

Creating Three Dimensional Environments from As-Built Plans

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Introduction

To create a three-dimensional environment requires significantly more point data than an orthographic two-dimensional diagram. Ideally, this point data is acquired through a total station survey of the site. However, circumstances occur when a survey is not possible. The roadway improvements may have changed since the date of the accident, or regulatory and safety issues prevent you from performing a survey.

Construction plans exist for the majority of paved streets and highways in the United States. Changes made during construction are often recorded on a set of revised plans called *As-Built* plans. Three-dimensional environments can be generated from these plans in lieu of a site survey. This paper describes a step-by-step guide to building an environment from an *As-Built* plan.

The user constructs a “virtual” roadway in a computer environment. A robust computer aided drafting or 3-D modeling program is necessary to create the environment, which can then be imported into HVE. The process is

similar to what occurs when the actual roadway is built. That is, first the roadway is staked, then cut to grade, and finally the surfaces are poured.

Survey Line

The survey line establishes the traverse of the roadway construction project. Often this line is the centerline of the roadway and may be labeled as such. Divided and controlled access highways may have two survey lines, one for each direction of travel. The path of the survey line is well described, and precisely located when the roadway is constructed. Typically the right-of-way lines run parallel to the survey line.

As when the roadway was constructed, the survey line acts as the spine from which the environment will be created. The initial step is to plot the survey line through the area covered by the environment. To accomplish this, the user must be knowledgeable of the methods used to describe its path.

Stations

The survey line of a roadway project may have many curves and angles. For this reason, a rectangular coordinate system is not practical for establishing points along the survey line. Instead, **stations** are used where horizontal distances are measured along the survey line. Distances are given in the format 5+91.88, where the value to the left of the plus (+) sign represents one hundred foot intervals. Therefore, the station 5+91.88 is located 591.88' from the origin.

The origin (0+00) is typically located at the beginning of the construction project, or may be the continuation of a contiguous project. Specifying a direction from the origin is unnecessary, as the stations run in only one direction from the origin. Perpendicular distances from the survey line are specified left or right as viewed forward from the origin.

Even numbered stations are typically denoted by a hash mark on the survey line, and dimensioned at 200' or 500' intervals. A **match line** is used to orient the continuation of the survey line on subsequent sheets. The match line is drawn perpendicular to the survey line, typically at an even numbered station.

In some instances, two construction projects meet where the stations do not match. A **station equation** establishes the gap (or overlap) in the stations. The station equation is specified at a

common point and is given in the format: 10+00 AHEAD = 7+00 BACK. In this example there is a 300' gap in the stationing. The station of the point is 7+00 based upon the stations preceding the point; and 10+00 based upon the stations following the point.

Horizontal Curves

Changes in direction to the survey line are accomplished by a horizontal curve. Horizontal curves are tangent to a straight section of the survey line, or another curve. The beginning of the curve is labeled the point of curvature, or P.C. The end is called the point of tangency, or P.T. These points are marked on the survey line, and their stations labeled. Additionally, the tangents of the curve are shown, and the station of the point of intersection, or P.I., is labeled.

The P.C. and P.T. stations follow the curved path of the survey line. However, the P.I. station is based upon the tangent length from the P.C. to the P.I. Since the P.T. station is based upon the arc length, the difference between the P.I. and P.T. stations will not equal to the tangent length.

Horizontal curve data is usually listed on the same sheet on which the curve appears, and is frequently referenced by curve numbers. Typical curve data appears in the Figure 1. Curve formulae are defined and depicted in Figure 2.

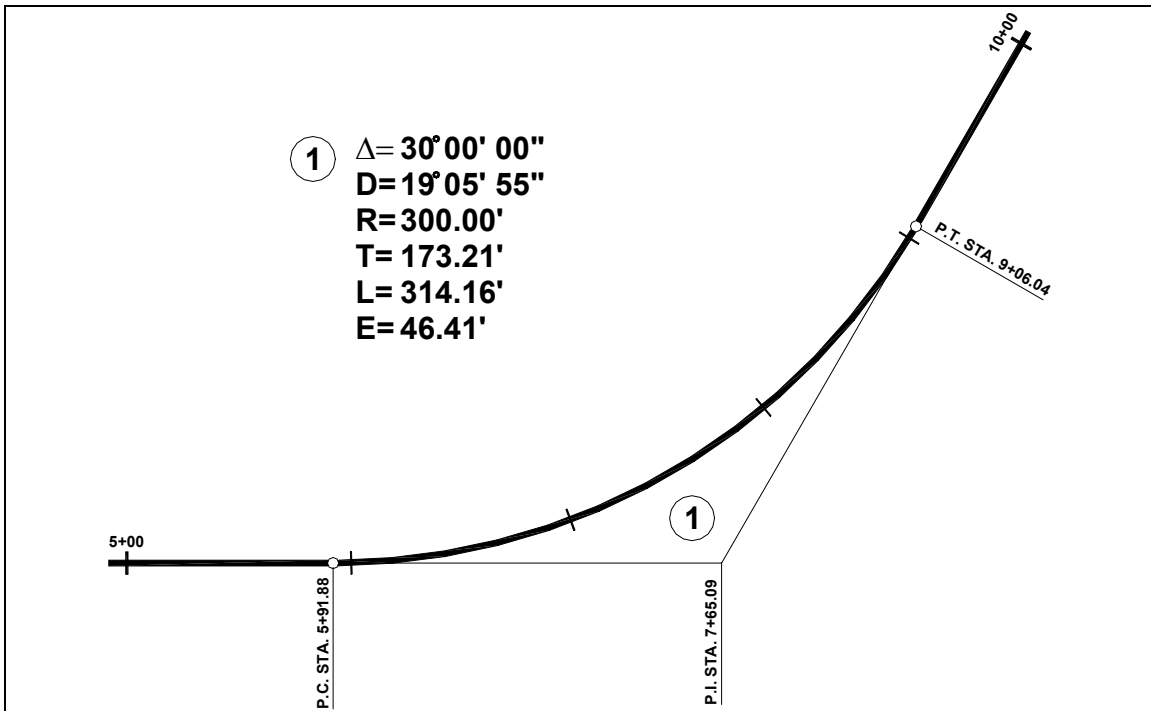


Figure 1: Curve data reference by number appears in the above format.

Where Δ is the delta angle of the curve; **D** is the degree of curve; **R** is the radius; **T** is the tangent length; **L** is the arc length; and **E** is the external.

The **delta angle**, or central angle, is the angular distance between radial lines drawn to the beginning and end of the curve. The delta angle is congruent to the deflection angle, or the angular distance between the tangents.

The **degree of curve** is an alternate method of specifying the radius of the curve. It represents the central angle that forms an arc length of 100'. The radius of the curve can be calculated by

dividing 5729.58 (the radius of a 1° curve) by the degree of curve.

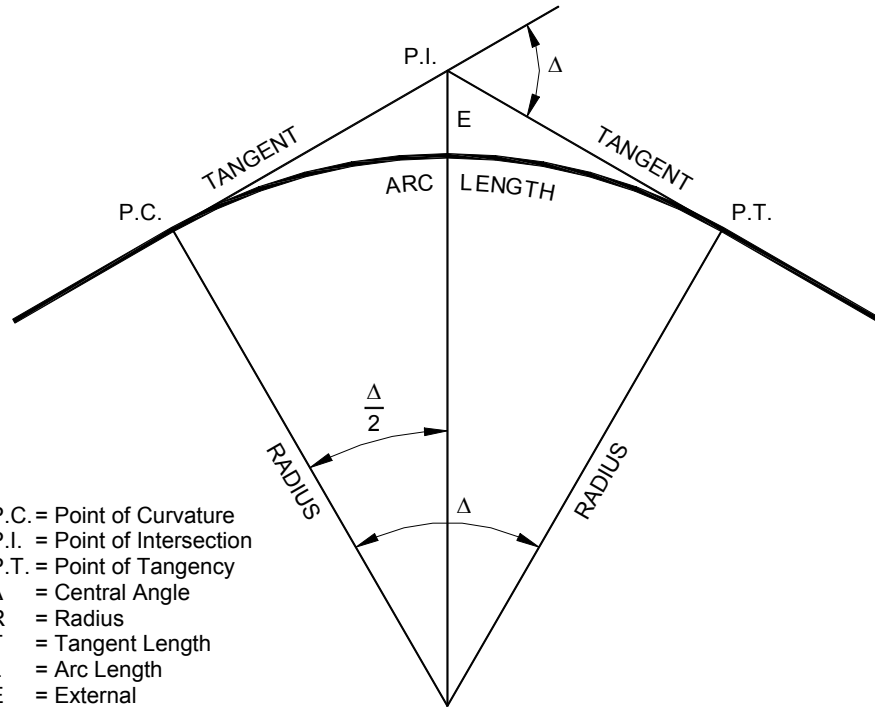
Often the **radius** is listed in addition to, or in lieu of the degree of curve.

The **tangent length** is the distance from either the point of curvature or tangency to the point of intersection. The tangent lengths are equal for a circular curve.

The **arc length** is the distance between the point of curvature and tangency measured along the arc.

The **external** is the radial distance from the point of intersection to a point along the arc.

CURVE FORMULAE



Degree of Curve	$D = \frac{5729.58}{R}$
Radius	$R = \frac{5729.58}{D}$
Tangent Length	$T = R \tan \frac{\Delta}{2}$
Arc Length	$L = \frac{\pi R \Delta}{180}$
External	$E = \frac{R}{\cos \frac{\Delta}{2}} - R$

Figure 2: Horizontal curve formulae are given in the above table.

Profiles

A profile view of the survey line typically appears below the plan view. The horizontal scale matches the corresponding plan view. However, the vertical scale is often larger, typically 1" = 5'. The grade and elevation of the survey line is depicted in this view.

Roadway grades are specified as a ratio of the longitudinal distance to the change in elevation. Generally it is expressed as a percent of grade, which is vertical rise (or fall) in a 100' run. Negative grades indicate a downgrade. The grade can be expressed:

$$G = \frac{\Delta Elevation}{d}$$

Where G is the grade; $\Delta Elevation$ is the change in elevation; and d is the

longitudinal distance. The grade is the tangent of the vertical angle of the survey line. The angle can be calculated by:

$$\tan\theta = \frac{\Delta Elevation}{d}$$

Where θ is the vertical angle of the roadway.

Changes in grade create sags and crests. The transition between two grades is accomplished by a vertical curve. The start of the vertical curve is labeled the vertical point of curvature, or V.P.C. The end is called the vertical point of tangency, or V.P.T. The intersection of the tangents is called the vertical point of intersection, or V.P.I.

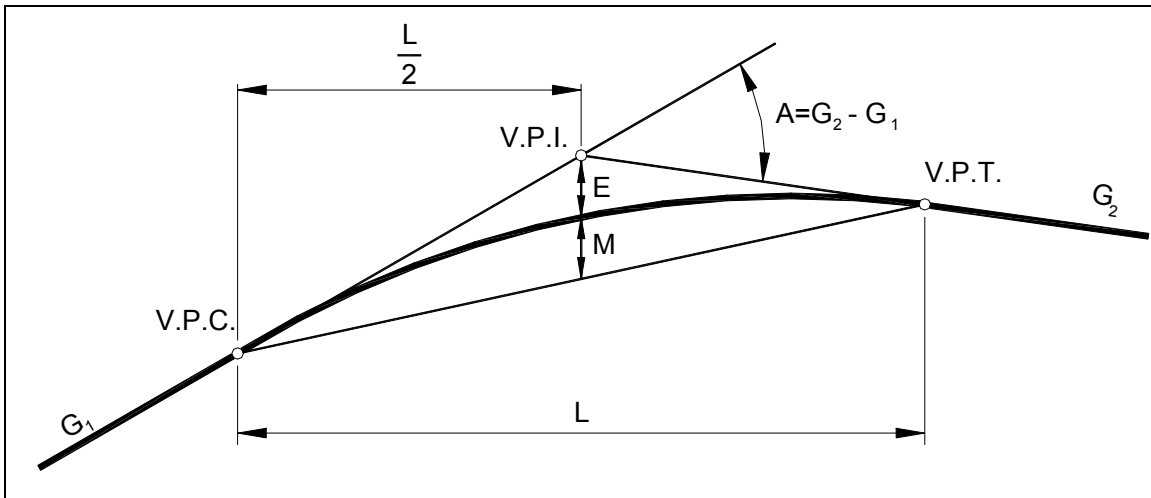


Figure 3: A vertical curve is specified by its horizontal length (L). The curve is centered over the vertical point of intersection. The parabolic curve is established by drawing a curve through the vertical point of curvature, tangency, and external, where the external and middle ordinate are equal.

The vertical curve is established by its longitudinal length. The station and elevation of the vertical point of intersection is labeled. The vertical curve is centered over the vertical point of intersection. The curve is parabolic with the external and middle ordinate of a vertical curve equal. The mid-point can be determined by establishing the middle of a vertical line that intersects the chord of the vertical curve.

The elevation of the mid-point can be calculated by adding or subtracting the external from the point of intersection elevation. The external is given by the equation:

$$E = \frac{AL}{800}$$

Where E is the external; A is the difference in the intersecting grades expressed in percent, ($A=G_2-G_1$); and L is the length of the vertical curve.

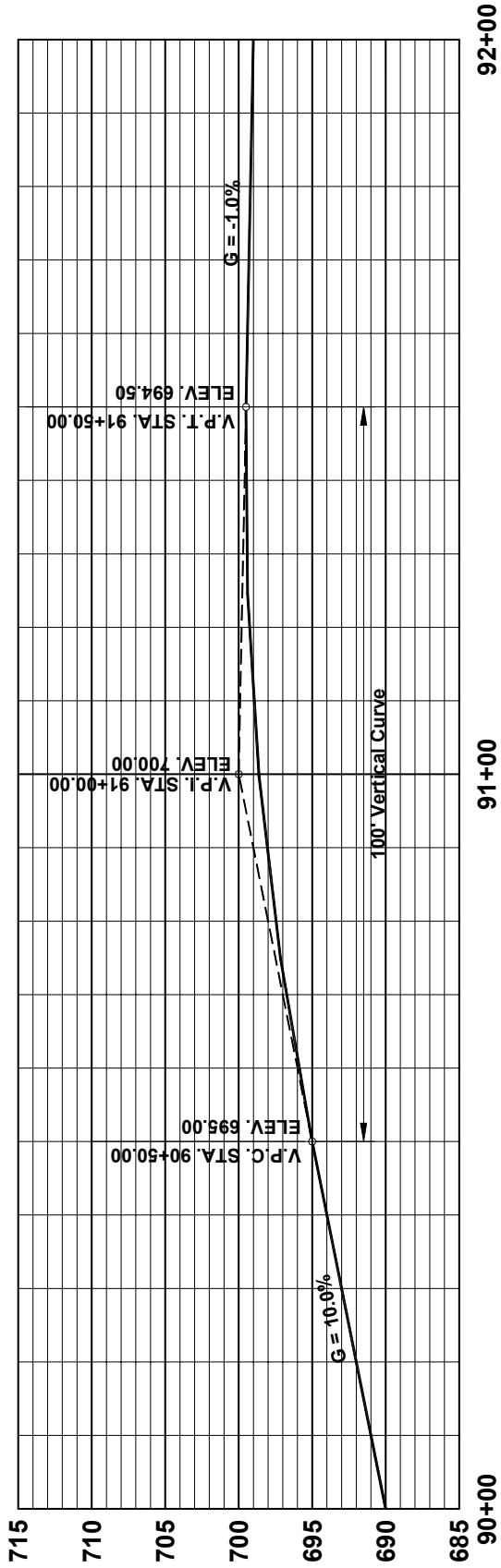


Figure 4 A typical profile appears below the corresponding plan view. Elevations are labeled along the vertical axis, and stations along the horizontal axis. Grades are given in percent with positive grades indicating rise, and negative grades indicating a fall. The elevation and station of the point of intersection of vertical curves are given. The length of the vertical is dimensioned and centered over the point of intersection. The vertical points of curvature and tangency may also be given.

Cross Sections

Cross sections depict vertical and lateral features. Details of the roadway width, cross slope, super-elevation, shoulder, curb and gutter, and roadside are specified. Cross sections typically appear on a sheet (or sheets) separate from the plan and profile views. Ensure that these detail sheets are included when obtaining as-built plans.

Unless otherwise specified, the centerline of the pavement is aligned with the survey line. Lateral distances to the pavement edge are dimensioned. Depending upon what features border the pavement, additional dimensions are needed. These may include shoulder

edge, centerline of ditch, top and toe of berm, curb and gutter, median, sidewalk, fence line, and right-of-way.

The cross slope of the pavement is typically labeled in feet per foot instead of percent grade. When present, the shoulder often has a different cross slope than the adjacent pavement. Curb and gutter details are given elsewhere, but are referenced in the cross section. Multiple cross sections are needed where changes in the roadway width, or cross slope occur. Divided highways may have a cross section for the pavement in each direction of travel. Ramps and frontage roads will have their own cross sections. The corresponding stations are listed below each cross section.

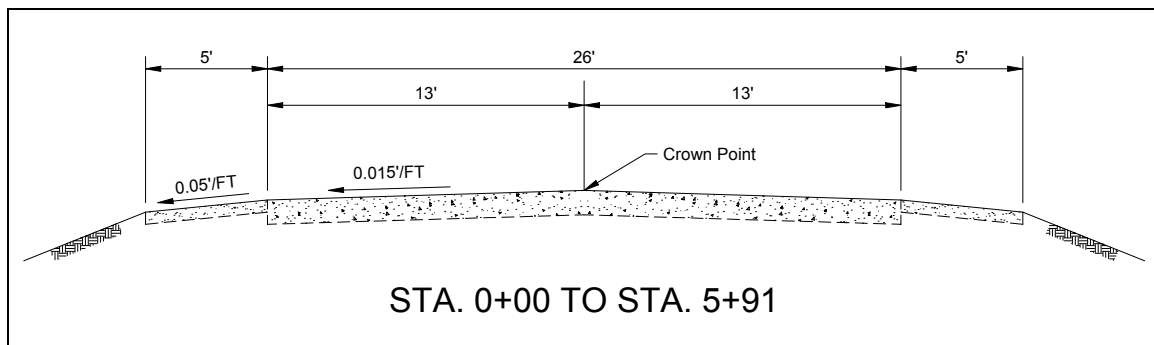


Figure 5: A typical cross section showing roadway and shoulder widths, and cross slope in ft/ft. This cross section applies to stations 0+00 to 5+91.

Straight sections of the pavement are typically crowned. However, through curve sections, the pavement will be super-elevated, or banked. The elevation of the outer edge of the pavement will be higher than the inside edge. The station at which the super-elevated cross section begins will be labeled, as will the station at which the crowned cross section ends. The gap between these stations serves as a transition between the cross sections.

Intersections

Intersection details are included in the plan view. Typically these details are limited to the area of the intersection only. If the environment is to include the approach of the intersecting street, construction plans for this roadway are also required. The survey line of the intersecting roadway is depicted on the plans. Its station is labeled, as is the angle of intersection. Return (small radius arcs which connect intersecting roadways) radii are dimensioned.

Roadside Detail

Construction plans typically include only the area immediately adjacent to the roadway. Roadside objects within the right-of-way are illustrated in the plan view. Seldom are any features outside the right-of-way shown. These features may include, but are not limited to, drives, turnouts, sidewalks, ditches, hydrants, and trees.

Objects not affected by the construction project are seldom dimensioned. The instruction to match the existing grade is given at the limits of excavation. The vertical alignment of these features is not well defined. Spot elevations may be listed on the plan view, or topo lines of the existing grade are shown. If roadside features are critical to the simulation, the construction plans may not provide sufficient precision to serve this purpose.

Plotting The Survey Line

The survey line will serve as the spine for the environment. Begin by plotting the survey line in the horizontal plane. Regardless of the roadway orientation, align the survey line with the **x axis** (it can rotated upon completion). Match the **x** coordinate to the stationing. This will expedite the drawing process, and eliminate the need to perform numerous calculations.

Decide upon the area to be included in the environment. Choose an even station to begin drawing the survey line, but avoid starting within a curve. Draw in the straight section of the survey line. If the survey line is straight throughout the environment, this is a quick step.

However, if a curve is present, the process becomes more complex.

If a curve is present, draw the first line segment from the beginning station to the point of curvature. Next draw the tangent from the point of curvature to the point of intersection. These lines will be on the **x axis**. Draw the tangent from the point of intersection to the point of tangency. Use relative polar coordinates to draw this line, where the length is equal to the tangent length, and the angle is the congruent to the central angle of the curve. This angle is positive if the curve deflects to the left, and negative if it deflects to the right. Then draw an arc at the specified radius, beginning at the point of curvature, and ending at the point of tangency.

The survey line continues from the point of tangency, however it is no longer on the **x axis**. Instead of calculating the coordinates of subsequent points, rotate the survey line about the point of intersection so that it remains on the **x axis**. Alternately, many CAD programs permit user coordinate systems, which permit the user to specify temporary or local coordinate systems with a different origin and axes.

Rotate the survey line an angular distance equal to the central angle of the curve. The direction of rotation will depend upon whether the survey line deflects toward the left or right. The tangent from the point of intersection to the point of tangency is now parallel with the **x axis**. However, since the stations follow the arc length, the point of tangency will not be at the appropriate **x** coordinate. Move the survey line so that the point of tangency is on the **x axis**, and its **x** coordinate is equal to the

P.T. station. Continue with the next straight section of the survey line.

Not all curves have contiguous straight sections. A compound curve is used when two or more curves with the same direction of deflection but different radii are adjoined. The point of common tangency establishes the end of the first curve, and the beginning of the second. The process to plot the survey line is the same, except that multiple points of intersections and tangency are required. Similarly, reverse curves are used when two curves with different deflections are adjoined. The point of reverse curvature establishes the end of the first curve and the beginning of the second.

Adjust Elevations

Finish plotting the survey line through the area included in the environment. At this point the z coordinate of all points is zero. The next step is to adjust the z coordinate to match the elevation of the survey line.

Break or trim the survey line at points where a change in grade occurs, and at the beginning and end of vertical curves (vertical points of curvature and tangency). First, adjust the elevation of the endpoints of the survey line along sections with a uniform grade. Most CAD programs have a stretch command that permits moving an end point of an entity a specified direction parallel to each axis.

The elevation of horizontal curves will have to be adjusted. The elevation of the points of curvature and tangency will have to be calculated when not dimensioned. The arc used to plot the

horizontal curve is planar. Unless the curve is level, the arc will have to be replaced with a spline. Snap the new entity to the point of curvature, midpoint of the arc, and point of tangency. Adjust the elevation of these points to match the profile.

Complete the plotting of the survey line by inserting the vertical curves. Extend the tangents of the vertical curve to establish the vertical point of intersection. Calculate the external distance, and add (or subtract) it from the point of intersection elevation to establish the elevation of the vertical curve at that point.

Alternately, the external can be solved graphically. This will also provide an entity to which the user can snap when plotting the vertical curve. Draw the chord of the vertical curve from the vertical point of curvature to the vertical point of tangency. Next, draw a vertical line from the vertical point of intersection to where it intersects the chord. This line is the sum of the external and middle ordinate. Since these lengths are equal in vertical curves, use the midpoint of the line to plot the vertical curve. Use a spline to connect the vertical point of curvature, the midpoint of the external/middle ordinate line, and the vertical point of tangency.

Plotting Cross Sections

The next step in constructing the skeleton is to create the cross sections. Determine which cross sections are used through the area covered by the environment. Construct each cross section using a separate line for every change in surface or cross slope.

Alternate the colors of each line so that they can be distinguished. Add curb and gutter details, and roadside features such as ditches, berms, and sidewalks.

Move a copy of the starting cross section to the beginning of the survey line. Snap the centerline of the cross section to the survey line, ensuring that it is perpendicular. Subsequent cross sections are needed at every horizontal point of curvature and tangency. Additionally, one cross section is required at the midpoint of the curve. These cross sections must be perpendicular to the survey line, and radial to the curve. When present, cross sections are needed at points of common tangency, and reverse curvature.

Note where changes in the cross sections occur, and copy the appropriate cross section to transitional stations along the survey line. This will include transitions between crowned and super-elevated cross sections, and changes in the pavement width, or other lateral features. The transition to a super-elevated curve typically straddles the horizontal point of curvature and tangency. The cross section at the point of curvature or tangency may not be specified in the construction plans. Use linear interpolation to create the intermediate cross sections at the point of curvature and tangency.

Finally, cross sections are needed at vertical points of curvature and tangency, and the midpoint of vertical curves. Ensure that the centerline of the cross section snaps to the desired point on the survey line. The elevation of these points must be common.

Creating Edges and Surfaces

The survey line and cross sections provide a skeleton from which the surface edges are constructed. By connecting corresponding points on each cross section, entities can be created from which the surfaces will be constructed.

Surface tools vary among computer aided drafting and 3-D modeling software. Specific entities are not discussed due to the differing requirements and limitations of the software. Notwithstanding their differences, most provide a means by which a surface can be created between lines and curves. Familiarity with your CAD or modeling software is necessary for selection of drawing entities. The number of segments will also depend upon the capabilities of your software.

Drawing entities must correspond with the entities used to construct the survey line. Lines can be used on straight grades. However, on vertical and horizontal curves, splines are required. Ensure that a separate drawing entity exists for every entity used to construct the survey line.

At intersections, a cross section is needed at the limits of the intersection. Draw returns at the appropriate radius. Since the arc entity is planar, a spline will be required to form the return. Adjust the spline to match the appropriate elevation. Draw the return tangents, and adjust the elevation of the point of intersection.

Every feature depicted in the environment will require an entity that establishes the edge between surfaces.

For instance, assume the environment consists of the pavement, unmountable curb, and sidewalk. Five entities are needed to create the surfaces on one side of the survey line. The first entity establishes the edge of the pavement and bottom face of the curb. The second and third entities define the top of the curb, and the fourth and fifth entities are the front and back of the sidewalk respectively.

Construct surfaces between these entities. Computer aided drafting and 3-

D modeling programs use varying forms of a polygon mesh to define a surface. It is critical that no gaps between adjacent surfaces exist. The vertices of adjacent polygon meshes must be common. Some programs permit “welding” surfaces together, while others require that the user specify the number of equidistant vertices used to form the mesh. The spacing can be altered so that a vertex may be snapped to the vertex of an adjacent surface to ensure a tight joint.

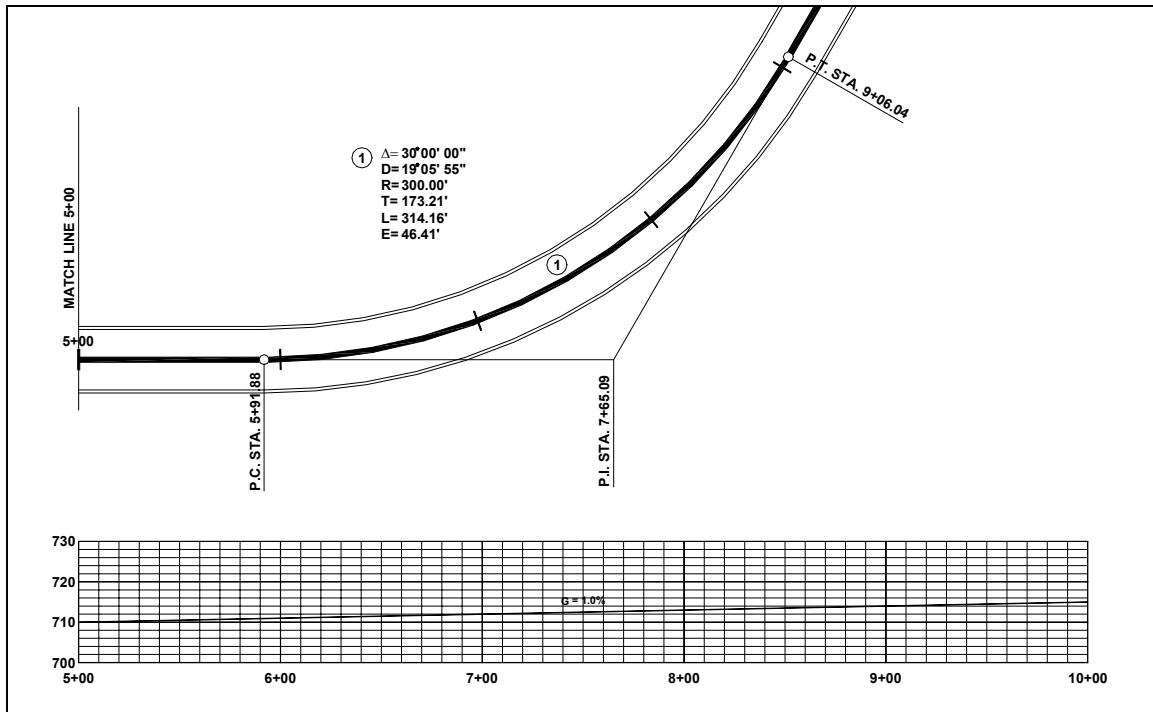


Figure 6: Typical plan and profile of horizontal curve on a grade.

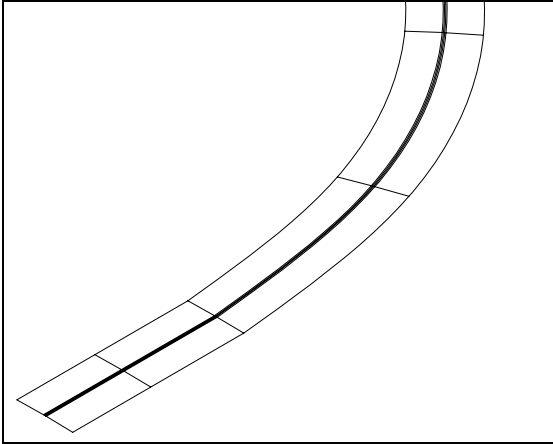


Figure 7: Survey line and cross sections plotted. Surface edges connected.

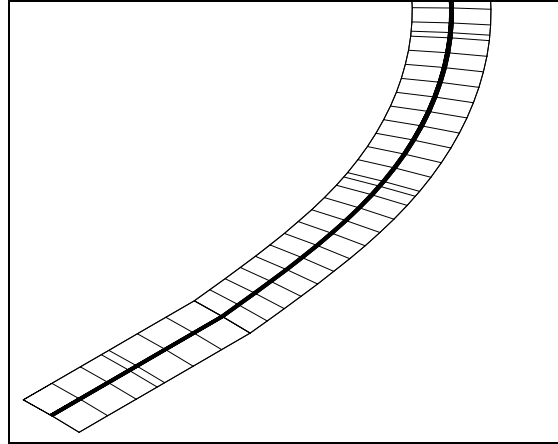


Figure 8: Surfaces created between entities.

Some CAD programs use line segments between vertices to form a surface. This requires special consideration when creating curved surfaces. The number of vertices must be set sufficiently high to give a smooth appearance to the curve.

Begin by creating the pavement surfaces. Before creating the adjacent surfaces, determine what roadside details are to be included. Drives, turnouts, or other roadway features will require additional entities before any surfaces can be created. These features typically appear in the plan view of the construction plans with only limited data. Often, only the centerline station and width of a drive is dimensioned. Check for a typical drive and approach detail in the plans, which may provide additional information.

Draw entities to establish the edges of drives and approaches. The end of the drive or approach where it intersects the pavement edge must be at the same elevation as the pavement. Often the elevation of the drive is not specified. The instruction, “Match to existing grade,” appears on existing drives. Use spot elevations, or topo lines when

present to establish the drive elevation beyond the pavement.

Unmountable curbs are “cut” at drives and ramped sidewalks. These curb cuts are usually tapered where they meet the drive or sidewalk. Additional entities are required to show a curb cut. The entities used to establish the top of curb must follow the tapered section. When the surface is created, ensure that a vertex is located at the beginning of the taper.

Medians are typically dimensioned on a separate detail sheet. Additional information may appear on the cross section. Horizontal data for medians can be obtained from the plan view. Use the median details to establish the vertical dimensions of the median, and then match the pavement elevations. Similarly, islands are treated in the same manner.

Lane striping seldom appears on construction plans. Separate striping plans and signage plans are drawn. Determine if pavement striping is present, and will be included in the environment. The striping must be

created from surfaces, else it will not be visible in the environment.

Lane stripes can be created by several means. The desired method will depend upon the software used to create the environment. The striping can be placed above the pavement, or be a part of the pavement surface. The first method requires that the striping be placed slightly above the surface so that the pavement color does not “bleed” into the striping. However, if it is placed too high, it will be noticeably above the pavement. Additionally, if tiremarks cross the striping, its object attribute type must be set to road or friction zone, else the tiremarks will not appear over the striping.

Lane stripes can be made part of the pavement surface. Some modeling software permits the user to trim or break out a surface. Create the entities necessary to define the edges of the

striping, and trim the pavement surface in these areas. Create or break out the surface for the lane striping and change the color as desired.

When this modeling tool is not available, establish the location of the striping edges when creating the cross sections. Connect these points as if it were a separate surface. Use these entities to create the striping surfaces.

Conclusion

This paper has presented a method for building a three-dimensional virtual environment for use within HVE utilizing *As-Built* roadway plans. The paper illustrates that an accurate environment can be constructed when it is impractical or impossible to have a total station survey made of a collision site.