SURVEY SECTION (METRIC)

ELEMENTS OF HIGHWAY CONSTRUCTION LAYOUT

In order to properly construct a project, it is essential that the field layout work be done accurately. The following discussions give field personnel some guidelines to assist in the staking operation. When the layout work and staking is done by the Contractor as a contract pay item, the Resident should review the Special Provisions to identify his/her responsibilities with regard to staking and checking.

Care of Department Owned Property

The Department has a considerable investment in vehicles, surveying and laboratory equipment. When this property is assigned to you for your use in the field, you become personally responsible for its care and condition. If damages occur to the equipment because of negligence or carelessness, the employee may be responsible for the cost of making repairs or replacements. Contractor-furnished equipment should be given similar care.

When you receive an instrument from the office you should take the time to read the instruction manual that comes with it. Take extra time to read the section on the proper care of the instrument. Proper care of equipment will extend its life and accuracy. Survey equipment is expensive and fragile, below are a few items to keep in mind when using any piece of survey equipment.

A. Handle the instruments carefully and cushion them against vibration and shock.

B. When taking the instruments out of their carrying case, handle them firmly until secured onto the tripod.

C. When carrying a transit, make sure both plates are locked and the telescope is also locked in the vertical position.

D. Before picking up the instrument and tripod, always check the centering screw to make certain the instrument is secured to the tripod.

E. Never over tighten the locking screws.

F. When carrying the instrument, on the tripod, carry it in a vertical position.

G. Never leave the instrument unattended for any length of time.

H. Clean the lenses only as specified in the owner’s manual.

I. Keep the instrument and carrying case dry. If they become wet, allow them to air dry before closing the carrying case. Extend level rod and let air dry overnight.

Field Notes

Field notes are the written record of pertinent layout information , measurements and inspection of the contract work. They should be kept according to uniform practices and conform as a minimum to the following general requirements:

A. Neatness. Use a sharp pencil of at least 3-H hardness. Avoid crowding. Keep the book as clean as possible.

B. Legibility. Use standard symbols and abbreviations to keep notes compact. Use plain lettering to avoid confusion.

C. Clarity. Plan work ahead so that data can be clearly indicated. Do not make ambiguous statements. Provide adequate descriptions and make sketches for clarity. Record data in a consistent manner. Assume that the person who will use your notes has no familiarity with the work.

D. Completeness. Show all pertinent measurements and inspection data. Use the degree of accuracy consistent with the survey requirement. If in doubt about the need for the data, record it. Review data before leaving the field. All entries must include:

   1. The date and weather conditions.
   2. Title of survey.
   3. Names (or initials) of all persons in the party and their assignments.

   The title page must be completed when the book or contract is started. The District's return address must be noted on the title page in case the book is lost. The book must be adequately indexed, pages numbered and cross-referenced to contents.

E. Permanence. All entries should be made directly into bound books. At completion of the contract, they should be filed as part of the permanent record in keeping with Department policy.

F. Accuracy. Record exactly what was done at the time it was done rather than depending on memory at a later time. Never erase. If an item is incorrectly entered, draw a line through the item and insert the corrected value immediately above. When it is necessary to add data to notes previously prepared, the additional item should be dated and initialed. Always enter notes directly into the record.

G. Self-checking. Notes should be so kept that the work can be checked without returning to the field. Any person familiar with the contract should be able to verify the accuracy of the work from the information contained in the notes. Use positive controls.

H. Examples of proper field notes are in the Documentation Section of this manual.

Setting & Recording Layout Stakes

A. Accuracy is the essential in setting vertical and horizontal control stakes. Remember that when you have set stakes the Contractor assumes they are correct. In order to avoid complaints from the Contractor that stakes were improperly set or that s/he incurred additional expense because of an error in setting a grade, instruct the Contractor to notify you at once if at any time they consider a grade stake to be in error. This will give you a chance to check the elevation in a timely manner

Service to the Contractor is another essential feature of the work. Do not wait for the Contractor to ask for stakes, but take the initiative and confer with him/her to determine the portions of the work to be staked first. Agree upon the lines and grades desired, the clearances required for construction equipment, and other matters relative to the layout work. Arrange your work so you will always have sufficient stakes set ahead so the Contractor will not be delayed in prosecuting the work.

Before stakes can be set, the survey line must be established and verified. It is advisable to tie in all control points, such as P.I.'s, P.O.T.'s, P.C's, and P.T.'s to reference points outside the area of construction. Benchmarks for use in construction should be set and checked before stakes are set. All level circuits used for setting stakes must be accurately closed on benchmarks before stakes are used. Once stakes are set they should be guarded with lath and high visibility flagging. The lath should clearly identify the stake and its use in order to avoid confusion.

Check, Check, Check. Whatever the method of surveying used, the more checking you do, the possibility of errors or mistakes Is greatly reduced. Grade elevations, curve data, etc., must be checked before being used. All measurements, level notes, and computed distances must be rechecked frequently. Check with the plans in hand instead of relying on memory. It is an embarrassment to the Department when a bridge is built to the wrong elevation or when the distance between bridge seats is too short or too long. These things have happened in the past, but they will be less likely to occur if the work is carefully checked.

Choice of Methods:

1. Methods optional. The field methods outlined below are acceptable methods for construction surveying. The Resident does not have to follow these methods and may use their own method. However, each suggested method is a good method to use if the Resident is in doubt as to how to proceed. Each method should be read carefully.

2. A standard method of staking should be followed but may be varied to meet topographical conditions, type of construction, equipment used and the Contractor's preference. This is a convenience to Contractors who work in more than one district, and also reduces the chance of confusion and misunderstanding between Residents in the field and the district office.

B. The Resident must keep a complete legible record of all stakes set. The description and elevation of all new benchmarks and the new ties for all points must be recorded and completely described. Grade changes and other changes from the original design must be recorded and carefully described. All records must be clear and complete so that any stake can be replaced easily, at any time, with a minimum amount of effort. It should never be necessary to rerun several hundred meters (yards) of line to replace one or two stakes.

C. Prepare in Advance. It is essential that field books containing the necessary grades, sketches, tie points, benchmarks and other data be prepared in advance. Delays and inconvenience result if it is necessary to refer to the plans often for layout information. Notes and sketches should be independently checked. The books should contain grade elevations at the intervals required, survey line ties, benchmarks, curve data and any other data required for frequent use.

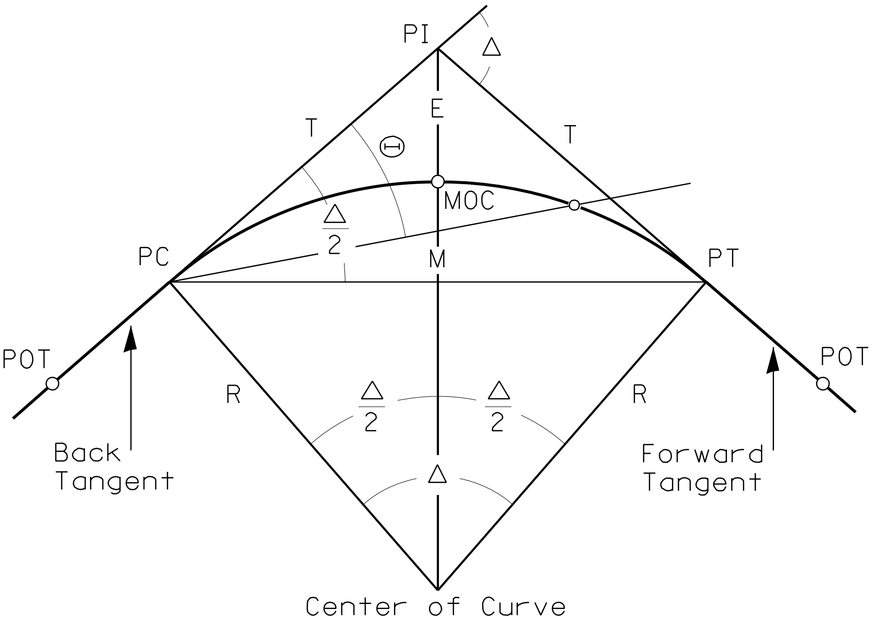
Horizontal Curvature in the Metric System

In previous highway work in Illinois, the degree of curve definition was used to lay out and calculate curve parts. The degree of curve is defined as the change in direction of a central angle per arc length of 100 feet. The relationship between the degree of curve and the radius in feet is stated by the following equation:

$$R = \frac{5729.58}{D}$$

For projects in which metric units will be used, the radius defines horizontal curvature only, and in this case, curves will be described in meters. The following figure illustrates the fundamental principals of a simple circular curve.

<u>FORMULAS & EXAMPLES</u> - <u>SIMPLE CIRCULAR CURVE</u>



<u>DEFINITIONS</u> Be sure the instrument and carrying case are kept dry. If they become wet, allow them to air dry before closing the carrying case. Extend level rod and let air dry overnight.

Back Tangent	=	Tangent from which the curve starts
Forward Tangent	=	Tangent on which the curve ends
POT	=	"Point on Tangent" - Any point on the tangent portion where the curve starts or ends
PC	=	"Point of Curvature" - Station on centerline where the curve starts
T	=	"Tangent" - The distance on a straight line from the PC to the PI or the PT to the PI
MOC	=	"Mid-Point of Curve"
PT	=	"Point of Tangency" - Station on centerline where the curve ends
L	=	"Length of Curve" - The distance <u>along the curved centerline</u> from the PC to the PT
PI	=	"Point of Intersection" - The point where the back tangent and the forward tangent intersect
R	=	"Radius of the Curve"
E	=	"External Distance" - Distance from the MOC to the PI
M	=	"Middle Ordinate" - Distance from the MOC to the mid-point of the straight line between the PC and the PT (the LC)
LC	=	"Long Chord" - Straight line distance from the PC to the PT
Δ	=	The Central Angle of the Curve - The angle between a radial line from the center of the curve to the PC and a radial line from the center of the curve to the PT; also equals the angle of intersection of the forward tangent with the back tangent

The following definitions can be written from the figure on the previous sheet:

Tangent distance (T) = $R \tan \frac{\Delta}{2}$

External distance (E) = $R\left(\sec \frac{\Delta}{2} - 1\right)$ = R exsec $\frac{\Delta}{2}$ = T sin $\frac{\Delta}{2}$ - M

Middle Ordinate (M) = $R\left(1 - \cos \frac{\Delta}{2}\right)$ = R vers $\frac{\Delta}{2}$ = $R - R\cos \frac{\Delta}{2}$

Long Chord (L.C.) = 2R sin $\frac{\Delta}{2}$ = 2T cos $\frac{\Delta}{2}$

Length of Curve (L) = $\frac{\Delta 2\pi R}{360^\circ} = \frac{\Delta R}{57.2958^\circ}$

To find the deflection angle to a point on the curve, the following proportion can be written, where Θ is the deflection angle:

$\frac{2 \text{ x deflection angle}}{\text{arc length}} = \frac{360^\circ}{2\pi R}$ where R and the arc length are in meters.

deflection angle (minutes) = $\frac{1718.873}{R}$ x arc length

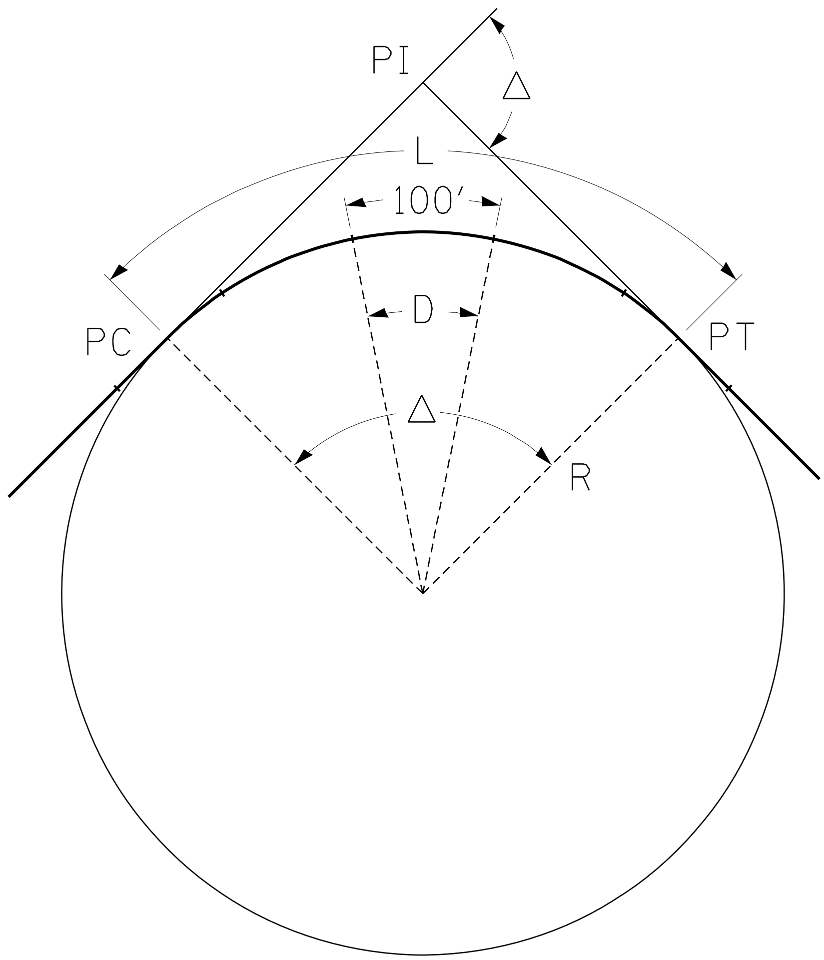
deflection angle (degrees) = $\frac{28.648}{R}$ x arc length

When laying out a horizontal curve in the metric system, the following guidelines are recommended for measuring chord distances around a curve. Where the radius is greater than 600 meters, use 25 m chords. For radii between 600 meters and 250 meters, use 15 m cords, and for radii between 250 meters and 125 meters, use 10 m chords. The chord distance between two points on a curve may not always equal the arc distance. The following equation is used to determine the chord distance for any arc length:

Chord distance = $2R \sin\left(\frac{90}{\pi R} \text{ x arc length}\right)$ = 2 R sin Θ

In addition to the preceding definitions, the following term is used in the English system of surveying.

D = Degree of Curve – The angle formed by 100 ft segment (100 ft arc) of the curve



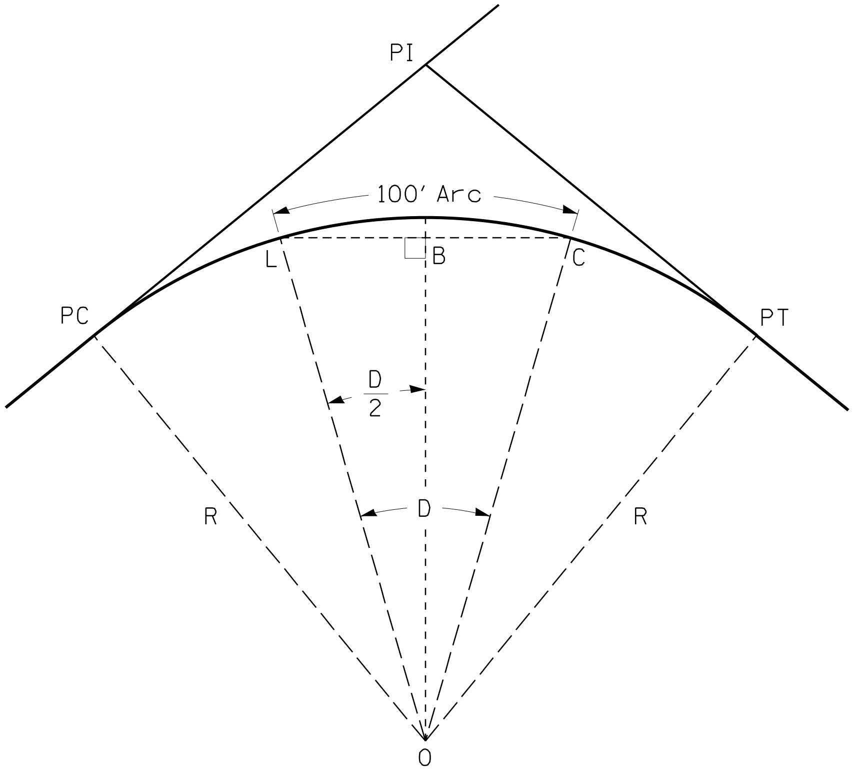
FORMULAS:

By Proportion: $\frac{\Delta}{360} = \frac{L}{2\pi R}$

$$\frac{D}{360} = \frac{100}{2\pi R} \qquad \left[D = \frac{5729.58}{R}\right]$$

$$\frac{D}{\Delta} = \frac{100}{L}$$

SIMPLE CIRCULAR CURVE
DERIVATION OF FORMULAS



Using triangle O-L-B:

$$\sin \frac{D}{2} = \frac{\frac{LC_{100}}{2}}{R}$$

$$R \sin \frac{D}{2} = \frac{LC_{100}}{2}$$

$LC_{100} = 2R \sin \frac{D}{2}$, where LC_{100} = the chord distance for a 100' Arc

$LC_{50} = 2R \sin \frac{D}{4}$, where LC_{50} = the chord distance for a 50' Arc

$LC_{25} = 2R \sin \frac{D}{8}$, where LC_{25} = the chord distance for a 25' Arc

CALCULATIONS FOR A CIRCULAR CURVE

Given

P.I. Sta. 107+67.90 Δ = 11^{o}00'00" D = 2^{o}30'00"

Calculate

Radius
R = 5729.58/D
R = 5729.58/2^{o}30'00"
R = 2291.83'

Tangent Distance
T = R(Tan Δ /2)
T = 2291.83(Tan 11^{o}00'00"/2)
T = 220.68'

Length of Curve
L = 100 (Δ/D)
L = 100(11^{o}00"/2^{o}30'00")
L = 440.00'

External Distance
E = T(Tan Δ/4)
E = 220.68(Tan 11^{o}00'00"/4)
E = 10.60'

P.C. Station
P.C. = P.I. Station - Tangent Dist.
P.C. = 107+67.90 - 220.68
P.C. = 105+47.22

P.T. Station
P.T. = P.C. Sta. + Length of Curve
P.T. = 105+47.22 + 440.00
P.T. = 109+87.22

Deflection for 100' Arc
100' Arc = D/2
100' Arc = 2o30'00"/2
100' Arc = 1o15'00"

Deflection for 50' Arc
50' Arc = D/4
50' Arc = 2^{o}30'00"/4
50' Arc = 0^{o}37'30"

Deflection for 25' Arc
25' Arc = D/8
25' Arc = 2^{o}30'00"/8
25' Arc = 0^{o}18'45"

Deflection for 1' Arc
1' Arc = D/200
1' Arc = 2^{o}30'00"/200
1' Arc = 0^{o}0'45"

Chord Length 100' Arc
100' Arc = (2)(R)(Sin Deflection Angle)
100' Arc = (2)(2291.83)(Sin 1^{o}15'00")
100' Arc = 99.99

Chord Length 50' Arc
50' Arc = (2) (R) (Sin Deflection Angle)
50' Arc = (2)(2291.83)(Sin 0^{o}37'30")
50' Arc = 50

CALCULATE THE DEFLECTION FOR THE FIRST STATION FROM P.C. OR

ANY ODD STATION ALONG THE CURVE

1. Take the distance from the last point with a known deflection to the station you are calculating.

2. Multiply this distance by the deflection of a 1' arc (D/200); this will give you the deflection between these two points

Example: Find deflection angle at Sta. 108+55.

(108+55 - 105+47.22) = 307.78'

307.78'(0^o0'45") = 3^o50'50"

As discussed in the above paragraphs, angular measurements in the metric system will continue to be expressed in degrees, minutes, and seconds. However, the radius definition of horizontal curves will be used rather than the degree of curve. For example, a proposed 3-degree horizontal curve on new a location (Radius = 1909.86 ft or 582.125 m) shall be referred to as a 580 meter radius curve. Metric radii for new horizontal curves shall always be expressed in multiples of 5 meter increments for simplicity.

Conversely, alignments that incorporate a previously defined horizontal curve should continue to use the same existing radius, and the radius would be re-defined to the nearest 0.001 meter. If the 3 degree curve noted above is a re-creation of a previously established curve, it would be assigned a 582.125 meter radius.

Shown below are three possible cases defining horizontal curvature. In all three cases, it is assumed the curve starts at P.C. STA 300+59.41 (English units) or the equivalent P.C. station in metric units of kilometer STA 9+162.108.

Case A: English curve definition

Case B: Metric definition assuming that Case A curve data defines the roadway centerline from a previous survey and is to be retained. All curve data is a direct or soft conversion from English to metric units.

Case C: Metric definition of a paper relocation on mapping. The P.C. location will start at kilometer STA 9+162.108 and have approximately the same curvature as the Case A curve. Therefore, R will be set at 580 m.

CASE A	**CASE B**	**CASE C**
PI STA = 302+68.57	PI STA = 9+225.860	PI STA = 9+225.628
Δ = 12° 30’	Δ = 12° 30’	Δ = 12° 30’
D = 3° 00’	R = 582.125 m	R = 580.000 m
T = 209.16 ft	T = 63.752 m	T = 63.520 m
L = 416.67 ft	L = 127.001 m	L = 126.535 m

To aid technical staff in laying out horizontal curves in the field, the following Tables of Deflections for Various Radii and Arc Lengths has been developed.

RADIUS (meters)	DEFLECTION IN MINUTES Per Meter of Arc	DEFLECTIONS FOR ARCS OF 10 meters			15 meters			25 meters		
		Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec
10	17.1887	2	51	53	4	17	50	7	9	43
150	11.4592	1	54	35	2	51	53	4	46	29
200	8.5944	1	25	57	2	8	55	3	34	52
250	6.8755	1	8	45	1	43	8	2	51	53
300	5.7296	0	57	18	1	25	57	2	23	14
350	4.9111	0	49	7	1	13	40	2	2	47
400	4.2972	0	42	58	1	4	27	1	47	26
450	3.8197	0	38	12	0	57	18	1	35	30
500	3.4377	0	34	23	0	51	34	1	25	57
550	3.1252	0	31	15	0	46	53	1	18	8
600	2.8648	0	28	39	0	42	58	1	11	37
650	2.6444	0	26	27	0	39	40	1	6	7
700	2.4555	0	24	33	0	36	50	1	1	23
750	2.2918	0	22	55	0	34	23	0	57	18
800	2.1486	0	21	29	0	32	14	0	53	43
850	2.0222	0	20	13	0	30	20	0	50	33
900	1.9099	0	19	6	0	28	39	0	47	45
950	1.8093	0	18	6	0	27	8	0	45	14
1000	1.7189	0	17	11	0	25	47	0	42	58
1050	1.6370	0	16	22	0	24	33	0	40	56
1100	1.5626	0	15	38	0	23	26	0	39	4
1150	1.4947	0	14	57	0	22	25	0	37	22
1200	1.4324	0	14	19	0	21	29	0	35	49
1250	1.3751	0	13	45	0	20	38	0	34	23
1300	1.3222	0	13	13	0	19	50	0	33	3
1350	1.2732	0	12	44	0	19	6	0	31	50
1400	1.2278	0	12	17	0	18	25	0	30	42
1450	1.1854	0	11	51	0	17	47	0	29	38
1500	1.1459	0	11	28	0	17	11	0	28	39
1550	1.1090	0	11	5	0	16	38	0	27	43
1600	1.0743	0	10	45	0	16	7	0	26	51
1650	1.0417	0	10	25	0	15	38	0	26	3
1700	1.0111	0	10	7	0	15	10	0	25	17
1750	0.9822	0	9	49	0	14	44	0	24	33
1800	0.9549	0	9	33	0	14	19	0	23	52
1850	0.9291	0	9	17	0	13	56	0	23	14
1900	0.9047	0	9	3	0	13	34	0	22	37
1950	0.8815	0	8	49	0	13	13	0	22	2
2000	0.8594	0	8	36	0	12	53	0	21	29
2050	0.8385	0	8	23	0	12	35	0	20	58
2100	0.8185	0	8	11	0	12	17	0	20	28
2150	0.7995	0	7	60	0	11	60	0	19	59
2200	0.7813	0	7	49	0	11	43	0	19	32
2250	0.7639	0	7	38	0	11	28	0	19	6
2300	0.7473	0	7	28	0	11	13	0	18	41
2350	0.7314	0	7	19	0	10	58	0	18	17
2400	0.7162	0	7	10	0	10	45	0	17	54
2450	0.7016	0	7	1	0	10	31	0	17	32
2500	0.6875	0	6	53	0	10	19	0	17	11
2550	0.6741	0	6	44	0	10	7	0	16	51
2600	0.6611	0	6	37	0	9	55	0	16	32
2650	0.6486	0	6	29	0	9	44	0	16	13
2700	0.6366	0	6	22	0	9	33	0	15	55
2750	0.6250	0	6	15	0	9	23	0	15	38
2800	0.6139	0	6	8	0	9	12	0	15	21
2850	0.6031	0	6	2	0	9	3	0	15	5
2900	0.5927	0	5	56	0	8	53	0	14	49
2950	0.5827	0	5	50	0	8	44	0	14	34
3000	0.5730	0	5	44	0	8	36	0	14	19

RADIUS (meters)	DEFLECTION IN MINUTES Per Meter of	DEFLECTIONS FOR ARCS OF 10 meters			15 meters			25 meters		
		Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec
3050	0.5636	0	5	38	0	8	27	0	14	5
3100	0.5545	0	5	33	0	8	19	0	13	52
3150	0.5457	0	5	27	0	8	11	0	13	39
3200	0.5371	0	5	22	0	8	3	0	13	26
3250	0.5289	0	5	17	0	7	56	0	13	13
3300	0.5209	0	5	13	0	7	49	0	13	1
3350	0.5131	0	5	8	0	7	42	0	12	50
3400	0.5056	0	5	3	0	7	35	0	12	38
3450	0.4982	0	4	59	0	7	28	0	12	27
3500	0.4911	0	4	55	0	7	22	0	12	17
3550	0.4842	0	4	51	0	7	16	0	12	6
3600	0.4775	0	4	46	0	7	10	0	11	56
3650	0.4709	0	4	43	0	7	4	0	11	16
3700	0.4646	0	4	39	0	6	58	0	11	37
3750	0.4584	0	4	35	0	6	53	0	11	28
3800	0.4523	0	4	31	0	6	47	0	11	19
3850	0.4465	0	4	28	0	6	42	0	11	10
3900	0.4407	0	4	24	0	6	37	0	11	1
3950	0.4352	0	4	21	0	6	32	0	10	53
4000	0.4297	0	4	18	0	6	27	0	10	45
4050	0.4244	0	4	15	0	6	22	0	10	37
4100	0.4192	0	4	12	0	6	17	0	10	29
4150	0.4142	0	4	9	0	6	13	0	10	21
4200	0.4093	0	4	6	0	6	8	0	10	14
4250	0.4044	0	4	3	0	6	4	0	10	7
4300	0.3997	0	3	60	0	5	60	0	9	60
4350	0.3951	0	3	57	0	5	56	0	9	53
4400	0.3907	0	3	54	0	5	52	0	9	46
4450	0.3863	0	3	52	0	5	48	0	9	39
4500	0.3820	0	3	49	0	5	44	0	9	33
4550	0.3778	0	3	47	0	5	40	0	9	27
4600	0.3737	0	3	44	0	5	36	0	9	21
4650	0.3697	0	3	42	0	5	33	0	9	14
4700	0.3657	0	3	39	0	5	29	0	9	9
4750	0.3619	0	3	37	0	5	26	0	9	3
4800	0.3581	0	3	35	0	5	22	0	8	57
4850	0.3544	0	3	33	0	5	19	0	8	52
4900	0.3508	0	3	30	0	5	16	0	8	46
4950	0.3472	0	3	28	0	5	13	0	8	41
5000	0.3438	0	3	26	0	5	9	0	8	36
5050	0.3404	0	3	24	0	5	6	0	8	31
5100	0.3370	0	3	22	0	5	3	0	8	26
5150	0.3338	0	3	20	0	5	0	0	8	21
5200	0.3306	0	3	18	0	4	57	0	8	16
5250	0.3274	0	3	16	0	4	55	0	8	11
5300	0.3243	0	3	15	0	4	52	0	8	6
5350	0.3213	0	3	13	0	4	49	0	8	2
5400	0.3183	0	3	11	0	4	46	0	7	57
5450	0.3154	0	3	9	1	4	44	0	7	53
5500	0.3125	0	3	8	0	4	41	0	7	49
5550	0.3097	0	3	6	0	4	39	0	7	45
5600	0.3069	0	3	4	0	4	36	0	7	40
5650	0.3042	0	3	3	0	4	34	0	7	36
5700	0.3016	0	3	1	0	4	31	0	7	32
5750	0.2989	0	2	59	0	4	29	0	7	28
5800	0.2964	0	2	58	0	4	27	0	7	25
5850	0.2938	0	2	56	0	4	24	0	7	21
5900	0.2913	0	2	55	0	4	22	0	7	17
5950	0.2889	0	2	53	0	4	20	0	7	13
6000	0.2865	0	2	52	0	4	18	0	7	10

Layout of Horizontal Curves

The curve data listed in the plans must be carefully checked, including the P.I.'s and the P.O.T.'s. You will encounter considerable difficulty in running the curves if the intersection angles do not check and new curve data must be calculated. Usually, this is done when verifying the transit line. Any discrepancies found, which you do not know how to correct, should be discussed with your Supervisor.

If practical, reestablish P.I's and the necessary P.O.T.'s. Record intersection angles, reference all P.I.'s and P.O.T.'s and record their stations and reference points.

Setting Stakes. Where practical, set up on the P.I. having as a foresight and backsight the P.I. or P.O.T. on either side of the P.I. over which you are set. Using the transit for line, measure accurately the tangent distance in each direction and set substantial hubs at the P.C. and P.T. of your curve. The station number of the P.C. is the station of the P.I. minus the tangent distance. The station of the P.T. is the station of the P.C. plus the curve length.

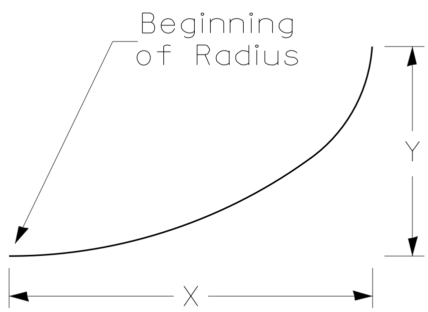
Before running curves, the notebook table of stations, deflection angles and chord lengths (including chord corrections if needed) must be set up and checked. See example in this Section. Curve data from computer programs should be spot-checked. After the P.C. and P.T. are established, set up over the P.C. and proceed to run in the curve. Offset the stakes the proper distance each way from the centerline.

It is often necessary to run curves in the reverse direction to that of the stationing. On long curves where the view is obstructed, it is necessary to turn at one or more points on the curve.

Curves should close within about 75 mm per 300 m (0.25 ft per 1000 ft) of length. The error of closure should be proportionally distributed over sufficient length so that the eye can detect no break in the alignment. On flat curves having an external distance of 600 mm (2 ft) or less, it is faster to run in the curves by tangent offsets using the equation on the next page:

Horizontal Curve Layout Using Tangent Offsets:

Beginning of Radius $$Y = R - \sqrt{R^2 - X^2}$$



R = Given

X = Distance from beginning of radius to point in question

Y = Distance from projected line (tangent at beginning of radius) to curve

Example

Given: R = 15 m

X (meters)	Y (meters)
0	0
1	.033
2	.134
3	.303
4	.543
5	.858
6	1.252
7	1.734
8	2.311
9	3.000
10	3.820
11	4.802
12	6.000
13	7.517
14	9.615
15	15.000

HORIZONTAL CURVE EXAMPLE

Information on the plans: P.I. Station 8+533.835

Δ = 3° 24' 29" (LT)

R = 1,513.073 m

Find: T, E, L.C., L, PC Station and PT Station

Tangent distance (T) = $R \tan \frac{\Delta}{2}$ = $1{,}513.073 \tan \frac{3^\circ\ 24'\ 29''}{2}$ = 45.013 m

External distance (E) = $R\left(\sec \frac{\Delta}{2} - 1\right)$ = $1513.073 \left[\frac{1}{\cos \frac{3^\circ 24' 29''}{2}} - 1 \right]$ = 0.669 m

Long Chord (L.C.) = 2R sin $\frac{\Delta}{2}$ = $(2)\left(1513.073 \sin \frac{3^\circ 24' 29''}{2}\right) = 89.987$ m

Length of Curve (L) = $\frac{\Delta R}{57.2958}$ = $\frac{(3^\circ 24' 29'')(1513.073)}{57.2958} = 90.000$ m

PC Station = PI Station - T = 8+533.835 - 45.013 m = 8+488.822

PT Station = PC Station + L = 8+488.822 + 90.000 m = 8+578.822

FIELD BOOK FOR HORIZONTAL CURVE (metric)

Station	Distance	Chord Distance	Deflection Angle	Total Deflection	Remarks
8+578.822	3.822	3.822	0°04'21"	1°42'15"	PT
8+575	25	25	0°28'24"	1°37'54"	
8+550	25	25	0°28'24"	1°09'30"	
8+525	25	25	0°28'24"	0°41'06"	
8+500	11.178	11.178	0°12'42"	0°12'42"	
8+488.822	0	0	0	0	PC
8+475					

Note: Total deflection @ PT should equal Δ / 2

FIELD BOOK FOR HORIZONTAL CURVE (English)

Deflections For Curve #1

Sta.	Dist	Chord Dist	Defl. Angle	Total Defl	
105+00					
+47.22	0	0	0	0	P.C.
+50	2.78’	2.78’	0^{o}02’05”	0^{o}02’05”	
106+00	50	50.00	0^{o}37’30”	0^{o}39’35”	
+50	50	50.00	0^{o}37’30”	1^{o}17’05”	
107+00	50	50.00	0^{o}37’30”	1^{o}54’35”	
+50	50	50.00	0^{o}37’30”	2^{o}32’05”	
108+00	50	50.00	0^{o}37’30”	3^{o}9’35”	
+50	50	50.00	0^{o}37’30”	3^{o}47’5”	
109+00	50	50.00	0^{o}37’30”	4^{o}24’35”	
+50	50	50.00	0^{o}37’30”	5^{o}2’5”	
+87.22	37.22	37.22	0^{o}27’55”	5^{o}30’00”	P.T.
	Calc by KAB 7-20-93 Checked by AN 7-21-93				

Δ = 11^{o}00'00" D = 2^{o}30'00"
P.C. P.K. Nail

Deflection Angles

100’ Arc = D/2 = 2^{o}30’00”/2
= 1^{o}15100”
50’ Arc = D/4 = 2^{o}30'00"/4
= 0^{o}37'30"
1’ Arc = D/200 = 2^{o}30'00"/200
= 0^{o}0'45"

Chord Lengths

100’ Arc = (2)(R)(SIN DEFL. ∠)
= (2)(2291.83)(SIN 1^{o}15’00”
= 99.99'
50’ Arc = (2)(R)(SIN DEFL. ∠)
= (2)(R)(SIN 0^{o}37'30")
= 50.00'

P.T. (Note: Total Deflection Should equal $\Delta/2$)

CHANGING DECIMAL TO DEGREE OR DEGREE TO DECIMAL

The following calculations illustrate the proper method for converting degrees (sometimes referred to as "hours") to degrees, minutes and seconds (0° 0' 0") and vice versa.

- To find the degree equivalent of 88.461111°

1) Everything left of the decimal is the whole degree.

    8°00’00”

2) Multiply everything right of the decimal by 60.

    0.46111 x 60 = 27.66666

3) Everything left of the decimal in step 2 are now the minutes. Add this to step 1.

    88°27’00”

4) Multiply everything right of the decimal in step 2 by 60. These are now the seconds.

    0.66666 x 60 = 40

5) Add the answer in step 4 to the answer in step 3. This is the degree equivalent.

    88°27’40”

- To find the decimal equivalent of 88°27’40”

1) Take the number of seconds and divide them by 60

    40 ÷ 60 = 0.66666

2) Add the number of minutes to the answer from step I and divide them by 60 again.

    0.66666 + 27 = 27.66666 ÷ 60 = 0.461111

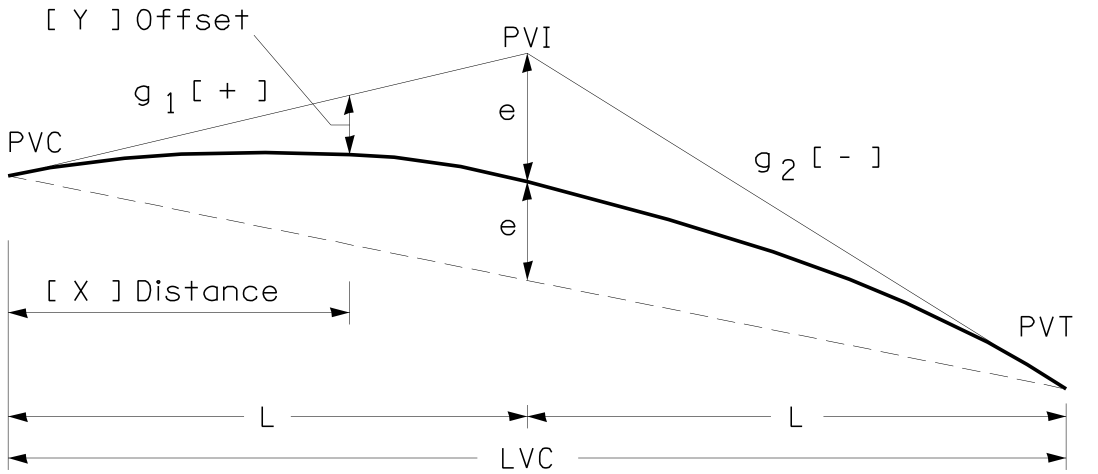
3) Add the number of degrees to the answer from step 2.

    This is the decimal equivalent.

    88 + 0.461111 = 88.461111°

Layout of Vertical Curves

Vertical curves are used to provide smooth transitions between tangent grade changes. The figure below shows the various relationships of a simple vertical curve in the metric system.



LVC Length of Vertical Curve, meters

L $\dfrac{\text{Length of Vertical Curve}}{2}$

PVC Point of Vertical Curve - station where the vertical curve starts

PVT Point of Vertical Tangency

g Grade in Percent

A Algebraic difference in grades, % = $g_2 - g_1$

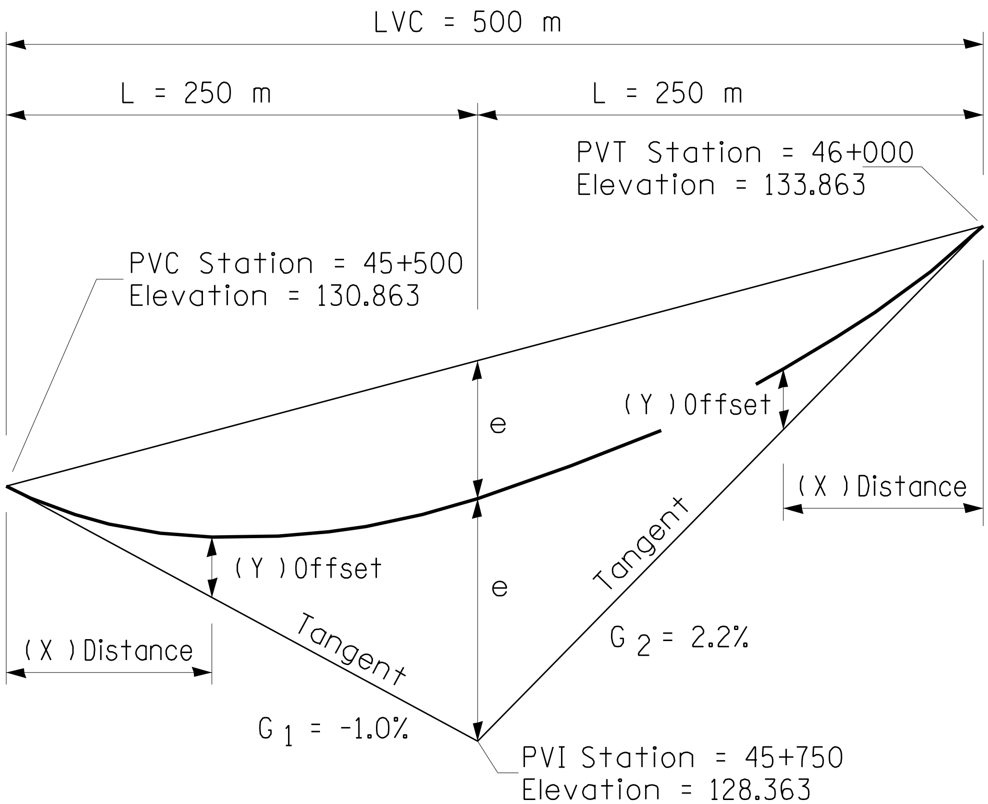
e Tangent offset of the midpoint of the curve = $\dfrac{AL}{400} = (g_2 - g_1)L/400$

X Distance from PVC or distance from PVT (never greater than L)

y Other tangent offsets which vary as the square of their distance from the start or the end of the curve = $\dfrac{\left(\dfrac{AL}{400}\right)X^2}{(L)^2}$ or $e\left(\dfrac{X}{L}\right)^2$

Elevation @ x = Elev. @ PVC + $(g_1)(x) + e\,x^2/L^2$

EXAMPLE CALCULATION OF A VERTICAL CURVE



For the above example find e, centerline profile elevations along the curve, and the station and elevation of the low point.

- e = A L/400 = (2.2-(-1.0)) 250/400 = 3.2(250)/400 = 2.0
- (Y)Offset @ a given station = $e\left(\frac{\text{(X)Distance}}{L}\right)^2$

Example: @ 45 + 850 (X) Distance = 150; (Y) Offset = 2.0 (150.00/250)^2 = 0.720 m

Tangent elevation at a given station =

$$\left[\text{(X)Distance} \times \left(\frac{g_1}{100}\right)\right] + \text{PVC elevation}$$

or

$$\text{PVT elevation} - \left[\text{(X)Distance} \times \left(\frac{g_2}{100}\right)\right]$$

Example: @ 45 + 850 Tangent Elevation = 133.863 - [150 x (.022)] = 130.563 m

CENTERLINE PROFILE ELEVATIONS

Station	(X) Distance	Tangent Elevation	(Y) Offset	Elevation on Curve
45+500		130.863		130.863
45+525	25.00	130.613	0.020	130.633
45+550	50.00	130.363	0.080	130.443
45+575	75.00	130.113	0.180	130.293
45+600	100.00	129.863	0.320	130.183
45+625	125.00	129.613	0.500	130.113
45+650	150.00	129.363	0.720	130.083
45+675	175.00	129.113	0.980	130.093
45+700	200.00	128.863	1.280	130.143
45+725	225.00	128.613	1.620	130.233
45+750	250.00	128.363	2.000	130.363
45+775	225.00	128.913	1.620	130.533
45+800	200.00	129.463	1.280	130.743
45+825	175.00	130.013	0.980	130.993
45+850	150.00	130.563	0.720	131.283
45+875	125.00	131.113	0.500	131.613
45+900	100.00	131.663	0.320	131.983
45+925	75.00	132.213	0.180	132.393
45+950	50.00	132.763	0.080	132.843
45+975	25.00	133.313	0.020	133.333
46+000		133.863		133.863

STATION AND ELEVATION OF LOW POINT

The lowest point on a sag curve or the highest point on a crest curve lies at a distance Z from the end of the curve with the flatter gradient. This point is at a distance $Z = \frac{2|g|L}{A}$

Z (In meters from PVC) = $\frac{2|g|L}{A}$ = 2(1.0)(250)/(2.2-(-1.0)) = 2.0(250)/3.2 = 156.25 m

Station of Low Point = PVC + Z = (45+500) + (156.25) = 45+656.25

Elevation of Low Point = Tangent Elevation + (Y) Offset

(X) Distance = 156.25 : Tangent Elevation = 130.863 + (156.25)(- 0.01) = 129.301

(Y) Offset = $(156.25/250)^2$ (2.0) = 0.781

Elevation of Low Point = 129.301 + 0.781 = 130.082

Tying Out Control Points

As stated before, it is very critical that control points are tied off and recorded accurately. There are basically two methods for tying off a point. 1) Swing ties; this is when a tape is used to measure between the point and a permanent object. 2) Transit ties; this method is used when there are no topographical features to measure to.

Qualities of a Good Tie Point

Swing Ties

1) They should not exceed 30 m (100 ft) in length.

2) There should be at least four ties for each point.

3) They should be something permanent and out of the construction zone. For example, a nail and a bottle cap in a tree, fence post or utility pole or a chiseled "X" on a concrete headwall.

4) Must be able to pull the tape straight between the two points.

5) Try not to have the ties straight across from each other. Doing this would cause the arcs to cross each other twice in a very short distance making it difficult to determine which point is the correct one.

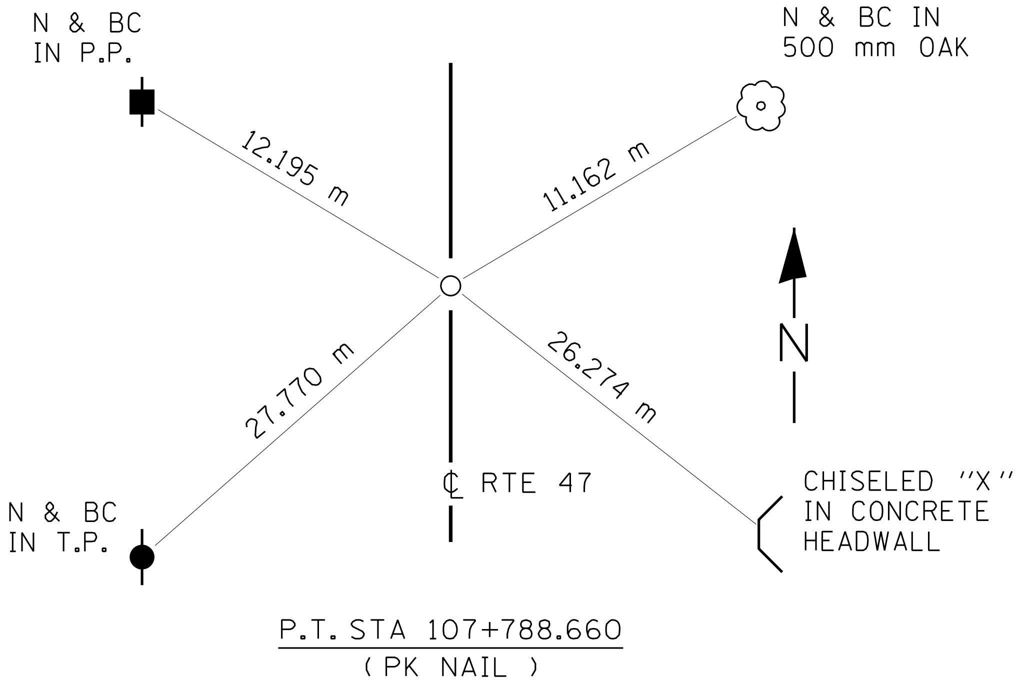
Transit Ties

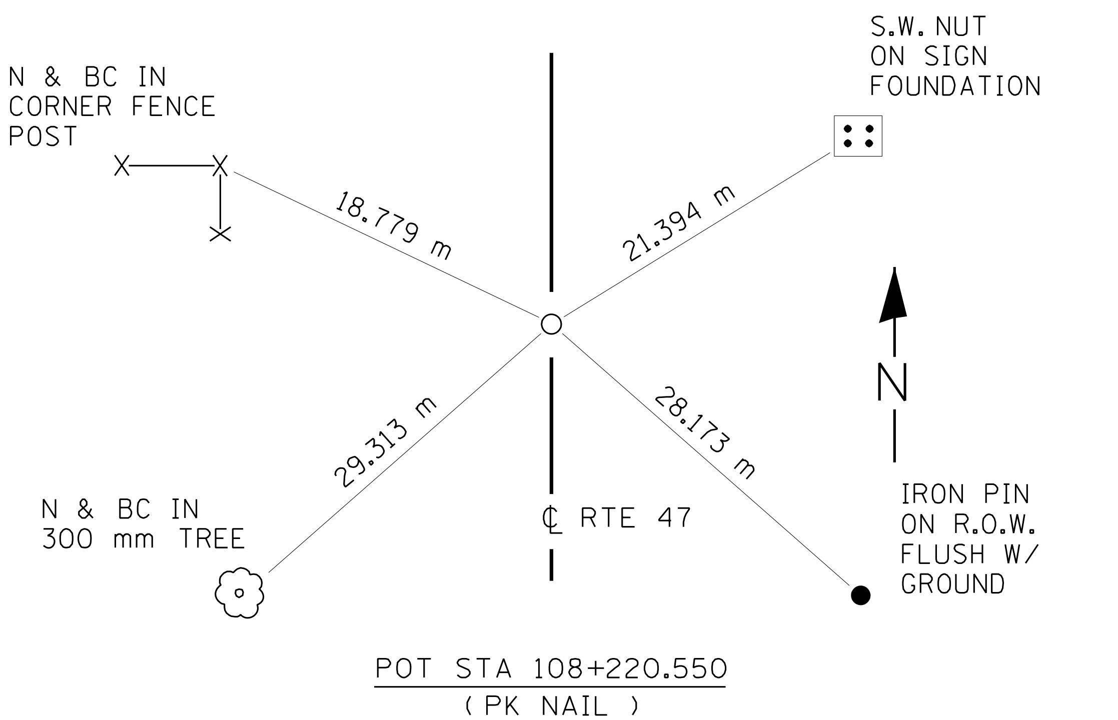
1) If using a solid pin or a hub as your sight points, be sure to mark the exact point on them with a center punch or a tack.

2) Drive your sight points flush with the ground at the R.O.W. and lath them. This will ensure that they will not be damaged by mowers and will be easy to find when the time comes to untie the point.

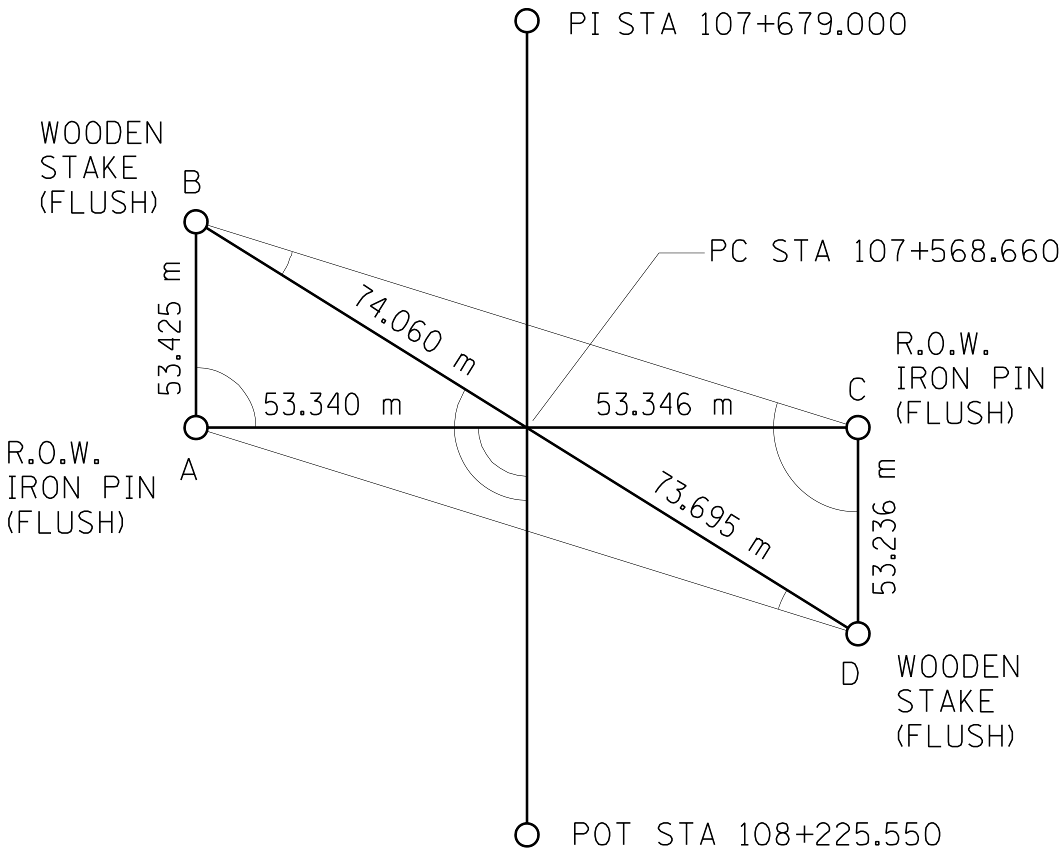
3) When finished turning the angles, check to make sure that all the proper angles add up.

EXAMPLES OF CROSS TIES





EXAMPLE OF TRANSIT TIES

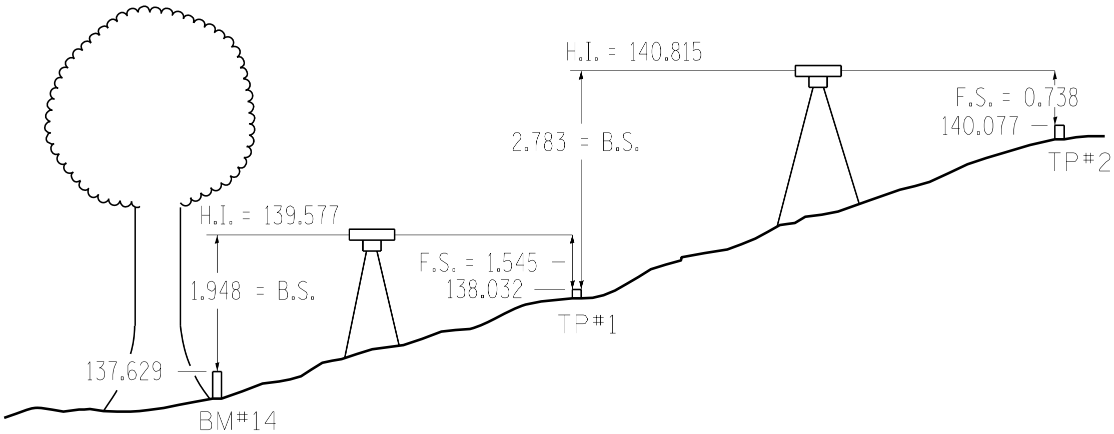


TIE POINTS FOR P.C. STA 107+568.66

@ PC,	SIGHT POT, TURN TO A	90°00'00"
@ PC,	SIGHT POT, TURN TO B	135°00'00"
@ A,	SIGHT PC, ESTABLISH C	
@ A,	SIGHT C, CHECK PC, TURN TO B	90°31'00"
@ B,	SIGHT PC, ESTABLISH D	
@ B,	SIGHT D, CHECK PC, TURN TO A	44°29'00"
@ B,	SIGHT D, CHECK PC, TURN TO C	18°28'00"
@ C,	SIGHT A, CHECK PC, TURN TO B	26°32'00"
@ C,	SIGHT A, CHECK PC, TURN TO D	88°32'00"
@ D,	SIGHT B, CHECK PC, TURN TO C	46°28'00"
@ D,	SIGHT B, CHECK PC, TURN TO A	18°33'00"

CHECK C-PC-D, 180°00'00" - 88°32'00" - 46°28'00" = 45°00'00"

TYPICAL LEVEL LINE



STA.	(+) B.S.	H.I.	(-) F.S.	ELEV.
BM#14	1.948	139.577		137.629
TP#1	2.783	140.815	1.545	138.032
TP#2			0.738	140.077

Setting Stakes for Bridges

a) General. Prior to staking a bridge, plan dimensions and elevations must be checked. It is extremely important to check the bottom of footing elevations by working down from the profile grade line at each pier and abutment, using plan dimensions, beam depths, etc.

The entire structure must be staked before construction operations begin. Remember that the stakes you set are going to be used over and over again from the time you stake the footing excavation until the bridge is finally completed. As the work progresses, you will not be able to see from one stake to another as you did in the beginning and you should give this fact consideration when staking the bridge. It is better to have a few extra points than not to have enough. A substantial number of stakes located out of the way of Contractor's equipment and material should be used. At least three stakes on each line should be set each way from the site. Check all elevations and be sure all the stakes are protected, well referenced and clearly identified.

When you have completed the staking, notify your supervisor so that someone assigned to your office may make an independent check of your calculations and layout work before the Contractor starts work on the structure. When the layout work and staking is done by the Contractor as a contract pay item, the Resident must review the Special Provisions to identify his/her responsibilities with regard to staking and checking.

Thorough and accurate layout work that is checked by an independent party is essential for structures, however, the checking should not stop here. It is important to have positive control points on each pier and abutment, so as the bridge cone embankments are being constructed, instrument checks can be made easily to determine any movement. Be particularly careful when the embankment toes out near the bottom of tall piers, as frequently happens with railroad structures.

Each stake set should be recorded, as well as all elevations that are given to the Contractor. It is good practice to sketch each feature of the bridge and show the stakes with the references and distances of their respective locations. See the end of this section for a sample staking diagram. It is also a good practice to share staking diagrams and information with the Contractor to avoid possible future disputes.

Triangulation and E.D.M. System. On multiple or long span bridges, especially bridges with steel superstructures where the width of the stream or other conditions prevent direct measurements, the location of abutments of piers must be measured with an electronic distance measuring (E.D.M.) system and/or by triangulation methods. Precise methods are required in such work and are necessary for long structures. This E.D.M. system or triangulation should be supervised by the Resident in charge of the work.

In triangulating locations for long bridges, concrete monuments, large stakes set deep and cut off near ground level, etc. should be used. Remember that the location may be affected by freezing and thawing, floods, driftwood and ice. Measurements should be corrected for temperature and a scale should be used to set the pull that is standard for the tape that is used. Long measurements should be made with an E.D.M. When possible, intersection lines should be set for each pier at an angle of 45 degrees with the base line, and the base line should extend both sides from the centerline of bridge. The intersection lines should be run out to points above high water on both sides of the river so that the locations can be set when the low ground is flooded. Angles should be set using repetition and should be checked by measurements. Guard stakes should be placed at each hub and the layout should be marked so that no confusion may result.

In some cases it is desirable to establish a low water and a high water base line. A base line that is above low water elevation can usually be placed nearer the bridge site and will be found very convenient.

Span Length. In staking the abutments, an allowance must be made for any anticipated deflection of the abutments so that the span length after deflection will be as shown on the plans. Theoretically, the amount of deflection can be figured, but practically it is somewhat indeterminate because of the variable conditions of the footings and backfill. It is assumed that the pressure of the backfill will move the top of a closed abutment or a concrete pile abutment horizontally 5 mm for each meter (1/16 inch for each foot) of height measured from bridge seat to bottom of footing. For open abutments, the assumed movement is 3 mm per meter (1/32 of an inch per foot).

In the case of a single span, if a correction is necessary for the deflection of the abutments, add the total deflection of both abutments to the span length shown on the plans to get the length for locating the abutments. In case of a multiple span bridge, add the deflection of one abutment to the length of the end span only.

Locating Centerline. Care must be exercised in locating the centerline of structure. The centerline of roadway and structure are not always the same. From the road plans or original survey notes, establish at least two P.I.'s or P.O.T.'s in each direction from the bridge and tie them in permanently. This should be done to ascertain if the intersection angle in both directions from the bridge is correct. If the P.I. or P.O.T. in each direction cannot be seen from the bridge, establish a P.O.T. on each side of the bridge and as close to the original P.I. or P.O.T. as possible. Place a permanent hub on centerline each side of and as close to the bridge as possible without interfering with the Contractor's operation. The Contractor should be requested to assist you by keeping equipment and materials clear of the line between these hubs. When possible, a permanent foresight should be set on centerline of bridge as high as the ground permits. It should be possible to set centerline from either side of the stream.

Establish hubs on centerline of bearing or back of abutments and on the centerline of each pier. These hubs should be heavy stakes and nails should be used for line. It is very important that the Resident and Contractor clearly understand and agree on what lines are staked. You may provide the Contractor with a sketch of all lines and stakes set.

Establish permanent bench marks close to the bridge. The benchmarks on the plan or original survey must be checked before establishing your benches at the bridge site. Transfer your benchmarks to permanent concrete or piling on the structure. Use the benchmarks established on the structure for the remaining work. Do not set temporary benchmarks on newly constructed embankments since they may settle. Be sure that your transit and levels maintain proper adjustment.

b) Staking Abutments. On the hub that is set on centerline of bearing or the back of abutment with the centerline of structure set up and turn the skew angle; on this line, set hubs; one close to the bridge and two at distances of 60 and 120 m (200 and 400 ft). If this cannot be done, set them as far as possible from the bridge. Check skew angle by repetition before proceeding.

c) Staking Piers. From the hubs established on centerline of structure turn the skew angle and set additional hubs in each direction, the same as you did for the abutment. Care must be exercised in establishing this line since the centerline of bearing and centerline of pier are not always the same. The vertical alignment of piers should be monitored with a transit during concrete placement.

Measure the distance from centerline to each hub and record it. Measurements for bridge layouts are often made on rough, uneven ground. It is necessary to have the chain horizontal and to use a plumb bob for accurate measurements on such terrain. Check your measurements often. Whenever possible, physical measurements should be made as the work progresses.

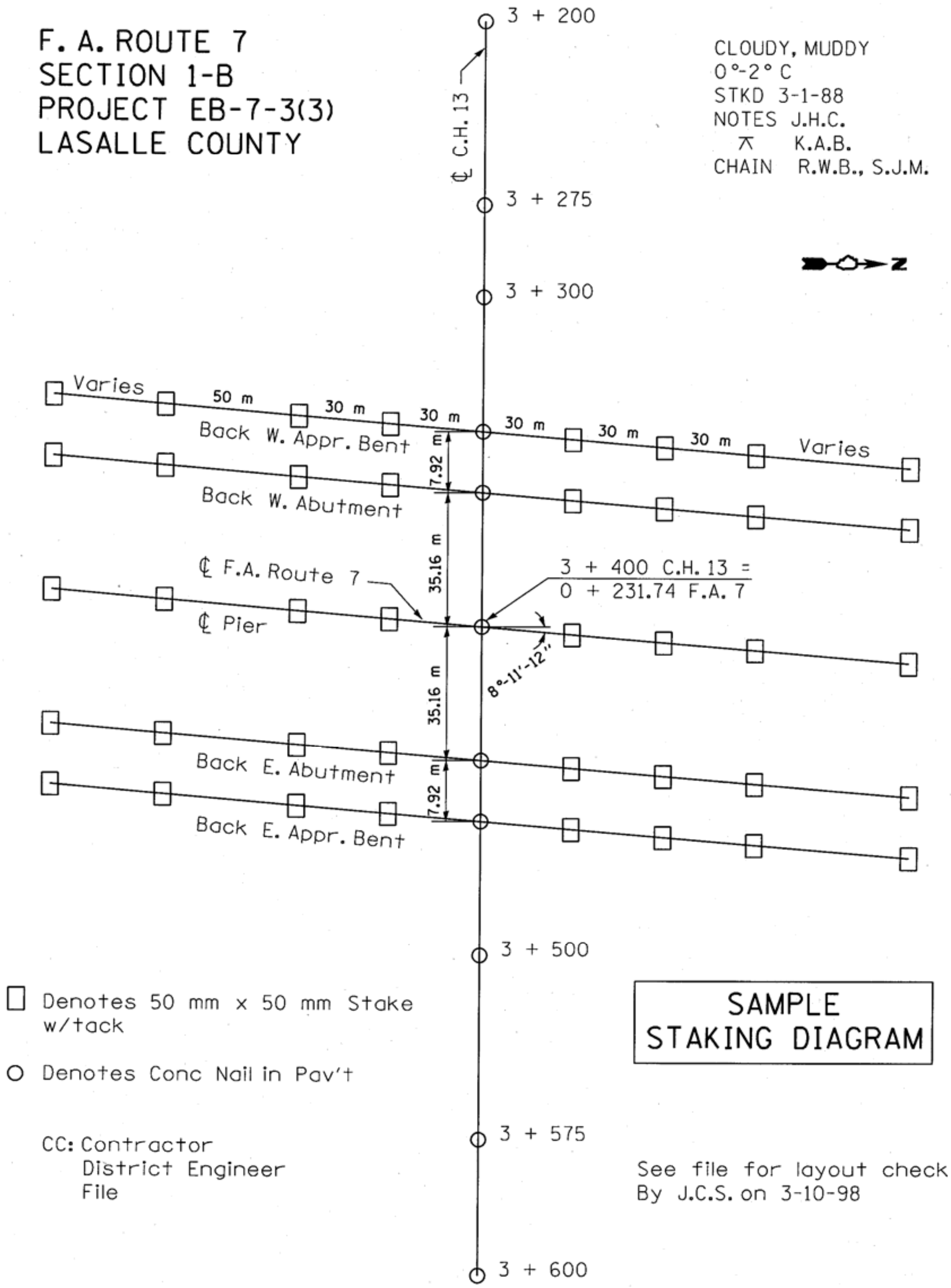
d) Staking Cofferdams. In fixing the location of cofferdams, it is usually best to give the Contractor only the center of the pier and centerline of structure. The Contractor can then determine the width and length, knowing what allowance is needed for footing forms, drainage outside the forms, size of whalers and struts, etc. Cofferdams in deep water may be located by triangulation. Proper alignment may be secured by placing marks at the intersection of the centerlines with each edge of the frame to be spotted and moving the frame until both marks are on the transit line.

e) Staking Footings. Check carefully the elevation of the bottom of footing as shown on the plans and compare it with the distance below streambed that you actually find. If there is a discrepancy of 300 mm (1 ft) or more, consult your Supervisor.

Keep the contractor informed at all times as to the work you are doing, and give him/her a record of all stakes set. When the neat line forms of the footing are in place, the top of footing should be established by setting nails with an instrument at convenient points around the footing. When footings are too deep to set elevations directly, turns may be established by measuring down to a nail from a point of known elevation.

f) Miscellaneous Elevations. After the forms for either an abutment seat or pier cap have been built, grade points for the bridge seat elevations should be set with an instrument. The level circuit for setting the bridge seat elevations should be checked by using one of these set elevations as a turning point. Elevations at tops and wings should also be set with an instrument. Seat elevations should be checked after the concrete is placed. Bridge seat elevations should be checked by subtracting the deck thickness, minimum fillet, permanent camber (if any), beam heights and bearing heights from the finished deck elevations before laying out the bridge seat elevations in the field.

On steel truss spans supported by falsework, it is essential that each panel point of support be set at the exact camber elevation before any connections are made.



Setting Stakes for Borrow Pits and Cross Sections

Although setting stakes and running cross sections for a borrow pit seem to be a simple matter, it is, nevertheless, a matter that calls for more than ordinary accuracy. Inaccuracy or lax procedures anywhere from start to finish will almost certainly result in confusion and possibly in a dispute with the Contractor over the volume involved.

If the borrow pit is furnished by the State, it should be staked before construction starts so that the Contractor will not encroach upon private property. If the Contractor furnishes the pit, s/he should obtain the necessary approval and show you the location of the boundaries in sufficient time to take cross sections.

When the pit is furnished by the State, establish its location from the plans. For pits adjacent to the right-of-way, it is often convenient to use the centerline as a base line, if on a tangent. Usually the base line should be chosen parallel to the long dimension of the pit, which means that it may not always be parallel to the centerline of the roadway. In all cases, the base line must be readily reestablished or preserved until all work is finished. If the centerline is not used, the base line chosen should be tied accurately. Base lines should always be straight line regardless of the shape of the borrow pit. It is often convenient to locate the base line in a fence line or other location where hubs on the line will not be destroyed. The base line should be referenced to points which will remain after borrow is completed.

See the drawing of a typical borrow pit layout following this section.

Stakes for Base Line. The drawing indicates the pit is parallel to the centerline. The base line is parallel to the centerline and is as close to the borrow pit as can conveniently be placed without being disturbed by the Contractor's operations. From the base line run a parallel line on the opposite side of the borrow pit and reference it, locating it close to the pit (perhaps within 3 m (10 ft)) but out of the way of the Contractor's operation. Use an instrument to turn angles and a steel tape for all measurements, and be sure to have the lines on each side of the borrow pit well hubbed and referenced. Base line stakes should be marked with the station numbers and driven solidly. Borrow pits often stand over the winter season before borrow is completed. You must be able to reestablish any line easily, at any time, at its exact original location.

If the boundary of the borrow pit is a curved line, this curvature must be taken into consideration in taking cross sections and computing final quantities.

Stakes for Cross Sections. The base line and its parallel line on the opposite side of the borrow pit are marked lines "A" and "B". The borrow pit limits as staked out are to be visible, carefully referenced, and accurately measured from the centerline.

On line "A" at 8 m (25 ft) intervals (or not more than 30 m (100 ft)), and at all breaks in the grade, set stakes. Record the distance to each stake. Set a corresponding stake on line "B" by turning an angle of 90 degrees from line "A". In placing stakes on the original ground surface, keep in mind the contour of the finished pit and take enough points to cover breaks in both the original and final ground lines. Do this along the base line, its parallel line and along each cross section. It is often convenient to use a range pole or flag, set at the far end of the sections to be taken, as a foresight to ensure that the sections are taken on a straight line and in the proper location.

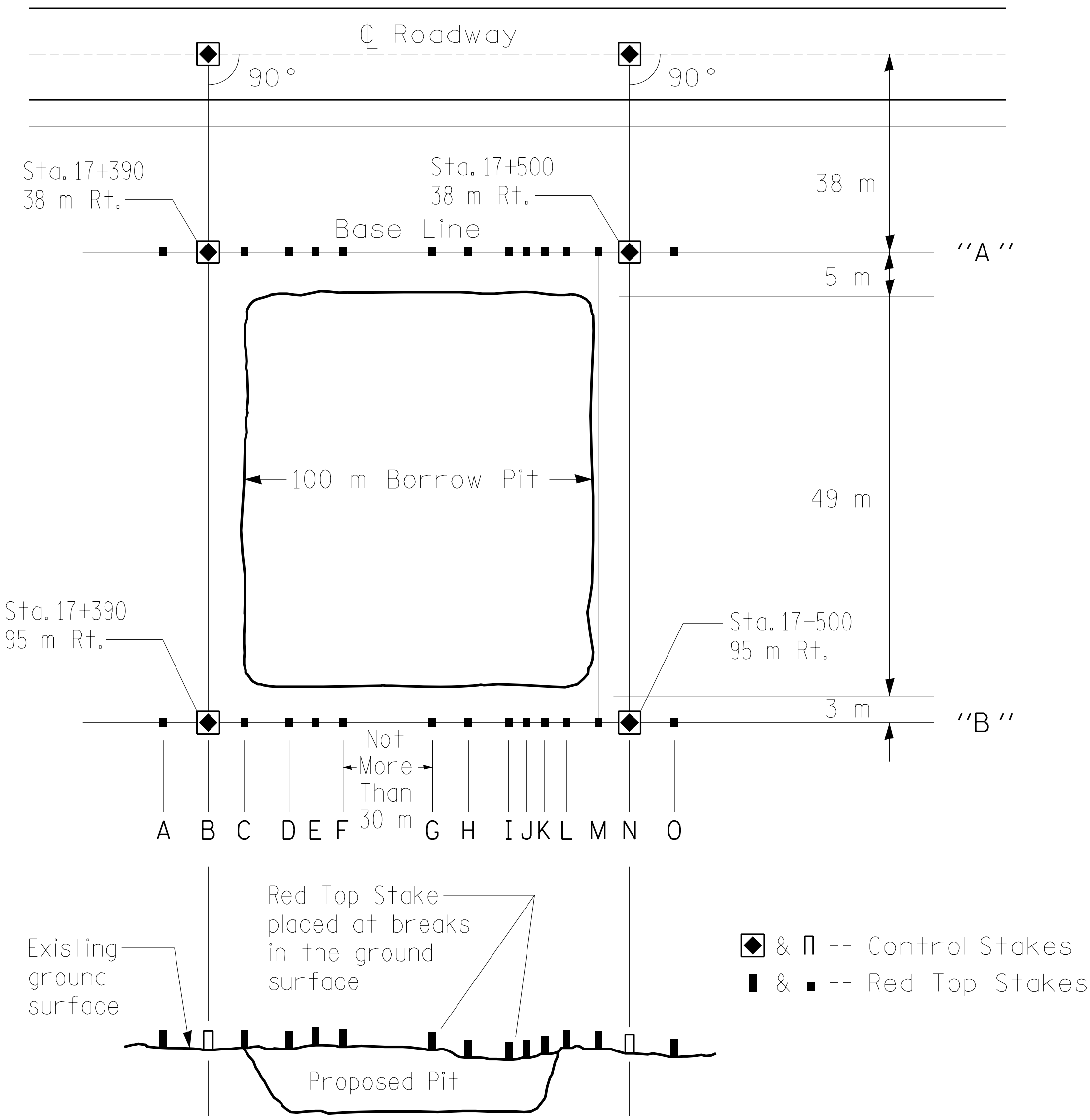
Original Cross Section: Cross sections must be taken before excavation starts. Establish a permanent bench mark close the borrow pit, using plan datum if possible. Then take readings along each cross section established between line “A” and “B”, making those readings often enough to get all the breaks in the grade on each section measuring the distance to each point accurately. Have the cross section reading extend several meters (feet) outside of lines “A” and “B”. It is a good idea to take a few cross sections beyond the ends of the borrow pits also, as it may be necessary to enlarge the pit after excavation starts. Be sure to check cross section distances against stakes previously set in the base line and offset line. Close the level circuit on a benchmark of known elevation.

Final Cross Section. After the excavation is completed and the borrow pit shaped, you should recross section the pit at the identical locations used previously. In addition, cross sections should be taken at the breaks between the back slopes and level parts of the pit. Original sections at these points may be interpolated. Usually, it is not possible to determine such points in advance. The recross sectioning should be done as soon as possible. It may be necessary to take cross sections before the borrow pit is leveled off, if the Contractor delays this finishing very long, because of the danger of the contour of the pit being changed by heavy rains. It is convenient to check borrow pit drainage in connection with the final cross sections.

Pits Subject to Overflow. If the borrow pit is subject to overflow and the Contractor suspends work for any considerable length of time, the pit should be cross sectioned immediately after work stops. If overflow occurs, the pit must again be cross sectioned before work starts as alluvial deposit may appreciably affect the quantities.

Computations. Plot your notes and compute the volume used on the project by the Contractor. If computations are to be made in the District Office Computer Section, retain a copy of your cross section notes. It is a good idea to spot check the cross sections yourself to make sure they close.

STAKES FOR BORROW PIT EXAMPLE



Location	Station	Location	Station
A	17+385	I	17+460
B	17+390	J	17+470
C	17+400	K	17+475
D	17+410	L	17+485
E	17+415	M	17+495
F	17+420	N	17+500
G	17+440	O	17+505
H	17+445		

CROSS SECTIONS FOR BORROW PIT EXAMPLE

Borrow Pit (Example)			April 1, 1998		Originals			
	B.S. (+)	(H.I.)	F.S. (-)				Instrument:	TLM
B.M. #4	1.728	(172.58)		170.853			Rod:	RJP
							Book:	TSA
Baseline	Rod						Party Chief:	J. Doe
	Distance						Weather:	13 C Hot, Sunny
+385	1.303	1.355	1.599	1.492		1.367		
	0	3m	9m	16m		57m		
17+390	1.297	1.364	1.621	1.541		1.429		
	0	2m	6m	14m				
17+400	1.234	1.321	1.432	1.567		1.543		
	0	4m	8m	21m		57m		
17+505	1.324	1.431	1.623	1.365		1.432		
	0	1m	4m	12m		57m		
B.M. #4	(check)		1.727	170.854	OK			
Final cross sections are taken in a similar manner								
If embankment is the pay item it may be necessary to								
take original and final cross sections in a similar manner								

Setting Stakes for Grading

Usually, three sets of stakes will be used for controlling a construction contract; (a) Right of Way, Control and Structure (b) Preliminary Grade, and (c) Finish Grade.

Before you start setting stakes consult the Contractor to learn whether your proposed method will suit his/her convenience. As much as possible adjust your method to his/her wishes. After you have come to an agreement, make a note of it in your fieldbook, and make certain that the Contractor understands just what method of staking you will use, at what points stakes will be set, and how they will be marked. It is best to give him/her this information in writing as this may avoid a future controversy. A 1.5 m (5 ft) offset, if possible, will permit satisfactory distances from the toe of slope or edge of ditch to permit the Contractor sufficient workroom for his/her operation. Each cut or fill entered on the grade stakes should be recorded in the fieldbook. Prior to the Contractor beginning dirtwork operations, the original ground elevations should be spot checked for accuracy.

After the earthwork is roughed in, the Contractor will request a line of stakes, usually down the centerline of the roadway, to establish the completed crown grade. This line of stakes should be set with an instrument and the grade shown as requested by the Contractor. When the roadway is built as close to grade as possible with the previous stakes, it will then be necessary to set line stakes and paving stakes at 15 m (50 ft) intervals, closer intervals are required on a tight horizontal or vertical curve. These stakes should be of hardwood, preferably a 1 in x 2 in or 2 in x 2 in size, or metal and of sufficient length to penetrate the grade far enough that the movement of equipment will not cause variations once the grade is established.

The subbase and pavement can be built from these paving stakes. The Contractor should be cautioned against destroying the stakes. If this condition is encountered, the Specifications permit a fee that can be assessed for replacing the stakes.

Curve Superelevation. Review the curve data and typical sections shown on the plans for superelevation rates, transition lengths, and points of rotation. In some instances, this superelevation may create drainage problems, especially in flat terrain and with wide pavements. Review the curve data shown on the plans for superelevation limits and rate.

Within Cities. Superelevation within the limits of villages or cities is designed for the slower speed required and is, therefore, generally less than found in rural areas where higher speeds prevail. The difference in superelevation is, as a rule, the result of the difference in speeds, although there may be specific instances where good judgment or local conditions call for some modification of our standard practice. If you have any doubt as to whether you should follow our standard practice, discuss the matter with your Supervisor.

Layout of Entrance Culverts

Location. All entrance culverts should be set such that they match the roadway ditch both line and grade.

Staking. The only stakes that are necessary to be set for an entrance culvert are two stakes on the centerline of the culvert barrel. On these stakes should be marked with the cut to the ditch flow line.

Elevations of Headwalls. If the headwalls are built, it is essential that the top elevation of the two headwalls be made parallel to the grade of the shoulder, even though the gradient of the ditch is not the same as that of the pavement.

Layout of Across-Road Culverts

Location: Prior to staking out an across-road culvert determine whether the location as shown on the plans will fit the channel to the best advantage. See the following page for How to Check Plan Pipe Culvert Lengths. If you think the culvert line or grade should be relocated or the skew angle changed, take the matter up with your supervisor. Channel locations should not be revised without approval from your supervisor.

Staking. The centerline of the culvert barrel should be staked first by placing a stake on the centerline not closer than 1.5 m (5 ft) outside of each headwall. Nails should be set in the stakes giving the exact line. The cut to flow line should be marked on the stake, measured from the top of the stake. Also, always check the plan length for accuracy.

Elevation of Headwalls. After the forms are built, it is sometimes necessary to set the elevation to be used for the top of headwalls and give the Contractor elevations on the forms at which to set the chamfer. Remember that the tops of the headwalls must be parallel to the grade of the centerline of the roadbed.

HOW TO CHECK PLAN PIPE CULVERT LENGTHS

When checking a culvert for length the following information is given:

W = Right angle distance from centerline to shoulder point. This may be found on the typical section sheet or from cross sections.

K = Difference in elevation between centerline elevation and shoulder point. Also given on typical section sheet (Special case superelevated curves).

Centerline Elevation: Given on plans or may be calculated.

Invert Elevation: The flowline of pipe culvert at inlet or outlet end. Given on plan sheet and cross sections.

N = Slope: Defined as the number of meters (feet) vertical per 1 meter (ft) horizontal (at right angle to centerline).

Skew Angle = α: The angle between the centerline of the pipe and a perpendicular line to the centerline of the roadway.

C = Distance from top of headwall to invert elevation found under Standard or Special Headwall Sheet listed for particular pipe. (See typical pipe data below).

t = Thickness of Headwall. (See typical pipe data below).

TYPICAL DATA GIVEN ON PLAN SHEETS FOR PIPE CULVERTS (metric)

STA 395+000
Double Pipe Culv Ty 2A
RCCP CL II 900mm 103 m
Hdwls Std 2102-D-900-2
Both Hdwls:
4.00 cu m Class SI Concrete
104 kg Reinf Bars
D.A. 1.6 ha
Method II Installation

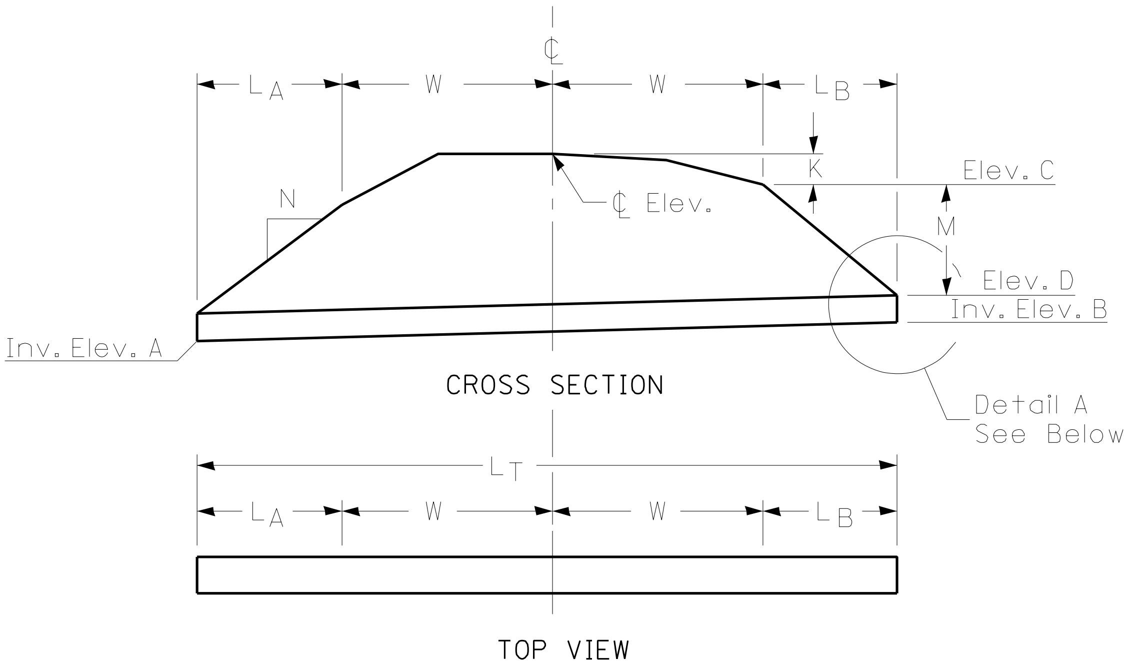
STA 390+055
Pipe Culvert Ty 2 A
RCCP CL II 900 mm 59 m
(Lt 29 m & Rt 30 m)
Hdwls Std 2051-DS-900-2
Both Hdwls
4.3 cu m Class SI Concrete
68 kg Lbs. Reinf Bars
Skew Angle = 25°
D.A= 0.9 ha

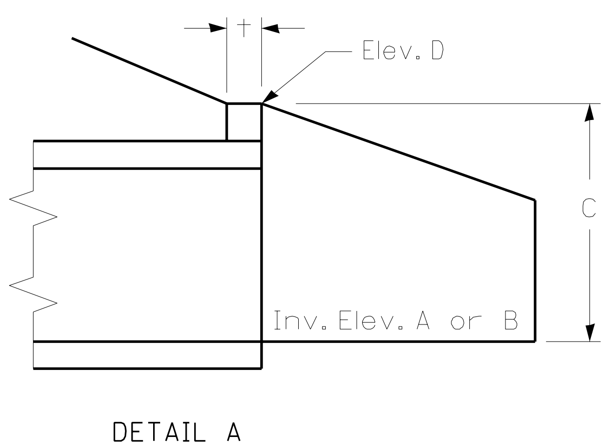
TYPICAL DATA GIVEN ON PLAN SHEETS FOR PIPE CULVERTS (English)

STA. 1395+00
Double Pipe Culv Ty 2A
RCCP CL II 36" 338 lin. ft
Hdwls. Std. 2102-D-36-2
Both Hdwls.:
5.00 Cu. Yds. CL "X" Conc (Hdwl)
230 Lbs. Reinf. Bars
D.A. 40AC
Method II installation

STA 1286+54
Pipe Culv Ty 2A
RCCP CL II 36" 192 lin. ft
(Lt 94' & Rt 98')
Hdwls. Std. 2051-DS-36-2
Both Hdwls.
5.6 Cu. Yds. CL "X" Conc (Hdwl)
150 Lbs. Reinf. Bars
Skew Angle = 25°
DA = 22AC

RIGHT ANGLE INSTALLATION





THE PROCEDURE IS AS FOLLOWS:

RIGHT ANGLE CULVERT (Skew Angle = 0)

A. Total Length $L_T = 2W + L_A + L_B$

B. For L_A or L_B
Elev C = C_L Elev - K
Elev D = Inv Elev (A or B) + C
M = Elev C - Elev D
$L_{AB} = N(M_{AB}) + t$

C. $L_T = 2W + L_A + L_B$

EXAMPLE RIGHT ANGLE CULVERT @ STA 10+000

W = 6.70 m K = 0.300 m C = 1.000 m t = 0.150 m N = 1:3

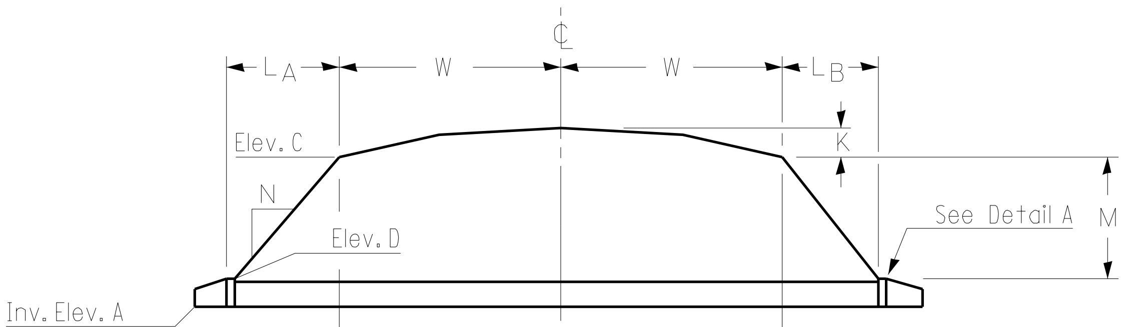
C_L Elev = 46.000 m Inv Elev A = 31.000 m Inv Elev B = 32.000 m

L_A Elev C = 46.000 - 0.300 = 45.700 m
Elev D = 31.000+1.000 = 32.000 m
M = 45.700 - 32.000 = 13.700 m
$L_A = NM_A + t = 3(13.700) + t = 41.100 + .1500 = 41.250$

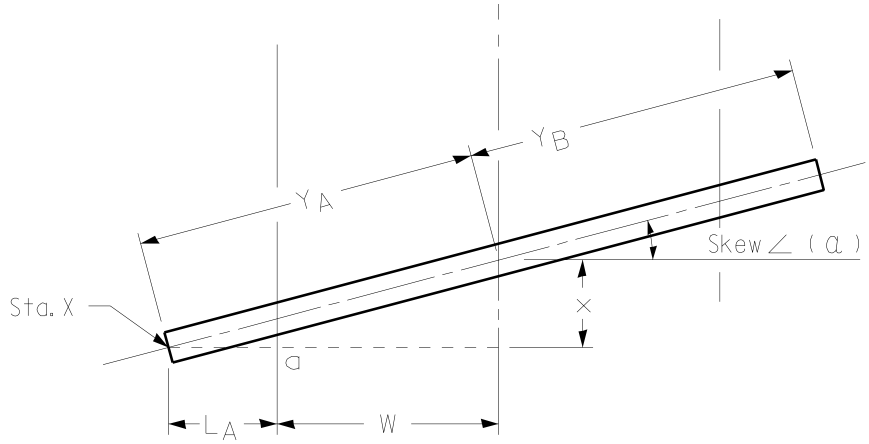
L_B Elev C = 45.700 m
Elev D = 32.000 + 1.000 = 33.000 m
M = 45.700 - 33.000 = 12.700 m
$L_B = NM_B + t = 3(12.700) + .150 = 38.100 + .150 = 38.250$

$L_T = 2W + L_A + L_B = 13.400 + 41.250 + 38.250 = 92.900$ m

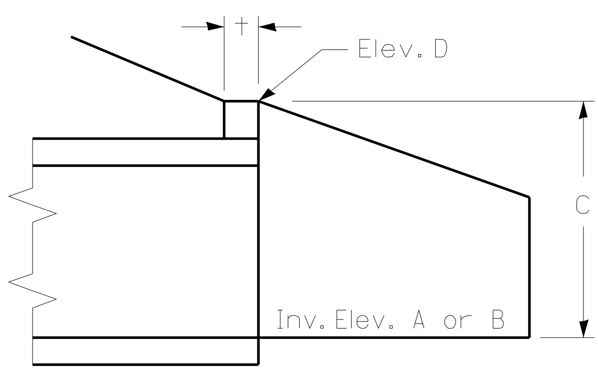
SKEWED CULVERT INSTALLATION



CROSS SECTION AT STA. X
With Skewed Culvert Projected Onto Section



TOP VIEW



DETAIL A

SKEWED PIPE CULVERT

1. Assume Y_A is correct.
2. $X = Y_A \sin \alpha$
3. Sta X = Sta of Pipe $\pm$ X
4. Calculate Centerline Elev of Sta X
5. Calculate shoulder break elevation at point “a” = Centerline Elev Sta X-K = Elev C
6. Elev D = Invert Elev A or B + C
7. M = Elev C - Elev D
8. $L_A = [N \times M] + t$
9. $Y_A = \dfrac{L_A + W}{\cos \alpha}$
10. Does Y_A (calculated) = Y_A (assumed)?
11. If No. 10 is not true, then a new Y_A must be assumed and the procedure repeated.

EXAMPLE SKEWED CULVERT

Same data as above with Skew Angle = 45° RT Forward

Given: Y_A = 67.000m Y_B = 61.000 m (Assumed correct but not checked for this problem - Check left side only.)

1. Y_A = 67.000m (assumed correct)
2. X = 67.000 (.70711) = 47.376 m
3. Sta X = 10+000 - 47.376 = 9 + 952.624
4. Elev Sta X = 46.000 - 47.376 (.01) = 45.526
5. Elev C = 45.526 - 0.300 = 45.226

6. Elev D = 31.000 + 1.000 = 32.000

7. M = 45.226 - 32.000 = 13.226

8. L_A = NM + t = 3 (13.226) + 0.500 = 40.178

9. $Y_A = \dfrac{40.178 + 6.700}{\cos 45°} = \dfrac{46.878}{0.70711} = 66.296$

10. Y_A (calculated) $\neq$ Y_A (assumed) , therefore repeat procedure

Recalculation

1. Y_A = 66.296

2. X = 66.296(sin 45°) = 46.878

3. STA X = 10 + 000.000 - 46.878 = 9 + 953.122

4. Elev STA X = 46.000 - 46.878(0.01) = 45.531

5. Elev C = 45.531 - 0.300 = 45.231

6. Elev D = 31.000 + 1.000 = 32.000

7. M = 45.231 - 32.000 = 13.231

8. L_A = NM + t = 3(13.231) + 0.500 = 40.193

9. $Y_A = \dfrac{40.193 + 6.700}{\cos 45°} = \dfrac{46.893}{0.70711} = 66.317$

10. Y_A (calculated) $\approx$ Y_A (recalculated) , therefore OK -- Use Y_A = 66.317

$$\frac{\text{Total Length of Culvert}}{Y_A + Y_\beta}$$

Layout of Pavement

Alignment and Grade. The essentials of a good paving section, alignment and grade, should be kept in mind continually when setting stakes for the work.

Field Book. Before setting any stakes, you should prepare your field book, check all computed grades shown on the plans as well as your calculated grades for other points. If the proposed pavement is to tie into existing pavement, the existing pavement elevations must be checked. Review the District Computer Programs for assistance. In addition to elevations, it is desirable to include the following data in your field book:

A. Elevations of each edge of pavement on superelevated curves and on superelevated transitions at ends of curves, at 15 m (50 ft) intervals;

B. Ties to all survey line control points, points of curve and tangent, bench mark elevations and locations;

C. Tables of curve deflection angles and chords;

D. Tables of offset from survey line to form stake line when required;

E. Your return address (in case book should be lost).

It is a convenience, and will save time, if all necessary information from the plans is carefully transferred to the field book.

Notes for Setting Grade Stakes and Stringlines for Automatic Grade Control Equipment

General Information. Automatic grade control equipment automatically transfers the accuracy of the predetermined plane, such as a stringline, to the subgrade, base or surface, resulting in a neat line profile.

Automatic grade control equipment makes the transfer by the use of sensing units that contact the stringline on either side of the grade.

Normal Stringline Setting. The Contractor will usually set metal stakes which are 1 m (42 in) long and are driven into the ground, normally at 15 m (50 ft) intervals along one side of the roadway when using a machine equipped with automatic slope control or along both sides of the roadway when using a machine with sensors installed on both the right and left sides of the machine. The metal stakes are set to the hubs (grade stakes set for the roadway) for both dual lane and single lane machines. On superelevated sections and ramps, the metal stakes should be set at 8 m (25 ft) intervals to gain a greater degree of accuracy.

Factors to Consider for Stringline Installation. The following factors should be considered before any preparation for setting the stringline is started, to determine the most feasible location for the stringline:

1. Other work that may be performed either between the stringlines, when two are used, or along the shoulders.

2. The amount of material to be wasted near the stringline and the disposition that will be made of the material.

3. Obstructions along either side of the roadway.

4. The limit of the autograde sensor arm supports.

5. The percent of fall from the centerline of the roadway to the hubs or edge of pavement.

6. The grade stakes should be set directly below the stringline, if possible, but could be offset by up to four feet in small areas.

Location of the stringline may vary with each section of the roadway, due to supers, crowns and offsets. Each section should be evaluated separately to determine the proper location or position of the stringline.

Stringline Hubs. Accurate operation of automatic grade control equipment depends on the correct installation of the stringline and the precise setting of the line and grade hubs. Considerable effort can be saved in the initial engineering if the Resident and Superintendent discuss the proper offset distance of the hubs and the specific machine to be used for each operation.

For autograde equipment with only one grade sensor and an automatic cross slope grade control, only one set of grade hubs is needed. See Figure A.

For automatic equipment operating from two stringlines, two sets of grade hubs are needed to work the roadway from the initial subgrade to the finished slab. See Figure B.

Each stringline must be set at a constant distance from the roadway centerline or a theoretical edge of the pavement. Each stringline must also be suspended at a constant height above the plane passing through the lower corners of the proposed slab.

AUTOGRADE WORKING FROM 1 POSITIVE HUB, WITH CROSS SLOPE SYSTEM

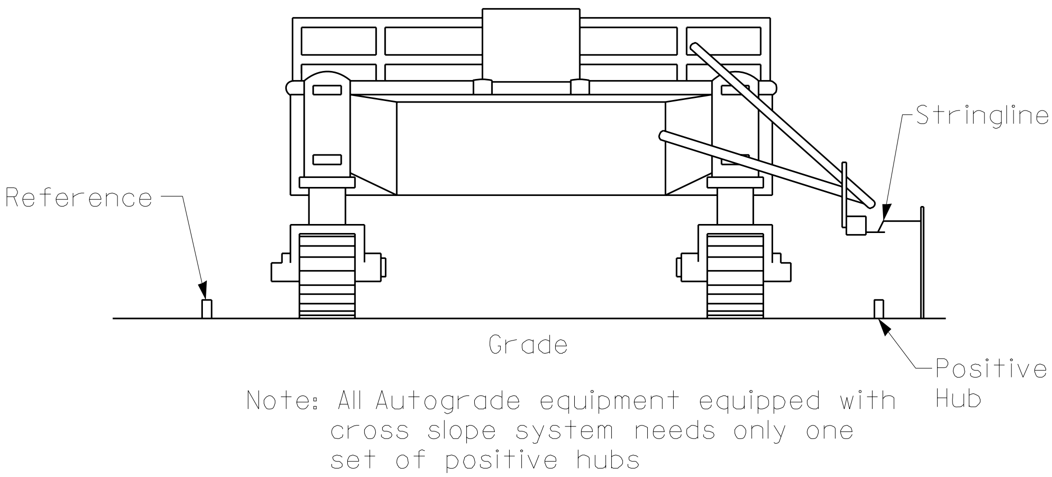


FIGURE A

AUTOGRADE WORKING FROM 2 STRINGLINES, WITH 2 POSITIVE HUBS

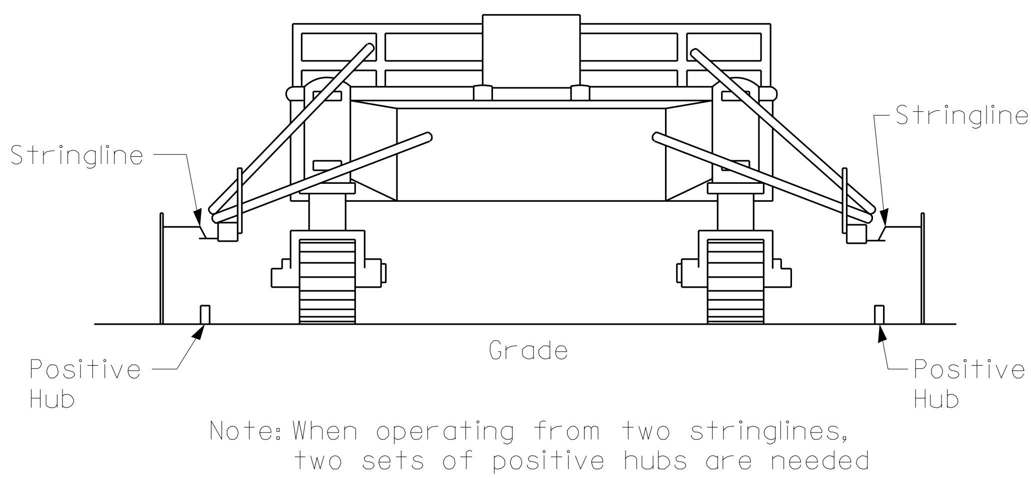


FIGURE B

Superelevation

On many horizontal curves, the cross-slope of the pavement is modified to provide greater comfort and safety to the motorist. For the majority of the length of the curve the pavement will be uniformly sloped toward the center of the curve. This uniform cross-slope is called the superelevation rate.

In order to change from the normal crown on the tangent portion of the pavement to the full superelevation portion of the curve (and vice versa) the cross-slope must undergo superelevation transition.

Superelevation transition length is defined as the distance required to transition the pavement or traveled way from a normal crown section to the full superelevation (e). The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length (L).

The tangent runout distance is the length required to bring the outside lane(s) up to a flat cross-slope. The superelevation runoff length is the remaining portion of the superelevation transition length.

For a detailed discussion of Superelevation, including design criteria and sample calculations, see Chapter 32 of the Bureau of Design and Environment Manual.

COMPUTER APPLICATIONS

The Resident should be aware of and optimize the use of the Department's computer service. The following programs are available at the District level.

Field Control

Coordinate Geometry - An ICES subsystem of solving geometric problems, determining coordinates for triangulation, and locating control points by station/offset values.

Roadway Analysis and Design System - An ICES subsystem capable of computing earthwork quantities, plotting cross sections, and producing printed tables of slope stake locations.

Offset Line Elevations - This program is capable of producing tables of offset line elevations for paving stakes. These tables may optionally be printed on field book size pages.

Circular Curve Deflection Angles - Produces, in tabular form, deflection angles for staking of circular curves in the field.

Three Point Problem - Determines plane coordinates for a point based upon sightings of three non-collinear points whose coordinates are known.

Bridge Deck Elevations - Provides a listing of bridge deck elevations along each beam of a bridge and can adjust these elevations to reflect dead local deflections.

Field Quantities

Bridge Fillet Quantities - Computes fillet quantities, based upon plan values and field measurements.

Borrow Pit, Embankment and Excavation Computations - Computes cut and/or fill, along with end-area for each cross section, as well as accumulated totals. Plotting of cross sections is available.

Reinforcing Steel Quantities - Tabulates total weight of reinforcing steel.

Quality Control

PCC Proportioning - Designs concrete mix for user specified material specific gravities.

Bearing Tables for Pile Hammers - Provides a table of bearings versus blows-per-meter (foot). Also computes blows-per-meter (foot) to reach a specific bearing.

Slope Stability Analysis Series - These programs analyze the stability of slopes using various test methods.