying out framing plans, before actually drawing the framing plans.

Unlike the other DCALC programs which present detailed calculations, GEOMETRY does not produce explicit derivations, since this would produce large output. It does display solutions graphically and DXF files which can be exported to CAD programs.

The purpose of this chapter is to describe the explicit mathematical solutions used by GEOMETRY. These solutions can also be easily programmed into a spreadsheet.

The GEOMETRY program originated from simple geometry programs which I had written in the 1980's for the Texas Instrument TI-59, before I owned my first PC. Each program had a little slide card which was inserted into the calculator. Fortunately, I had saved my mathematical solutions for this device!

(* http://www.designcalcs.com)

<u>13.3.1 Geometrical Elements:</u>

The GEOMETRY program defines all geometry in terms of four simple elements: Point, Line, Circle or Arc.

When defining an element, the user is asked to provide a name for the element. In subsequent operations, the user will refer to each element by name (as opposed to re-entering information).

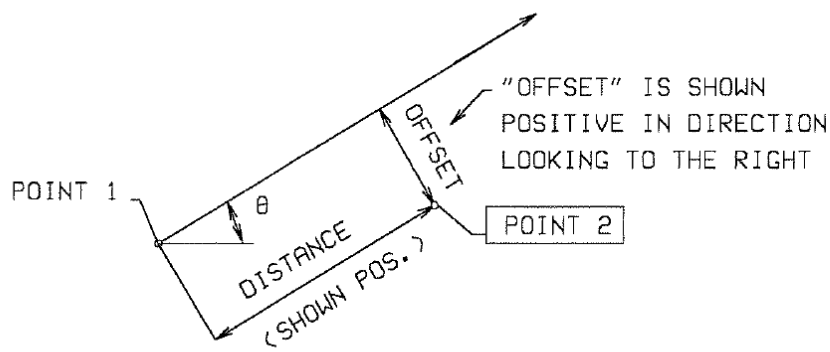
Example: Point “A” is defined by (0, 10)
Point “B” is defined by (2, 12)
Line “C” is defined by Point “A” to Point “B”

> Before running GEOMETRY, it is important that the user make a sketch identifying the key points, lines, circles and arcs, identifying the names of each element.

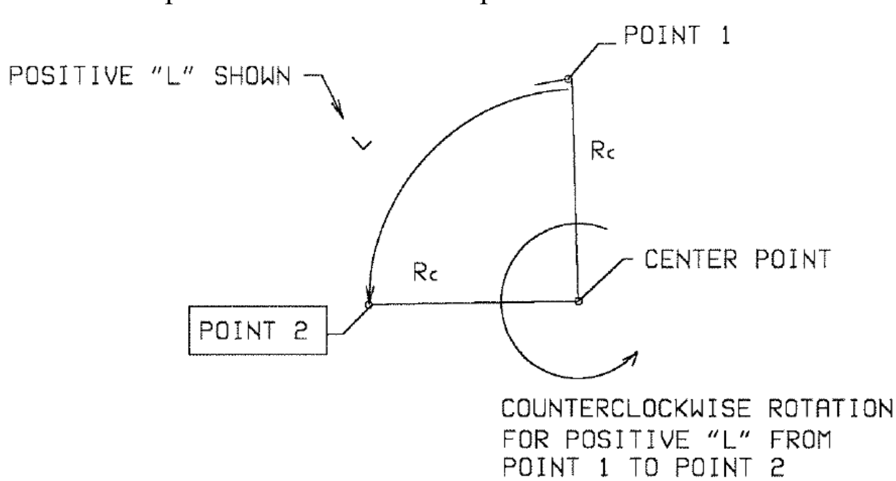
<u>Point Definition:</u>

The user has four options for defining a point:

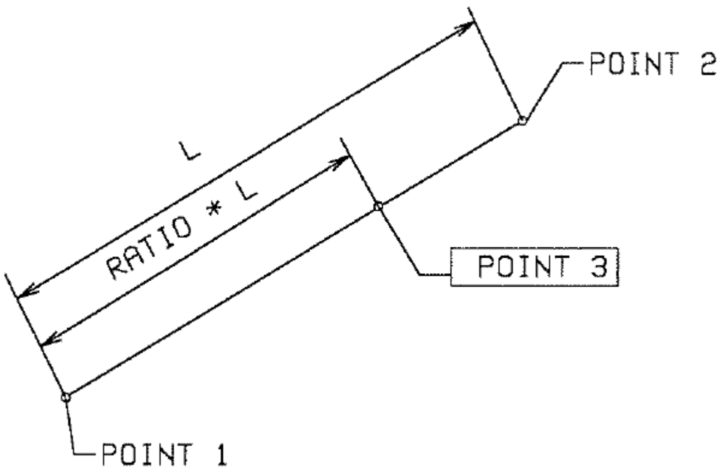
1. Define a point by entering (X,Y) coordinates
2. Define a new point relative to another point using a straight line bearing:



3. Define a new point relative to another point on an arc:



4. Define a new point based on the ratio of lengths between two points:

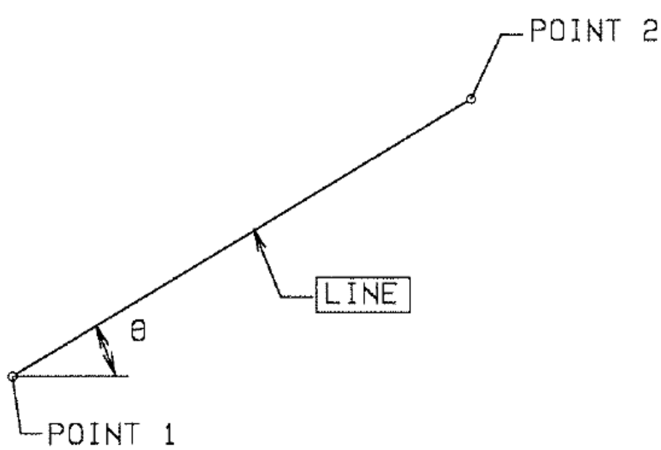


Mathematical Definition of a Point: (X,Y)

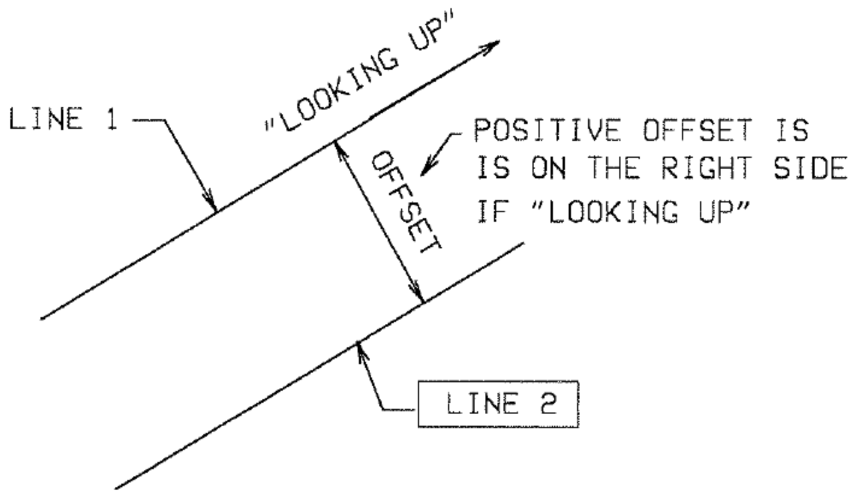
Line Definition:

The user has four options for defining a line:

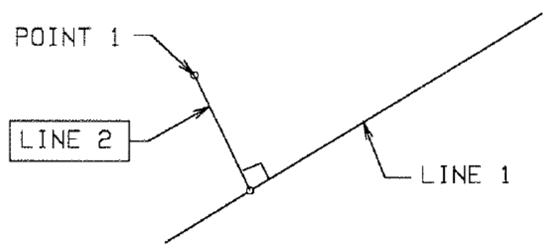
1. Using Point 1 and Point 2
2. Using Point 1 and angle θ (in this case, the program automatically generates a second point, Point 2, which is 50 feet from Point 1)



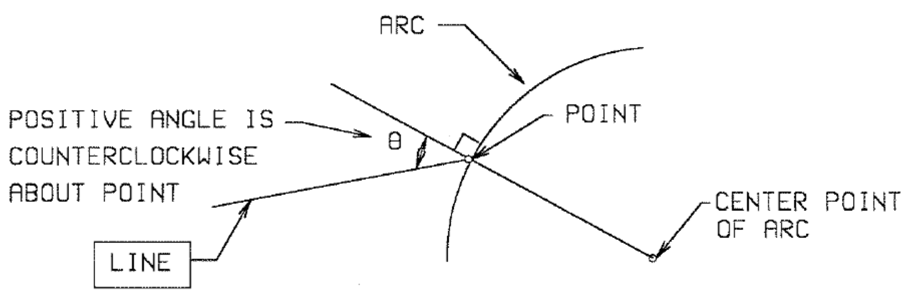
3. Defining a line at a parallel offset to another line:



4. Defining a line that is perpendicular to another line:



5. Defining a line that intersects a point on an arc:



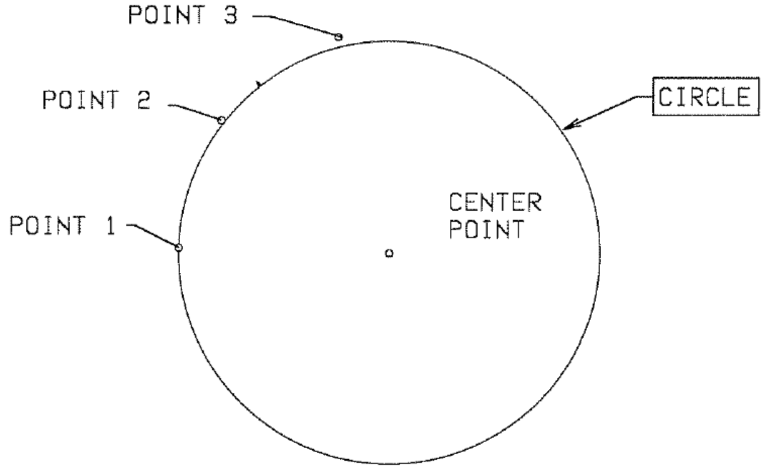
Mathematical Definition of a Line: $Y = M * X + b$

(Note that GEOMETRY assumes that lines extend into infinity, and are not limited to the region between points 1 and 2)

Circle Definition:

The user is given two options for defining a circle:

1. Circle define by three points on the circle: Point 1, Point 2 and Point 3
2. Circle defined by the center point (Xc, Yc) and the radius

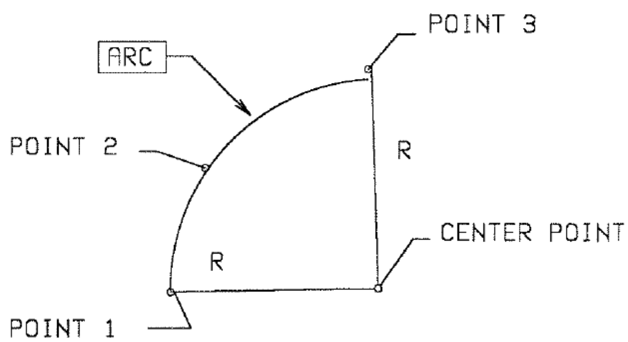


Mathematical Definition of A Circle: $R^2 = (X - Xc)^2 + (Y - Yc)^2$

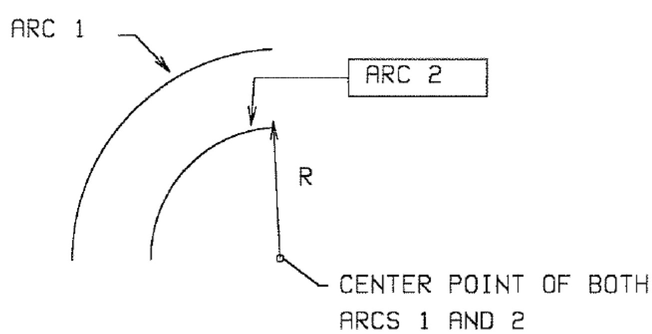
Arc Definition:

The user is given three options for defining an arc:

1. Arc defined by three points: Point 1, Point 2 and Point 3
2. Arc defined by end points, Point 1 and Point3, and a radius, R, "turning right" or "turning left"



3. Arc defined as parallel to an another arc:



Mathematical Definition of an Arc: $R^2 = (X - Xc)^2 + (Y - Yc)^2$

13.3.3 Types of Geometry Problem Solved:

Once the user has defined a point, line, circle or arc, we have the basis for solving various simple geometry problems. There are basically two types of problems to solve: Intersections problems and measurement problems

Solving for an Intersection Point:

GEOMETRY will provide solutions for the intersections of the following elements:

1. Intersection of two straight lines
2. Intersection of a line and circle
3. Intersection of a line and arc
4. Intersection of two circles
5. Intersection of two arcs

Computing a Measurement:

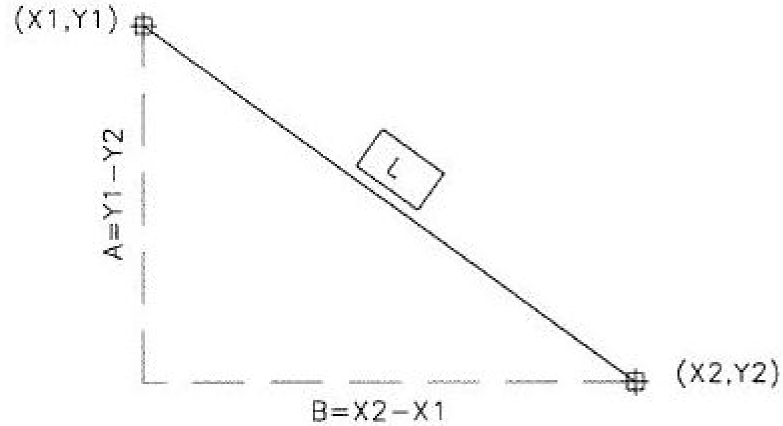
GEOMETRY will compute measurement solutions for the following:

1. Distance between two points along a straight line
2. Distance and offset of a point from another point along a line of bearing
3. Distance between two points along an arc
4. Angle between two straight lines
5. Angle between a straight line and an arc

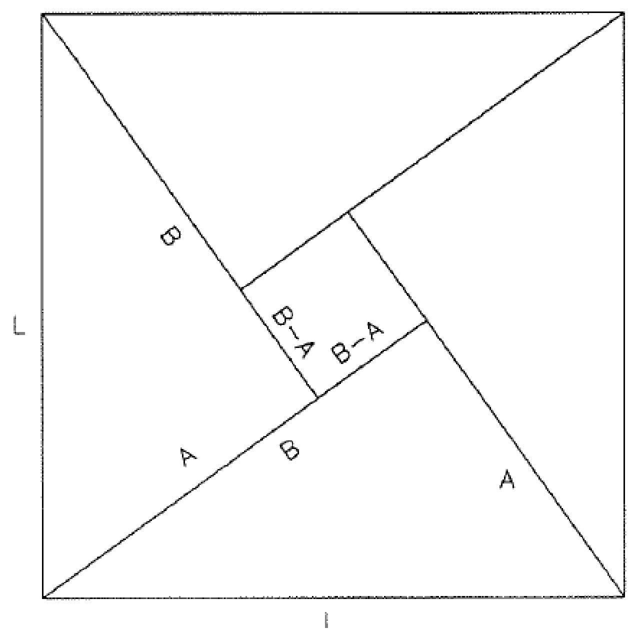
In the following pages, explicit mathematical derivations are shown for the solution of the above types of problems.

Some of these solutions may seem trivial (such as proof of the Pythagorean equation and the Quadratic equation), but are included in the interest of completeness.

13.3.4 Distance Between Two Points (Pythagorean Equation):



This is a proof of the Pythagorean equation. The below graphic shows 4 triangles, each with sides "A" and "B", arranged in a square:



Computing the area of the square,

$$4\,x\left(\frac{1}{2}\right)xAxB + (B - A)x(B - A) = L^2$$

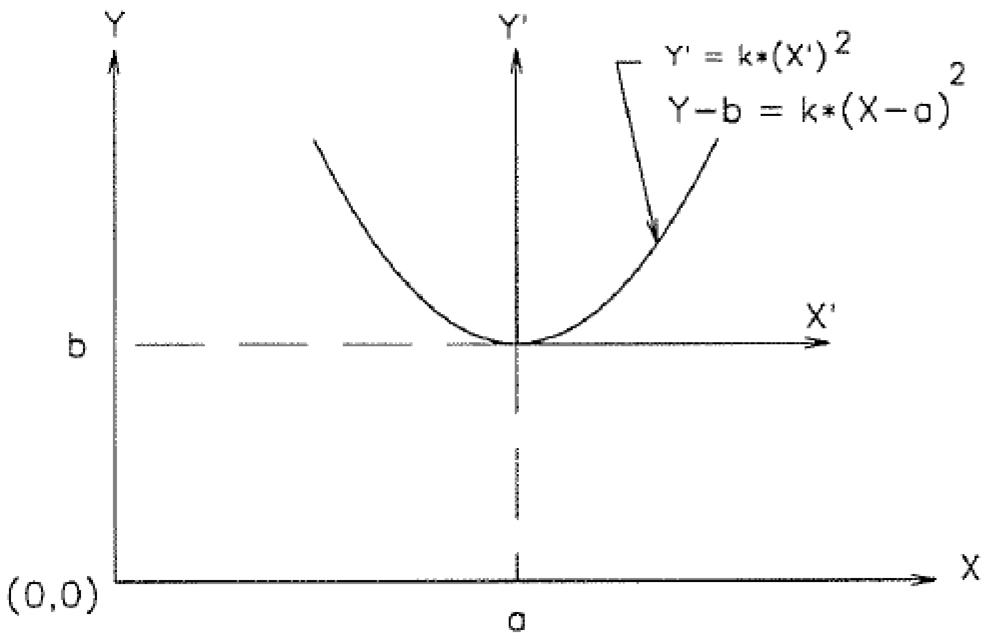
$$2x\;Ax\;B + B^2 - 2 * A * B + A^2 = L^2$$

$$B^2 + A^2 = L^2$$

$$\mathbf{L} = \sqrt{\mathbf{A^2 + B^2}}$$

13.3.5 The Quadratic Equation:

We can derive the quadratic equation by considering a parabola shown in general space:



The basic equation for a parabola relative to the symmetrical local axis X'-Y' is,

$$Y' = k * (X')^2 \qquad \text{(Equation1)}$$

Substituting $X - a = X'$,

$$Y' = k * (X - a)^2$$
$$Y' = k * X^2 - 2 * k * a * X + k * a^2$$
$$\rightarrow k * X^2 - 2 * k * a * X + k * a^2 - Y' = 0$$

Or in the generalized form we are familiar with,

$$\alpha * X^2 + \beta * X + c = 0$$

where,

$$\alpha = k$$
$$\beta = -2 * k * a \rightarrow a = -\frac{\beta}{2*k} = -\frac{\beta}{2*\alpha}$$
$$c = k * a^2 - y' \rightarrow y' = k * a^2 - c = \alpha * a^2 - c$$

From Equation 1, $Y' = k * (X')^2 \rightarrow (X')^2 = \frac{Y'}{k} = \frac{Y'}{\alpha}$

$$X' = \sqrt{\frac{Y'}{\alpha}} = \sqrt{\frac{\alpha*a^2-c}{\alpha}} = \sqrt{a^2 - \frac{c}{\alpha}} = \sqrt{\left(\frac{\beta}{2*\alpha}\right)^2 - \frac{c}{\alpha}} = \frac{\sqrt{\beta^2-4*\alpha*c}}{2*\alpha}$$

Since X' can be both positive and negative,

$$X = a \pm X'$$

$$X = -\frac{\beta}{2*\alpha} \pm \frac{\sqrt{\beta^2-4*\alpha*c}}{2*\alpha} = \frac{-\beta \pm \sqrt{\beta^2-4*\alpha*c}}{2*\alpha}$$

13.3.6 Intersection Point of 2 Straight Lines

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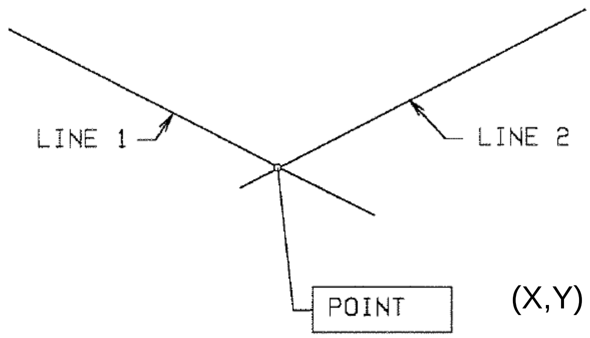


Line 1 Definition: $Y = M1\ x\ X + b1$

Line 2 Definition: $Y = M2\ x\ X + b2$

At intersection point,

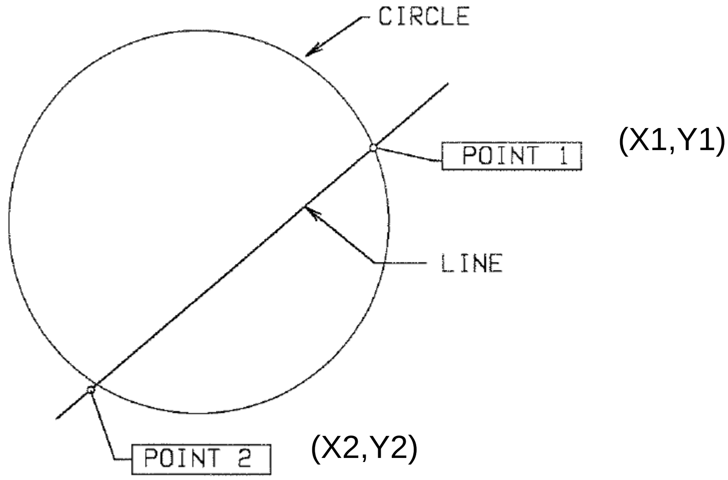
$$M1\ x\ X + b1 = M2\ x\ X + b2$$

$$(M1 - M2) x\ X = b2 - b1$$

$$X = \frac{b2 - b1}{M1 - M2}$$

$$Y = M1\ x\ X + b1$$

13.3.7 Intersection Points of a Straight Line and Circle (*)



Line Definition: $Y = M * \ X + b$

Circle Definition:

$$R^2 = (X - Xc)^2 + (Y - Yc)^2$$

$$= X^2 - 2 * X * Xc + Xc^2 + Y^2 - 2 * Y * Yc + Yc^2$$

$$= X^2 - 2 * X * Xc + Xc^2 + (M * X + b)^2 - 2 * (M * X + b) * Yc + Yc^2$$

$$= X^2 - 2 * X * Xc + Xc^2 + M^2 * X^2 + 2 * M * X + b^2 - 2 * M * X * Yc \\ -2 * b \ * Yc + Yc^2$$

Rearranging,

$$(1 + M^2) * X^2 + (-2 * Xc + 2 * M * b - 2 * M * Yc) * X + (Xc^2 + b^2 - 2 * b * Yc \\ + Yc^2 + R^2 = 0$$

Or

$$\alpha * X^2 + \ \beta * X + C = 0$$

where,

$$\alpha = 1 + m^2$$
$$\beta = -2 * Xc + 2 * M * b - 2 * M * Yc$$
$$C = Xc^2 + b^2 - 2 * b * Yc + Yc^2 - R^2$$

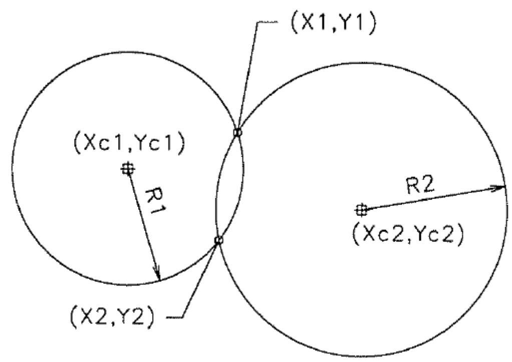
Solving using the quadratic equation,

$Point\ 1$: $X1 = (-\beta + \sqrt{\beta^2 - 4 * \alpha * c}\ ))/(2*\alpha)$
$Y1 = M * X1 + b$

$Point\ 2$: $X2 = (-\beta\ - \sqrt{\beta^2 - 4 * \alpha * c}\ )/(2*\alpha)$
$Y2 = M * X1 + b$

(* Note: This solution also applies to the intersection of a line and an arc)

13.3.7 Intersection Points of Two Circles (*)



Circle 1: $(X - Xc1)^2 + (Y - Yc1)^2 = R1^2$ (Equation 1)
$\rightarrow X^2 - 2*X*Xc1 + Xc1^2 + Y^2 - 2*Y*Yc1 + Yc1^2 = R1^2$ (Equation 2)
Circle 2: $(X - Xc2)^2 + (Y - Yc2)^2 = R2^2$
$\rightarrow X^2 - 2*X*Xc2 + Xc2^2 + Y^2 - 2*Y*Yc2 + Yc2^2 = R2^2$ (Equation 3)

Equation 2 – Equation 3,
$$2*(Xc2 - Xc1)*X + (Xc1^2 - Xc2^2) - 2*(Yc1 - Yc2)*Y + (Yc1^2 - Yc2^2) = R1^2 - R2\hat{}2$$
$$X = \frac{R1^2 - R2^2 - Xc1^2 + Xc^2 - Yc1^2 - Yc2^2}{2*(Xc2 - Xc1)} + \frac{Yc1 - Yc2}{Xc2 - Xc1}*Y$$
$$= \alpha1 + \alpha2*Y$$ (Equation 4)

where
$$\alpha1 = \frac{R1^2 - R2^2 - Xc1^2 + Xc^2 - Yc1^2 - Yc2^2}{2*(Xc2 - Xc1)} \text{ and } \alpha2 = \frac{Yc1 - Yc2}{Xc2 - Xc1}$$

Substitution of Equation 4 into Equation 1 leads to,
$$(\alpha1 + \alpha2*Y - Xc1)^2 + (Y - Yc1)^2 = R1^2$$
$$\left((\alpha1 - Xc1) + \alpha2*Y\right)^2 + (Y - Yc1)^2 = R1^2$$
$$(\alpha1 - Xc1)^2 + 2*\begin{pmatrix}\alpha1 \\ -Xc1\end{pmatrix}*\alpha2*Y + \alpha2^2*Y^2 + Y^2 - 2*Y*Yc1 + Yc1^2 = R1^2$$
$$(1+\alpha2)*Y^2 + (2*(\alpha1 - Xc1)*\alpha2 - 2*Yc1)*Y + ((\alpha1 - Xc1)^2 + Yc1^2 - R1^2) = 0$$

or
$$A*Y^2 + B*Y + C = 0$$

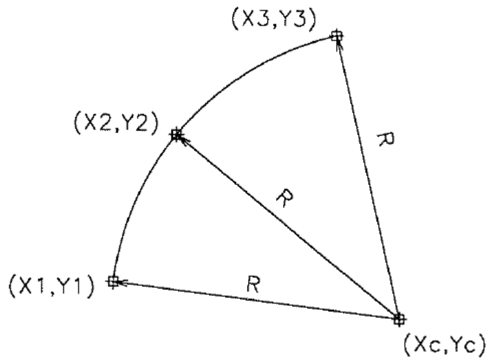
where
$$A = (1+\alpha2)$$
$$B = (2*(\alpha1 - Xc1)*\alpha2 - 2*Yc1)$$
$$C = ((\alpha1 - Xc1)^2 + Yc1^2 - R1^2)$$

Solving by the Quadratic equation,

$$Y1 = \frac{-B + \sqrt{B^2 - 4*A*C}}{2*A} \text{ and } X1 = \alpha1 + \alpha2*Y1$$
$$Y2 = \frac{-B - \sqrt{B^2 - 4*A*C}}{2*A} \text{ and } X2 = \alpha1 + \alpha2*Y2$$

(* Note this solution also applies to the intersection of arcs)

13.3.8 Fitting a Circle or Arc Through Three Points



From Point 1 to Center,

$(X1 - Xc)^2 + (Y1 - Yc)^2 = R^2$

$X1^2 - 2 * X1 * Xc + Xc^2 + Y1^2 - 2 * Y1 * Yc + Yc^2 = R^2$ (Equation 1)

Similarly, for Point 2 and Point 3,

$X2^2 - 2 * X2 * Xc + Xc^2 + Y2^2 - 2 * Y2 * Yc + Yc^2 = R^2$ (Equation 2)

$X3^2 - 2 * X3 * Xc + Xc^2 + Y3^2 - 2 * Y3 * Yc + Yc^2 = R^2$ (Equation 3)

Equation 1 – Equation 2:

$(X1^2 - X2^2) + 2 * (-X1 + X2) * Xc + (Y1^2 - Y2^2) + 2 * (-Y1 + Y2) * Yc = 0$

$2 * (X1 - X2) * Xc + 2 * (Y1 - Y2) * Yc = X1^2 - X2^2 + Y1^2 - Y2^2$

$\alpha 1 * Xc + \alpha 2 * Yc = \alpha 3$ (Equation 4)

where

$\alpha 1 = 2 * (X1 - X2)$

$\alpha 2 = 2 * (Y1 - Y2)$

$\alpha 3 = X1^2 - X2^2 + Y1^2 - Y2^2$

Equation 2 – Equation 3:

$(X2^2 - X3^2) + 2 * (-X2 + X3) * Xc + (Y2^2 - Y2^2) + 2 * (-Y2 + Y3) * Yc = 0$

$2 * (X2 - X3) * Xc + 2 * (Y2 - Y3) * Yc = X2^2 - X3^2 + Y2^2 - Y3^2$

$\beta 1 * Xc + \beta 2 * Yc = \beta 3$ (Equation 5)

where

$\beta 1 = 2 * (X2 - X3)$

$\beta 2 = 2 * (Y2 - Y3)$

$\beta 3 = X2^2 - X3^2 + Y2^2 - Y3$

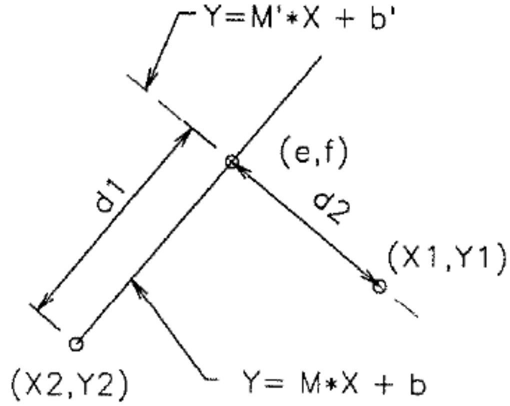
Solving simultaneous Equations 4 and 5 by Cramer's rule:

$$Xc = \frac{\alpha 3 * \beta 2 - \alpha 2 * \beta 3}{\alpha 1 * \beta 2 - \alpha 2 * \beta 1}$$

$$Yc = (\alpha 3 - \alpha 1 * Xc)/\alpha 2$$

$$R = \sqrt{(X1 - Xc)^2 + (Y1 - Yc)^2}$$

13.3.9 Computing Distance and Offset to A Point



Given a line with the following equation,

$$Y = M * X + b$$

The equation of a line perpendicular to that line passing through point (X1,Y1) is,

$$Y = M' * X + b'$$

where

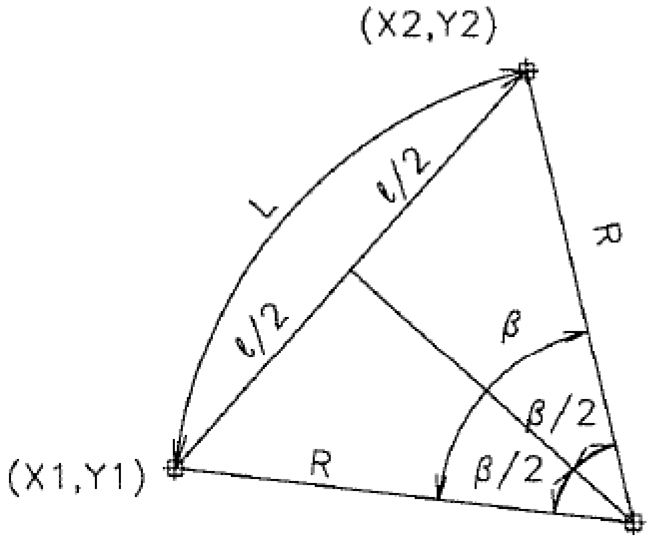
$$M' = -1/M$$
$$b' = Y1 - M' * X1$$

The two line intersect at the following point,

$$e = \frac{(b' - b)}{M - M'}$$
$$f = M * e + b$$

Distance: $d1 = \sqrt{(e - X2)^2 + (f - Y2)^2}$
Offset: $d2 = \sqrt{(e - X1)^2 + (f - Y1)^\wedge 2}$

13.3.9 Computing Distance Between Two Points on Arc:



$$l = \sqrt{(x2 - x1)^2 + (y2 - y1)^2}$$

$$\beta = 2 * \sin^{-1}\left(\frac{l}{2 * R}\right)$$

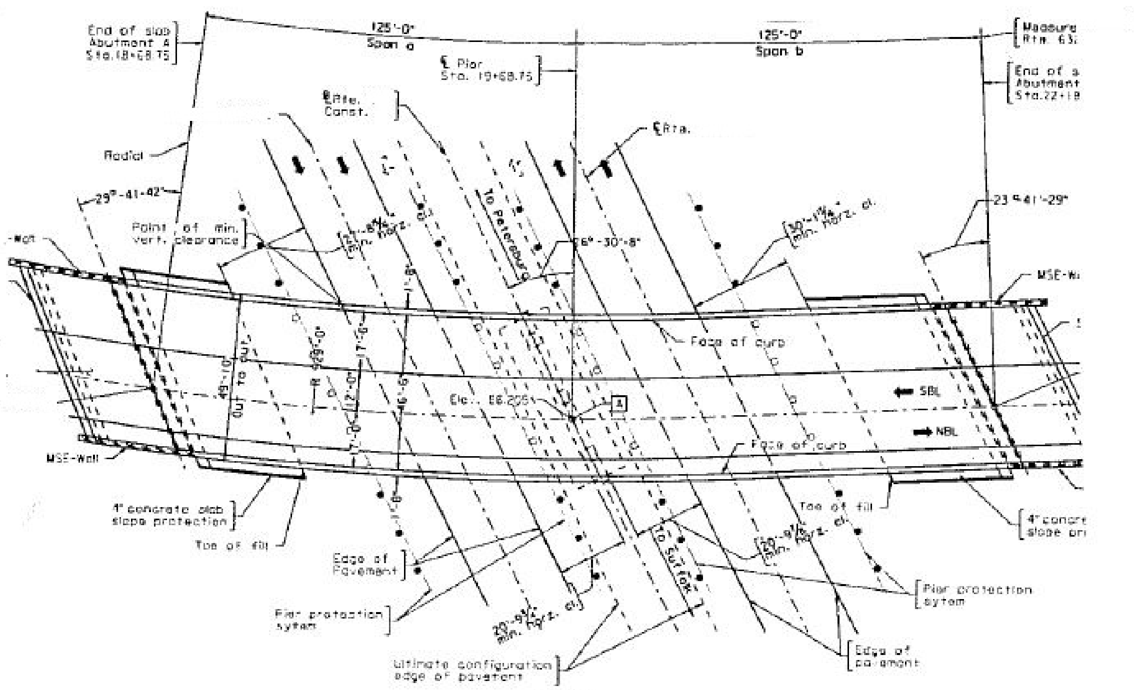
$$L = \beta * \pi * \frac{R}{180}$$

13.4 How to Use the GEOMETRY Program To Develop a Framing Plan

Suppose that you need to develop framing plans for a bridge that is on a curve with skewed piers and abutments. This is the type of problem that is well suited for running the GEOMETRY program. You will be able to quickly setup basic line geometry which you can subsequently enter into the DCALC program DCBRIDGE, which will generate DXF files for framing plans.

Or suppose that another consultant has prepared plans and you need to check their plan dimensions. This is also another type of problem that is well suited for running the GEOMETRY program.

Let's walk through an actual example problem. The below sketch shows the bridge to bel be used as an example:

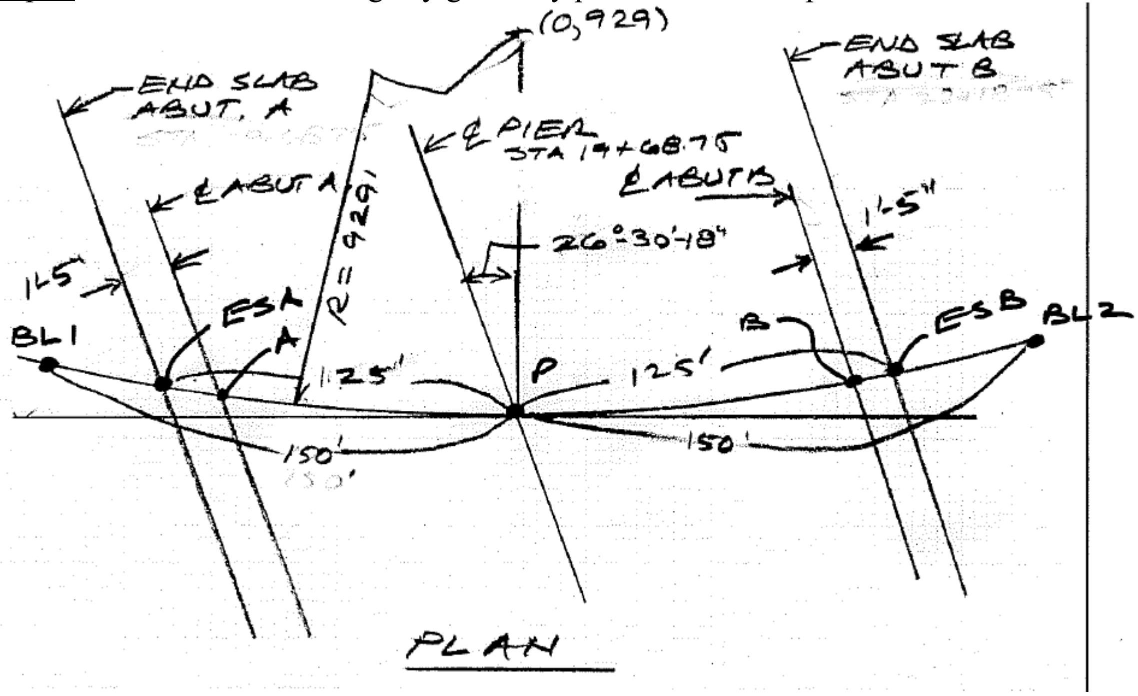


PLAN

The following data will be used:

- We look "upstation" when we refer to "left side" and "right side" of the bridge
- The bridge is "curving to the left" with a radius of 929'-0".
- The superstructure will consist of 6 prestressed bulb tee girders.
- Girders are straight and will be spaced equidistantly at each centerline of bearing
- The "left" exterior girders will be set with 4'-9" deck cantilevers at the centerlines of bearings
- The "right" exterior girders will be set with 2'-9" deck cantilevers at the centerlines of bearings

Step 1: Make a sketch showing key geometry points. Give each point and line a name:



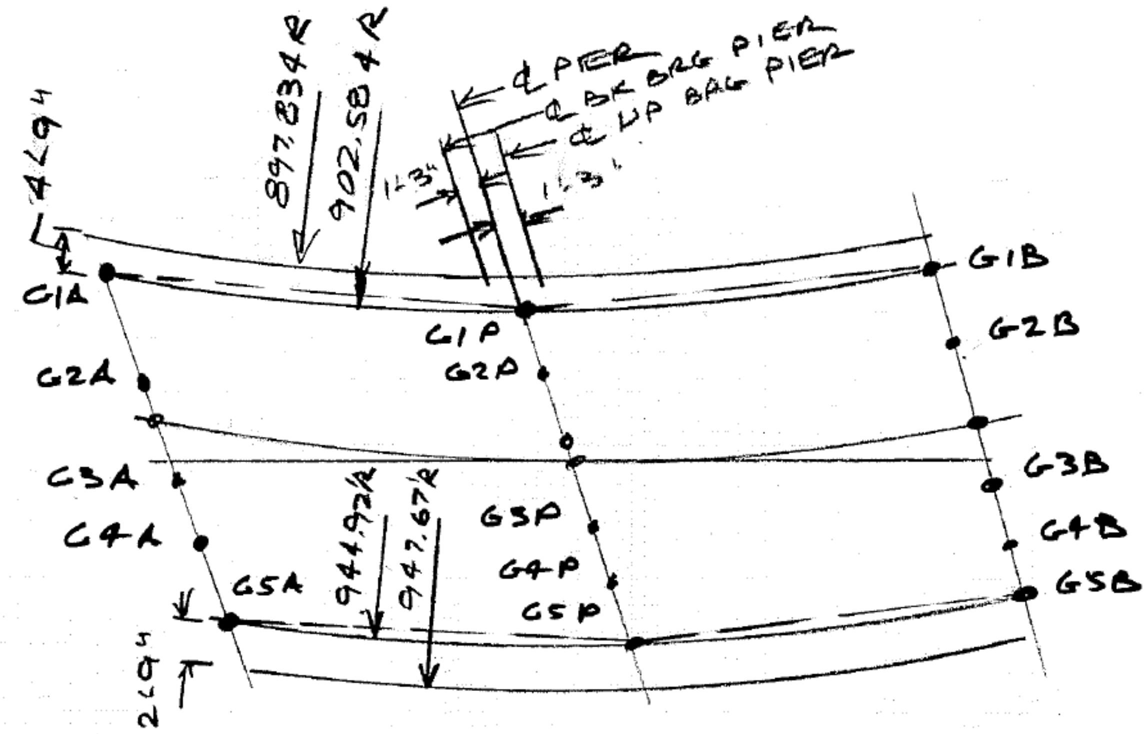
The purpose of the sketch is to organize your thoughts before using the GEOMETRY program, and also to have a record to the point and line names.

In this case, the steps will be as follows:

1. Define Point “P” first. It will be located at (0,0)
2. Define the center of the arc as Point “C”. It will be located at (0,929)
3. Define a Point “BL1” which will be set on the arc at a radial distance of -150 feet from Point “P”, using Point “C” as the center of arc
4. Define a Point “ESA” which is a radial distance of -125 feet from Point “P”
5. Define a Point “ESB” which is a radial distance of 125 feet from Point “P”
6. Define a Point “BL2” which is a radial distance of 150 feet from Point “P”
7. Define an arc using 3 points: “BL1”, “P” and “BL2”. Call this arc “CL”
8. Define the “CL Pier”. It will pass through Point “P” at the skew shown.
9. Define the “End/ Slab Abut A”. It will pass through Point “ESA” at the same skew as the pier. Call this line “ESA”
10. Define the “End/ Slab Abut B”. It will pass through Point “ESB” at the same skew as the pier.
11. Define “CL Abut A”. It will be parallel to “End/Slab Abut A”, with offset 1’5”
12. Define “CL Abut B”. It will be parallel to “End/Slab Abut B”, with offset -1’-5”

In this case, the final objective is to generate geometrical data which can be entered into the DCALC “DCBRIDGE” program. Using DCBRIDGE, you will be entering the arc (“BL”) as a “longitudinal line” and each centerline of bearing as a “transverse line”.

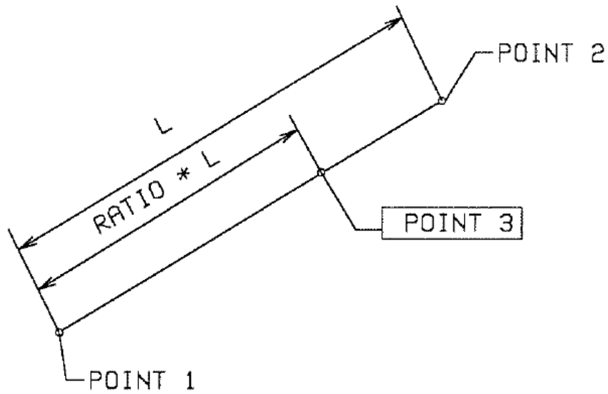
Next, you should prepare a sketch for the beam layout. You will solve for key intersection points of the beams which can be later entered into the DCBRIDGE program.



Thinking the process through, you will plan on the following steps in the GEOMETRY program:

13. Solve for the left exterior girder points. In this case, define an arc that is parallel to the “CL” arc. This new arc we will called “Target left girder radius”, which will have a radius of 902.584 feet
14. Solve for the intersection of “Target left girder radius” and the “CL East Abutment”. Call this point “G1A”
15. Similarly solve for points “G1P” and “G1B”
16. Solve for the right exterior girder points. In this case, define an arc that is parallel to the “CL” arc. This new arc will be called “Target right girder radius”, which will have a radius of 944.921 feet
17. Solve for intersection points “G5A”, “G5P” and “G5B”.

18. The interior girder bearing points will be set equidistantly. You will be using the following feature in GEOMETRY which sets a point based on the ratio between two end points:



In this case

- "G2A" will be set at Ratio=0.75 between "G5A" and "G1A"
- "G3A" will be set at Ratio=0.50 between "G5A" and "G1A"
- "G4A" will be set at Ratio=0.25 between "G5A" and "G1A"

Girder points at "CL Pier" and "CL Abutment B" will be set in a similar fashion.

19. Finally, since this will be a prestressed bulb-tee girder bridge, it will require 2 lines of bearings at the pier. You will need to define
    - "CL BK BRG" (the back station bearing) as a line parallel to "CL Pier" with offset = -1'-3"
    - "CL UP BRG" (the upstation bearing) as a line parallel to "CL Pier" with offset= 1'-3"

Once you have gone through the process you will realize the steps are very much like drawing in CAD. The advantage over CAD is, GEOMETRY will print a useful record of the geometrical operations and data points as needed. In this case, a framing plan can quickly be started, even before drawing anything in CAD.

13.5 Example GEOMETRY Output

The following output is from GEOMETRY for this bridge:

```
FIRM:DesignCalcs, Inc.                  JOB NO.1234567890 SHEET NO:  1
MADE BY:KJH  DATE:12-31-2013            CHECKED BY:        DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------
Number of points stored: 25
Point No.   1: P
X=         0.00000,   Y=        0.000000
(point was defined under operation no.   1 )
Point No.   2: C
X=         0.00000,   Y=      929.000000
(point was defined under operation no.   2 )
Point No.   3: BL1
X=      -149.35273,   Y=       12.084103
(point was defined under operation no.   3 )
Point No.   4: BL2
X=       149.34543,   Y=       12.082914
(point was defined under operation no.   4 )
Point No.   5: ESA
X=      -124.62682,   Y=        8.397396
(point was defined under operation no.   6 )
Point No.   6: ESB
X=       124.61949,   Y=        8.396404
(point was defined under operation no.   7 )
Point No.   7: A
X=      -122.93000,   Y=        8.169268
(point was defined under operation no.  15 )
Point No.   8: B
X=       123.13597,   Y=        8.196835
(point was defined under operation no.  16 )
Point No.   9: G1A
X=      -137.26719,   Y=       36.919063
(point was defined under operation no.  11 )
Point No.  10: G5A
X=      -114.38211,   Y=       -8.971489
(point was defined under operation no.  12 )
Point No.  11: G1P
X=       -13.22364,   Y=       26.516857
(point was defined under operation no.  13 )
Point No.  12: G5P
X=         7.92254,   Y=      -15.886773
(point was defined under operation no.  14 )
Point No.  13: G1B
X=       110.65297,   Y=       33.228485
(point was defined under operation no.  15 )
Point No.  14: G5B
X=       130.63761,   Y=       -6.845921
(point was defined under operation no.  16 )
```

```
FIRM:DesignCalcs, Inc.                  JOB NO.1234567890 SHEET NO:  2
MADE BY:KJH  DATE:12-31-2013            CHECKED BY:        DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------

Point No.  15: G2A
X=      -131.54592,   Y=       25.446424
(point was defined under operation no.  17 )
Point No.  16: G3A
X=      -125.82465,   Y=       13.973786
(point was defined under operation no.  18 )
Point No.  17: G4A
X=      -120.10338,   Y=        2.501148
(point was defined under operation no.  19 )
Point No.  18: G2P
X=        -7.93709,   Y=       15.915948
(point was defined under operation no.  20 )
Point No.  19: G3P
X=        -2.65054,   Y=        5.315041
(point was defined under operation no.  21 )
Point No.  20: G4P
X=         2.63599,   Y=       -5.285865
(point was defined under operation no.  22 )
Point No.  21: G2B
X=       115.64913,   Y=       23.209883
(point was defined under operation no.  23 )
Point No.  22: G3P
X=       120.64529,   Y=       13.191281
(point was defined under operation no.  24 )
Point No.  23: G4B
X=       125.64145,   Y=        3.172680
(point was defined under operation no.  25 )
Point No.  24: LEFT FF/A
X=      -110.53649,   Y=      -12.201389
(point was defined under operation no.  29 )
Point No.  25: FF/A RIGHT
X=      -137.44047,   Y=       41.748085
(point was defined under operation no.  30 )
-------------------------------------------------------------------------
Number of straight lines stored:  8
Line No.   1: CL PIER
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=      0.00000, Y1=      0.00000
To   X2=    -22.31371, Y2=     44.74481
(line was defined under operation no.   8 )
Line No.   2: ESA
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=   -124.62682, Y1=      8.39739
To   X2=   -146.94053, Y2=     53.14220
(line was defined under operation no.   9 )
```

```
FIRM:DesignCalcs, Inc.                  JOB NO.1234567890 SHEET NO:  3
MADE BY:KJH  DATE:12-31-2013            CHECKED BY:        DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------

Line No.   3: ESB
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=    124.61949, Y1=      8.39640
To   X2=    102.30577, Y2=     53.14121
(line was defined under operation no.  10 )
Line No.   4: CL ABUT A
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=   -123.35905, Y1=      9.02961
To   X2=   -145.67276, Y2=     53.77442
(line was defined under operation no.  11 )
Line No.   5: CL BK BRG PIER
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=     -1.11862, Y1=      -.55784
To   X2=    -23.43233, Y2=     44.18696
(line was defined under operation no.  12 )
Line No.   6: CL UP BRG. PIER
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=      1.11862, Y1=       .55784
To   X2=    -21.19509, Y2=     45.30265
(line was defined under operation no.  13 )
Line No.   7: CL ABUT B
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=    123.35173, Y1=      7.76418
To   X2=    101.03800, Y2=     52.50899
(line was defined under operation no.  14 )
Line No.   8: FF/ABUT A
Bearing Angle =116.504997 degrees with respect to horizontal
From X1=   -121.56925, Y1=      9.92216
To   X2=   -143.88296, Y2=     54.66697
(line was defined under operation no.  26 )
-------------------------------------------------------------------------
Number of circles stored:  0
-------------------------------------------------------------------------
Number of arcs stored:  5
Arc No.   1: BL
R =    929.00000, Xc=     -0.00000, Yc=    929.000
From X1=   -149.35273, Y1=     12.08410
To   X2=    149.34542, Y2=     12.08291
(arc was defined under operation no.    5
Arc No.   2: G1 TARGET RADIUS
R =    902.58001, Xc=     -0.00000, Yc=    929.000
From X1=   -145.10527, Y1=     38.16042
To   X2=    145.09816, Y2=     38.15924
(arc was defined under operation no.   17
```

```
FIRM:DesignCalcs, Inc.                  JOB NO.1234567890 SHEET NO:  4
MADE BY:KJH  DATE:12-31-2013            CHECKED BY:        DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------

Arc No.   3: G5 TARGET RADIUS
R =    944.91998, Xc=     -0.00000, Yc=    929.000
From X1=   -151.91215, Y1=     -3.62879
To   X2=    151.90471, Y2=     -3.63003
(arc was defined under operation no.   18
Arc No.   4: LEFT EDGE OF DECK
R =    897.83398, Xc=     -0.00000, Yc=    929.000
From X1=   -144.34226, Y1=     42.84472
To   X2=    144.33519, Y2=     42.84354
(arc was defined under operation no.   27
Arc No.   5: RIGHT EDGE OF DECK
R =    947.66998, Xc=     -0.00000, Yc=    929.000
From X1=   -152.35426, Y1=     -6.34302
To   X2=    152.34680, Y2=     -6.34426
(arc was defined under operation no.   28
```

```
FIRM:DesignCalcs, Inc.                  JOB NO.1234567890 SHEET NO:  5
MADE BY:KJH  DATE:12-31-2013            CHECKED BY:        DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------

GEOMETRICAL OPERATIONS:
-----------------------
Operation No.   1: Point Definition
Point   1 Description: P
X=         0.00000,   Y=        0.000000
-------------------------------------------------------------------------
Operation No.   2: Point Definition
Point   2 Description: C
X=         0.00000,   Y=      929.000000
-------------------------------------------------------------------------
Operation No.   3: Compute a point relative along an arc
Point   3 Description: BL1
From Point   1 with Center Point   2 and R=   929.0000000
at distance, L=   -150.00000 turning counterclockwise,
X=      -149.35273,   Y=       12.084103
-------------------------------------------------------------------------
Operation No.   4: Compute a point relative along an arc
Point   4 Description: BL2
From Point   1 with Center Point   2 and R=   929.0000000
at distance, L=    150.00000 turning counterclockwise,
X=       149.34543,   Y=       12.082914
-------------------------------------------------------------------------
Operation No.   5: Define an arc
Arc   1 Description:BL
Arc was defined by fitting through the following three points:
Begin Point No.   3, Point No.   1, End Point No.   4
R =    929.00000, Xc=     -0.00000, Yc=    929.000
-------------------------------------------------------------------------
Operation No.   6: Compute a point relative along an arc
Point   5 Description: ESA
From Point   1 with Center Point   2 and R=   929.0000000
at distance, L=   -125.00000 turning counterclockwise,
X=      -124.62682,   Y=        8.397396
-------------------------------------------------------------------------
Operation No.   7: Compute a point relative along an arc
Point   6 Description: ESB
From Point   1 with Center Point   2 and R=   929.0000000
at distance, L=    125.00000 turning counterclockwise,
X=       124.61949,   Y=        8.396404
-------------------------------------------------------------------------
```

```
FIRM:DesignCalcs, Inc.                  JOB NO.1234567890 SHEET NO:  6
MADE BY:KJH  DATE:12-31-2013            CHECKED BY:       DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------

Operation No.   8: Define a straight line
Line   1 Description: CL PIER
Line was defined by a point and angle:
Point No.   1 at a Bearing Angle =  116.5049972 degrees
-------------------------------------------------------------------------
Operation No.   9: Define a straight line
Line   2 Description: ESA
Line was defined by a point and angle:
Point No.   5 at a Bearing Angle =  116.5049972 degrees
-------------------------------------------------------------------------
Operation No.  10: Define a straight line
Line   3 Description: ESB
Line was defined by a point and angle:
Point No.   6 at a Bearing Angle =  116.5049972 degrees
-------------------------------------------------------------------------
Operation No.  17: Compute a point using prorated distance between points
Point  15 Description: G2A
Based on prorating the distance from Point  10 to Point   9
using a proration ratio =    .75000, the new point location is
X=      -131.54592,   Y=       25.446424
-------------------------------------------------------------------------
Operation No.  18: Compute a point using prorated distance between points
Point  16 Description: G3A
Based on prorating the distance from Point  10 to Point   9
using a proration ratio =    .50000, the new point location is
X=      -125.82465,   Y=       13.973786
-------------------------------------------------------------------------
Operation No.  19: Compute a point using prorated distance between points
Point  17 Description: G4A
Based on prorating the distance from Point  10 to Point   9
using a proration ratio =    .25000, the new point location is
X=      -120.10338,   Y=        2.501148
-------------------------------------------------------------------------
Operation No.  20: Compute a point using prorated distance between points
Point  18 Description: G2P
Based on prorating the distance from Point  12 to Point  11
using a proration ratio =    .75000, the new point location is
X=        -7.93709,   Y=       15.915948
-------------------------------------------------------------------------
```

```
FIRM:DesignCalcs, Inc.                  JOB NO.1234567890 SHEET NO:  7
MADE BY:KJH  DATE:12-31-2013            CHECKED BY:       DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------

Operation No.  21: Compute a point using prorated distance between points
Point  19 Description: G3P
Based on prorating the distance from Point  12 to Point  11
using a proration ratio =    .50000, the new point location is
X=        -2.65054,   Y=        5.315041
-------------------------------------------------------------------------
Operation No.  22: Compute a point using prorated distance between points
Point  20 Description: G4P
Based on prorating the distance from Point  12 to Point  11
using a proration ratio =    .25000, the new point location is
X=         2.63599,   Y=       -5.285865
-------------------------------------------------------------------------
Operation No.  23: Compute a point using prorated distance between points
Point  21 Description: G2B
Based on prorating the distance from Point  14 to Point  13
using a proration ratio =    .75000, the new point location is
X=       115.64913,   Y=       23.209883
-------------------------------------------------------------------------
Operation No.  24: Compute a point using prorated distance between points
Point  22 Description: G3P
Based on prorating the distance from Point  14 to Point  13
using a proration ratio =    .50000, the new point location is
X=       120.64529,   Y=       13.191281
-------------------------------------------------------------------------
Operation No.  25: Compute a point using prorated distance between points
Point  23 Description: G4B
Based on prorating the distance from Point  14 to Point  13
using a proration ratio =    .25000, the new point location is
X=       125.64145,   Y=        3.172680
-------------------------------------------------------------------------
Operation No.  26: Define a straight line parallel to an existing line
Line   8 Description: FF/ABUT A
Line is parallel to Line   4 at Offset=    2.00
Passes through X=      -121.56925,   Y=        9.922165
Bearing Angle =116.504997 degrees to horiz.
-------------------------------------------------------------------------
Operation No.  27: Define an arc parallel to another arc
Arc   4 Description:LEFT EDGE OF DECK
Arc has R=   897.8339843 and is parallel to Arc   1
Xc=     -0.00000, Yc=    929.00000
Begin Arc at X=    -144.34226, Y=     42.84472
End Arc at   X=     144.33519, Y=     42.84354
-------------------------------------------------------------------------
```

```
FIRM:DesignCalcs, Inc.                 JOB NO.1234567890 SHEET NO:  8
MADE BY:KJH  DATE:12-31-2013           CHECKED BY:        DATE:
TITLE:Example GEOMETRY Output
=========================================================================
GEOMETRY:
---------

Operation No.  28: Define an arc parallel to another arc
Arc   5 Description:RIGHT EDGE OF DECK
Arc has R=   947.6699829 and is parallel to Arc   1
Xc=     -0.00000, Yc=    929.00000
Begin Arc at X=    -152.35426, Y=     -6.34302
End Arc at   X=     152.34680, Y=     -6.34426
-------------------------------------------------------------------------
Operation No.  29: Compute intersections of a line and an arc
Line No.   8 and Arc No.    5
Intersection at Point No.  24: LEFT FF/A
X1=      -110.53649,   Y1=      -12.201389
-------------------------------------------------------------------------
Operation No.  30: Compute intersections of a line and an arc
Line No.   8 and Arc No.    4
Intersection at Point No.  25: FF/A RIGHT
X1=      -137.44047,   Y1=       41.748085
-------------------------------------------------------------------------
Operation No.  31:Compute distance and offset between 2 points
Measurement Description:FF/A DIM ON LEFT SIDE
From Point No.  24 to Point No.   10
along Bearing Angle = 116.50499725 degrees from horizontal
Distance=      4.6066203, Offset=      2.000001
-------------------------------------------------------------------------
Operation No.  32:Compute distance and offset between 2 points
Measurement Description:FF/A DIM ON RIGHT SIDE
From Point No.   9 to Point No.   25
along Bearing Angle = 116.50499725 degrees from horizontal
Distance=      4.3988051, Offset=      2.000001
-------------------------------------------------------------------------
```