

AutoCAD Civil 3D 2008

Grading Best Practices

Autodesk®

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Grading Best Practices

The surface modeling tools in AutoCAD® Civil 3D® software include generic ones such as points and breaklines, as well as purpose-built site grading tools for grading with feature lines and projected slopes. Understanding the strengths and limitations of each tool—and learning how to use them together—is a major part of learning best practices in grading.

In this chapter

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- [Feature Line Grading](#)
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Overview

Feature line grading involves creating a set of feature lines to define the graded region as surface breaklines, and then adjusting the elevation of key points to control the shape of the surface. This technique is ideal for wide, fairly flat areas such as parking lots or building pads. It is also well suited to areas with rapidly changing elevations or slopes where walls would normally be required to grade successfully. You can manually add or remove feature lines and adjust their location in three dimensions to achieve precise slope design. This process enables you to control water drainage or clean up difficult geometry in areas such as the intersection of two or more slopes.

Slope grading involves projecting a slope from a feature line to an intersection with a surface, or to a specified distance, elevation or elevation difference. This technique allows you to calculate proposed feature lines based on a number of criteria. A major benefit of projection grading is that the resulting grading projects remain true to the original criteria if the base feature line is edited. Additionally, the criteria can be edited and the grading model reflects the change. This technique works best when relationships between feature lines need to be maintained.

This goal of this paper is to explain some techniques for using each of these tools to get optimal results from AutoCAD Civil 3D.

Feature Line Grading

Feature lines are like an advanced 3D polyline, with the following differences:

- They support true geometric arcs.
- They interact with each other. Where two feature lines intersect at a point, editing the elevation of the point edits the elevation of both feature lines.
- They have much better editing support than 3D polylines.

Sites

A site is a collection of objects that are topologically related. The Civil 3D objects that can be included in a site are feature lines, parcel lot lines, and alignments. When you create any of these objects, you must specify a site. A key point to remember is that when objects in the same site intersect, they

acquire the same elevation at the crossing point, similar to crossing breaklines in a surface. If you want to create overlapping objects that do not interact this way, you can simply assign them to different sites. Let's look at some of the interaction of objects within a site.

Feature Lines

You can use multiple sites to manage feature lines in distinct groups. The Move to Site and Copy to Site commands are helpful in this process. For example, you can copy feature lines to another site, then lower them to create a subsurface.

Lot Lines

Traditionally, lot lines are thought of as 2D representations of parcels. However, in Civil 3D, lot lines can also have elevations and can be used in building a grading model. Feature line editing commands are used to assign elevations, including at intermediate elevation points. Lot lines interact with feature lines, sharing elevations at common points. They can also be added to surfaces as breaklines. When you display the lot lines, you can choose to use the elevations of the objects or you can flatten the elevations to a specific elevation. This option is available in Site Properties.

It is not always desirable to use lot lines directly for grading work. Inserting elevation points, or intersecting feature lines with lot lines creates break points in the lot line geometry, which affects labels. A lot line crossed by a feature line is split into two segments with separate labels. On a small site, it may be acceptable to use a mix of lot lines and feature lines in your grading site, ignoring the parcels that are created. But you can provide greater clarity in the design by preventing the interaction of lot lines with feature lines, using separate sites for parcel geometry and grading features. One approach is to replace the lot lines with feature lines in the grading site. There are several methods of doing this:

- If you created the lot lines from AutoCAD entities, use the same entities to create feature lines in the grading site.
- Copy the lot lines to the grading site, then explode these lot lines, turning them into AutoCAD entities. Then use grading tools to convert some or all of the lot lines into feature lines

- For a small site, trace the lot lines with AutoCAD entities to convert to feature lines, or use the Draw Feature Line command.

Alignments

Alignments don't have elevations assigned to them directly, but obtain elevations from a profile model. As with lot lines, alignments interact with feature lines in the same site. The most common problem is a split point created where a feature line crosses an alignment, and both objects acquire the same elevation at that point. Split points are more fully explained in the next section, "Point Types."

The recommended procedure when creating alignments is to not assign them to a site. This prevents interaction between alignments, feature lines, and parcels. For Civil 3D 2008, the default alignment creation options provide this behavior.

Point Types

The primary point that defines the geometry of the feature lines is called a point of intersection or PI. It is represented by a triangle symbol in the Elevation Editor, or when using a feature line editing command. The PI appears as a standard square grip when grip editing a feature line.

Elevation points can be inserted along a feature line to define grade breaks. They do not break the horizontal geometry of the feature line. They are represented by the circle symbol for both the feature line commands and grip editing. When grip editing, an elevation point can be dragged to a different position along the feature line.

Where two feature lines cross at a location where neither one has a PI point, a **split point** is created. This is shown in the editor with a white triangle, rather than a green PI triangle.

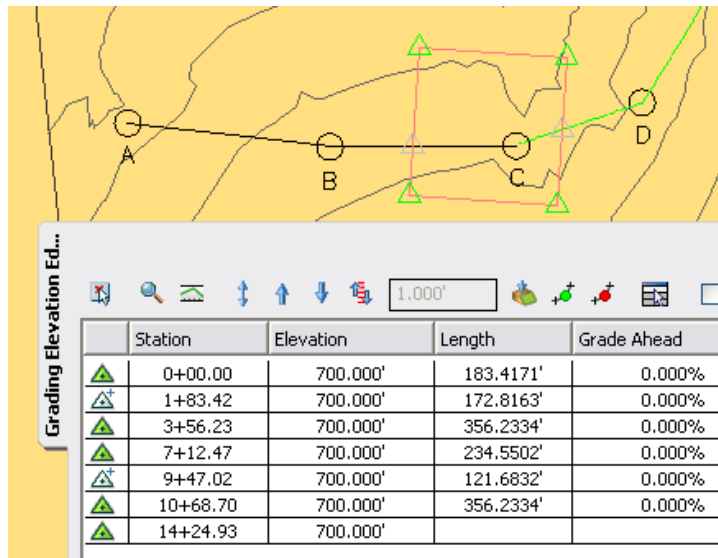


Figure 1: Elevation Editor, showing two split points

In Figure 1, the Elevation Editor shows the elevations for the square feature lines, including two split points where these lines cross feature lines BC and CD. In the Elevation Editor, the point symbol in the first column includes a plus sign (+) at any point that intersects with another feature line.

When feature lines within the same site cross each other and create a split point, that point acquires the elevation of the feature line that was last edited—commonly known as the “last one wins” rule. If the other feature line has a different elevation, it gets a grade break at the crossing point.

At split points there isn't an actual point, so you can't directly edit the elevation. When you edit one of the feature lines, its grade runs straight through the intersection, forcing the other feature line to break at the split point. If you create a feature line from AutoCAD entities, without assigning elevations, the new line has a default elevation of zero (0). To edit the elevation of a split point directly, or to have better control over that point, you can use the Insert PI command to create a permanent point at that location on one of the feature lines.

Feature Line Break/Trim/Extend

While the AutoCAD Extend command works with feature lines, they cannot be edited with AutoCAD Break or Trim commands because feature lines are too complex. To overcome this problem, dedicated feature line Break and Trim commands have been added to the Edit Feature Lines menu and toolbar, as shown in figure 2.

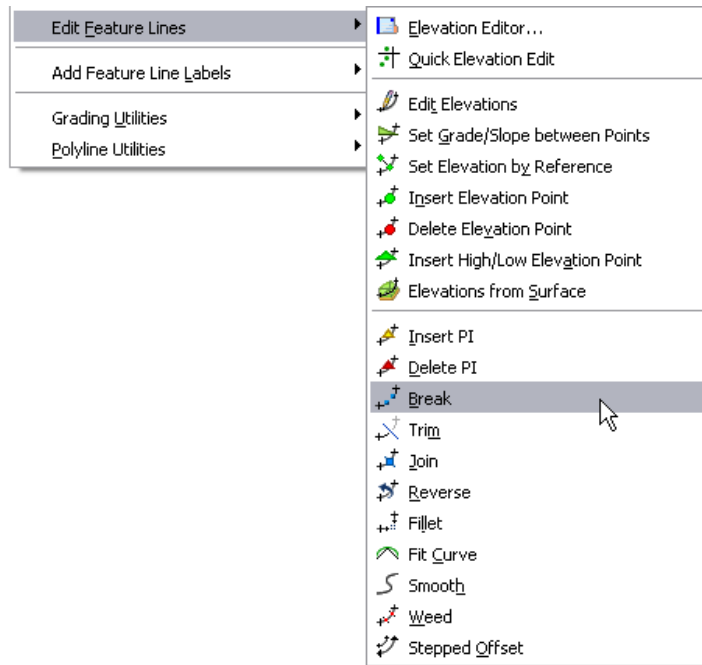


Figure 2: Feature line editing commands

These commands give you precise control over both simple and complex feature line editing operations.

Feature Line Move

When editing feature line elevations, the preferred method is to use the grading feature line tools, such as the Elevation Editor, which provides reliable controls for incrementally raising or lowering an entire line or specified points. AutoCAD commands such as MOVE and OSNAP can give undesirable results

unless used carefully. For instance, an accidental OSNAP to an object at elevation 0 will set the elevation to 0. However, the AutoCAD MOVE command is the standard way to move a feature line horizontally.

Feature Line Smoothing

A feature line created from a tessellated (segmented) polyline can be smoothed to a series of curves or a true geometric arc, as shown in figure 3.

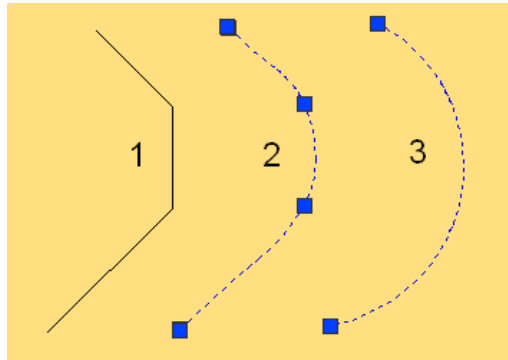


Figure 3: Comparing a smoothed line with a fitted arc

Polyline 1 on the left is smoothed on the right, using feature line editing commands as shown in figure 2. Line 2 was created with the Smooth command. When selected, it retains the four grips of a polyline. This type of line always retains tangency to the adjoining lines, and it can be adjusted to form a complex set of arcs, such as when you need to create an aesthetically pleasing landscape design. If you label this line, you can obtain the precise arc parameters for layout on the ground. Line 3 was created using the Fit Curve command. In this case, the three segments have been converted to a single arc. If you grip edit this arc, it does not always retain tangency with the adjoining lines. The single arc can be easier to lay out and usually results in a simpler grading design.

When creating gradings from corridor feature lines, the corridor command `CreateGradingFeatureLine` is very useful. This command has a new setting for AutoCAD Civil 3D 2008. As shown in figure 4, the setting, Feature Line Export Options, allows you to specify whether to smooth the feature line when it is exported.

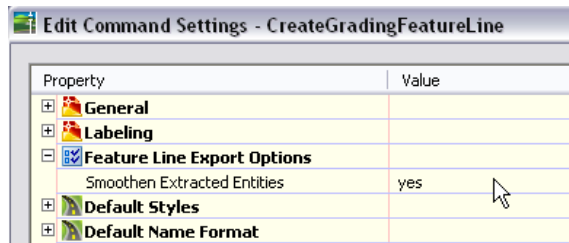


Figure 4: Command setting to smooth corridor feature lines for grading

Duplicate and Crossing Feature Lines

Feature lines in the same site can only have one elevation at a crossing point. If two feature lines approach within a tolerance distance of 0.0001, the points collapse to a single point. If feature lines are so close that they do not collapse but are very nearly overlapping, the topology model becomes much more difficult to represent. In these cases the model creates very small “sliver” enclosed areas, analogous to sliver triangles in a surface TIN model.

In most cases, sliver areas are not a problem, but excessive overlapping can be difficult to model in the topology and can extend the surface processing time. In particular, this can happen when you have multiple feature lines overlapping with slightly different geometry. Also, arcs tend to have more problems than lines when resolving overlapping geometry. Keep this in mind when creating feature lines for your grading plan. In general, if you are trying to represent duplicate feature lines, it is a good practice to put them in unique sites. Otherwise, visually inspect the feature lines within a site and remove any that are nearly tangent and not required. You should also keep these practices in mind when creating lot lines and alignments.

Feature Line Labels

Feature lines are labeled using the general multipurpose line and curve label style Grade Only. In some drawing templates, the default behavior of this label style shows the grade with a direction arrow that points in the forward direction of the feature line.

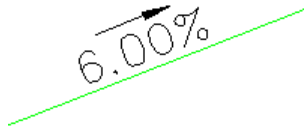


Figure 5: Default display of a Grade Only label on a feature line

By means of an expression, you can configure the direction arrows in this label style to point in the downhill grade direction, which may be more useful. To do this, edit the Arrow component of the Grade Only style, as shown in figure 6.

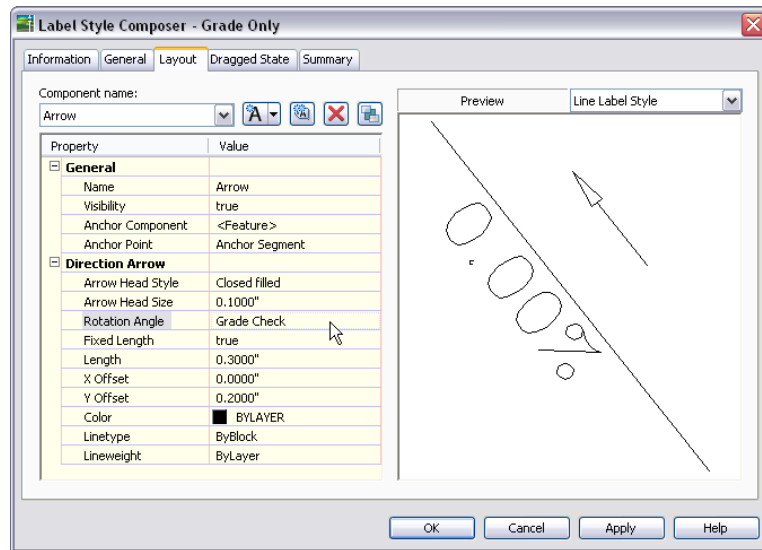


Figure 6: Configuring Grade Check arrows in Grade Only label style

In the Label Style Composer, in the Rotation Angle property, select Grade Check for the value, and then apply the change. Arrows on the Grade Only labels will point in the downhill direction.

Projection Grading

The grading projection is constructed from feature lines. As shown in figure 7, the controlling feature line to which a grading is attached is called the

footprint. This feature can be edited using the feature line commands. The grading projection creates another line at the outer edge, known as a daylight line. Depending on the grading criteria, the daylight can be at a specified elevation, distance, or where the grading meets the existing surface. The daylight line is controlled by the grading object and cannot be edited directly.

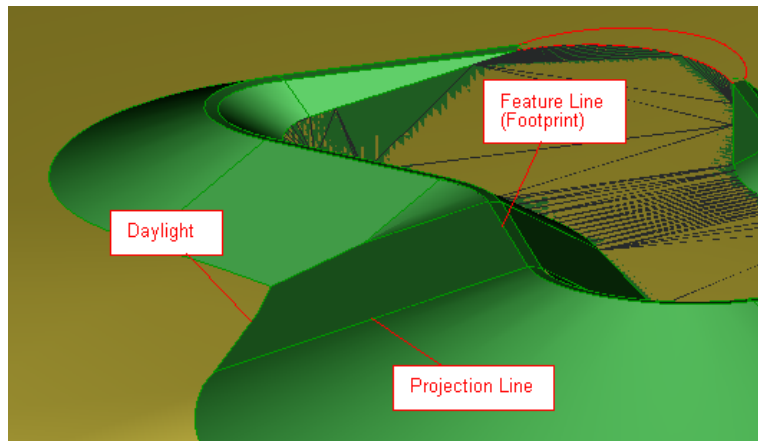


Figure 7: Parts of a grading object, shown on a 3D solid

Projection lines connect the footprint to the daylight line at key design points, such as the start and end of transitions. These projection lines are created with non-editable feature lines. The grading has a 3D solid that is used to shade the surface and appears automatically in a 3D view. This can be used to view the grading without creating a terrain model.

How Projection Grading Works

Grading algorithms used in some commercial civil engineering products employ a simple method of ray projection. A ray is simply projected from the footprint at the given criteria to find the intersection with the surface. This method does not fully resolve situations where the grading intersects itself in 3D, such as in a tight inside corner, or where the grading is projecting past the radius of the footprint, as shown in figure 8.

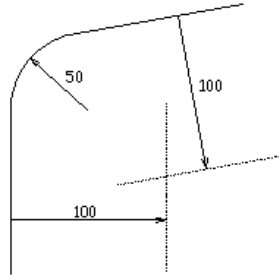


Figure 8: Projecting past the radius of a footprint

Figure 8 shows a case in which the footprint has a rounded corner with a radius of 50 feet. Gradings are projected out 100 feet to the surface, and the gradings along two adjacent sides intersect far from the corner. The region of intersection can be quite complicated if the two segments have different footprint elevations or slope projections, resulting in ambiguous elevations where they meet.

Boundary Representation

AutoCAD Civil 3D slope grading uses a technique known as boundary representation, or b-Rep modeling. For each segment of the footprint, a bounded cone, plane, or spline region is created to match the grading criteria for that segment. These pieces are intersected against each other, and the resulting pieces are joined together in order to create a grading with real 3D intelligence.

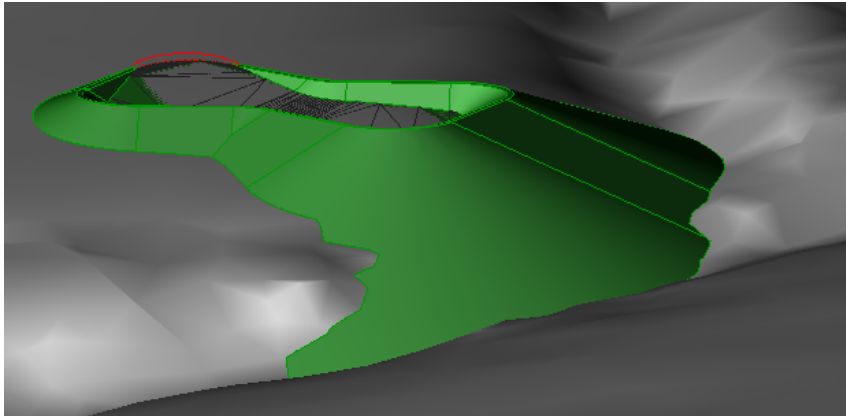


Figure 9: Corner of a large projection grading

Figure 9 shows exactly how the cone on the outside corner of a pond intersects with the surface. Notice that you cannot draw a straight projection line from the footprint to the part of the grading that flows along the valley in the lower left. A simple ray projection algorithm would not generate this part of the solution, because it would find only the first ray intersection with the surface, at a higher elevation. By showing accurate results of the grading criteria, Civil 3D makes it easier for engineers to see important details and explore realistic design options. For example, in this case we can see that a retaining wall could prevent the grading from flowing along the valley, and we could revise the design to include such a wall.

Finding a good solution becomes more difficult if the grading segments do not intersect each other fully. AutoCAD Civil 3D uses straightening and averaging algorithms to handle these and other problem spots in a second computing pass. While the 2D daylight is reasonably clear in most cases, finding the complete 3D edited solution can be much more complicated. Another complicating factor is the limited precision with which computers can calculate intersections. For these reasons, short segments and shallow angles can also be problematic.

Case Study: Two Intersecting Gradings

We can learn more about how Civil 3D creates gradings by looking at some examples of grading intersection. Figure 10 shows the top view of two overlapping gradings. The segment on the left has a grade of 0%, and the one on the right has a steep grade of 100% with a cross-slope of 2:1.

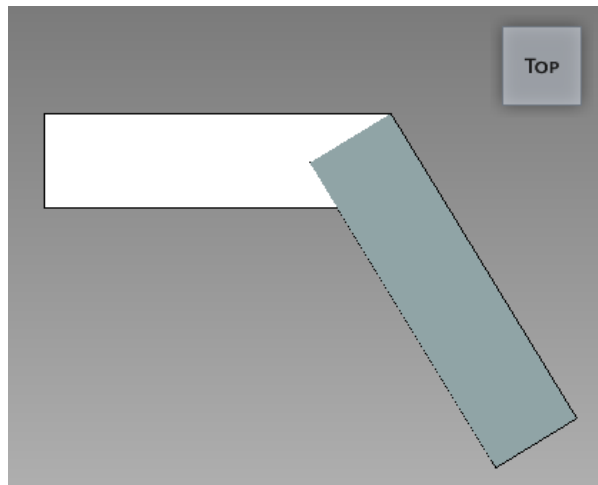


Figure 10: Top view of two intersecting gradings

Figure 11 shows a side view of the gradings, which reveals that they have only a single point of intersection. This results in a “chasing grade” situation between the two segments, without a mathematical intersection line between the two patches, except for the degenerate intersection at the corner point.

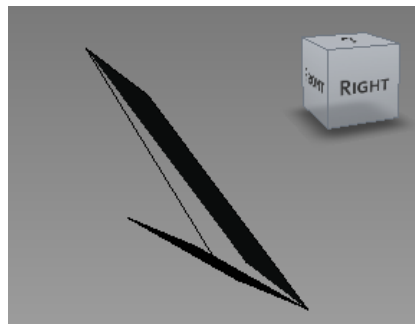


Figure 11: Side view of two intersecting gradings

The slopes and grades were exaggerated for this example in order to show the problem more clearly, but a similar problem can easily happen any time the slope along the footprint exceeds the cross slope. If two gradings do not intersect, AutoCAD Civil 3D can handle the problem by averaging the slopes and elevations in the intersection zone. This effectively transitions the cross slope in most cases, as shown in figure 12.

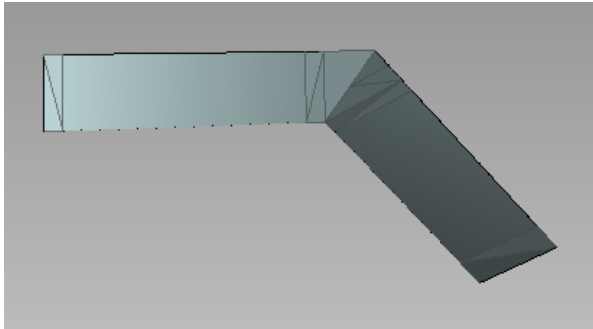


Figure 12: Calculated transition for two intersecting gradings

This situation is very common in real-world grading scenarios. In particular, it occurs when grading to the inside of a footprint where elevations of the footprint vary. Similar grading intersection problems can also occur when transitioning around inside corners.

Case Study: Three Intersecting Gradings

When more than two patches overlap each other from the top view, but do not intersect completely in 3D, finding a solution gets increasingly complex. Consider the example in figure 13.

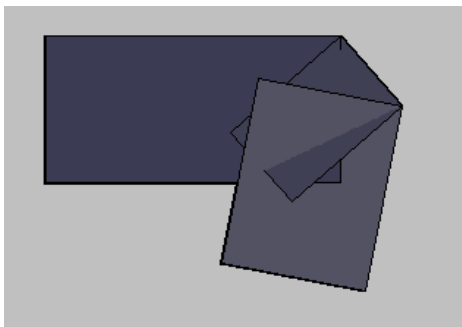


Figure 13: Plan view of three intersecting gradings

If you look closely from the side, you can see that two of the patches don't intersect at all, and the other intersections are incomplete.

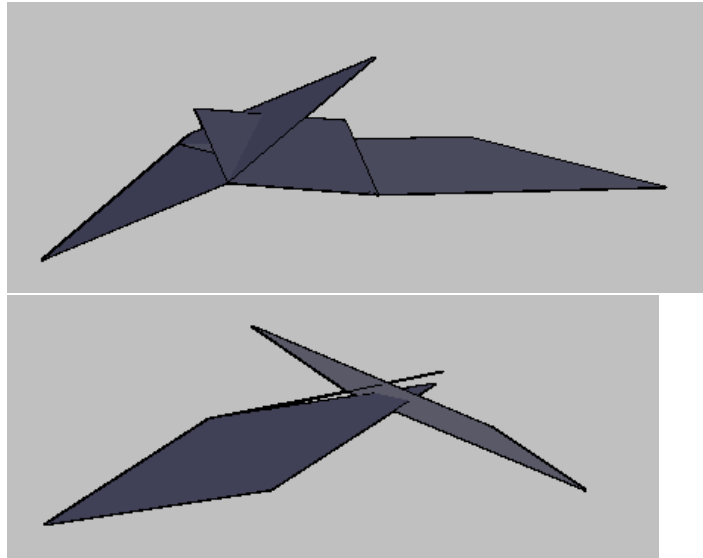


Figure 14: Side views of three intersecting gradings

In this case, Civil 3D is able to resolve the conflict through a process of elevation averaging, but as the ambiguous region becomes more complex, the resolution gets more difficult. Figure 15 shows the cleaned up 3D view of the three intersecting gradings.

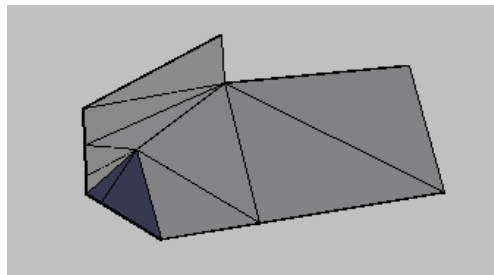


Figure 15: Calculated transition for three intersecting gradings

Preparing the Footprint

The previous section offered some insight into how AutoCAD Civil 3D models complex geometries. With these concepts in mind, there are a number of best

practices to use in preparing a footprint for grading. For example, you can use feature line editing tools in AutoCAD Civil 3D to clean up and simplify feature lines. Some of the best practices are as follows:

- Use the Elevation Editor to verify the elevations along feature lines. Look for locations where an elevation may unintentionally drop to zero, such as at a split point.
- Use the Weed command (WeedFeatures) to remove unnecessary points and simplify grading geometry where possible. This operation can significantly improve the results where two or more gradings intersect.
- Use the Fit curve command (FitCurveFeature) to replace tessellated segments with an arc. This operation creates a smoothly curved grading face, rather than many short straight segments. Tessellated segments are common with feature lines created from 3D polylines that don't have arc support, such as those created with the Land Desktop grading commands.

Figure 16 shows the dialog box for configuring the weeding operation. You can specify which weeding factors to apply, adjust the numeric values, and preview the results before committing. In the example shown in figure 16, note the report near the bottom of the dialog box that “52 of 90 vertices will be weeded.” When all four check boxes were selected, only one vertex would have been removed. By pressing the Help button on this dialog box, you can see the Help topic for weeding and learn how to use these controls for best results.

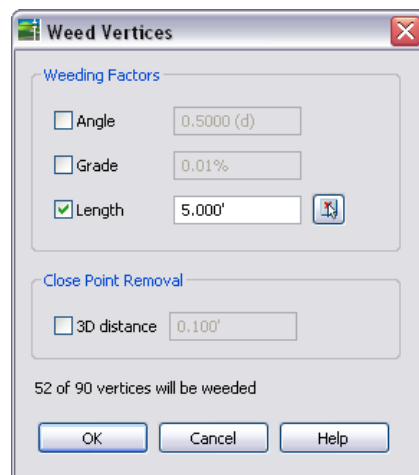


Figure 16: Weeding controls

The grading in figure 17 on the left is graded to the inside of a curve that has been tessellated by line segments. The grading on the right is graded from a true arc. As you can see, the edited shape of the true arc is a more realistic grading.

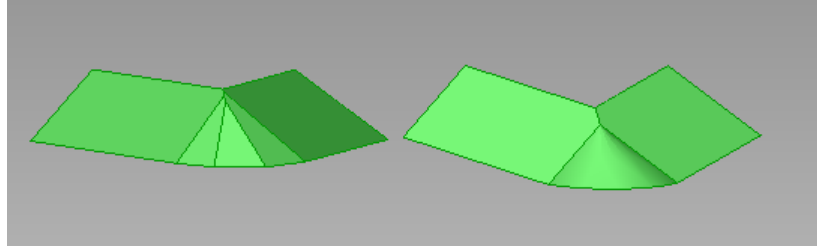


Figure 17: Grading a segmented curve versus a true arc

You can use the Smooth command to convert a tessellated feature line to a true arc, similar to the polyline fit curve.

Grading to a Surface or Absolute Elevation

Grading to an absolute elevation is treated as though you were grading to a flat surface at that elevation. If you are unsure of a grading's ability to intersect with the surface, start with a steeper slope, then edit to a flatter slope.

Grading to Distance, Relative Elevation, or Stepped Offset

Grading design often makes use of offset feature lines for features such as curbs and ditches. You can create these in two general ways, depending on whether you want the secondary line to be dependent or independent of the footprint:

- Grading to a distance or to a relative elevation creates a dependent parallel line linked to the footprint. In this case, editing the footprint also updates the offset line.
- Using the Stepped Offset command creates an independent parallel line that can be edited separately from the footprint.

Grading Group Surfaces

When the Automatic Surface Creation option is turned on, a surface is generated from the gradings. Any curves on the gradings are tessellated using the grading group tessellation settings. The grading group is added to the surface as a single operation. It appears in the Surface Properties, on the Definition page, in the lower Operation Type box. By default, Automatic Rebuild is turned on for the grading surface. When working on large grading groups in large drawings, you can turn this option off to get better performance. Additional surface data, such as points or breaklines, can be added to the grading group surface using the Surface Data commands. The creation of the Automatic Surface can be turned on or off as necessary.

You can also create a detached surface from a grading group by converting the grading information into breaklines. Once created, a detached surface is no longer linked to the grading group, so it will not update with changes to the gradings. When surfaces are created from grading groups, boundaries are created around the gradings so that the surface represents the exact definition of the gradings. If the grading closes around on itself, this creates a hole in the surface. To fill in the hole, create grading infill. A grading infill can be created in any region that is entirely enclosed by feature lines.

Slope Patterns

When refining a particular grading solution, you can improve system performance by temporarily turning off automatic surface rebuilding, and editing the grading style to turn off slope shading and slope patterns. These operations take extra time, and add extra complexity to the grading process. If the base grading doesn't have a good solution, these operations will also have trouble completing correctly.

Explode

If a grading object is exploded, the projection lines and daylight lines become editable feature lines. You can do this to modify projection lines or a daylight line, then add them to the design surface as breaklines for use in an existing or new grading.

Exploding the grading object creates a closed polyline that includes the footprint, projection lines, and daylight, so it completely bounds the face.

Exploding the daylight alone creates a polyline from the daylight. Whether 2D or 3D polylines are created is determined by the Site Display Mode site property, which specifies either “flatten to elevation” or “use elevation.” On the other hand, using the ERASE or EXPLODE command on the footprint preserves the daylight as a feature line, but not the projection lines.

Using Feature Lines and Projection Grading Together

Sometimes, inside corners are simply not well suited to a projection grading solution. In reality, the projection grading result is often different from what will be constructed in the field. Let's look at a building footprint example to illustrate a technique for using the best of both feature line tools and projection grading tools.

We start with a building pad that already has the basic elevations assigned. In this case, the top portion of the pad is at an elevation of 402 feet and the bottom portion is at 400 feet.

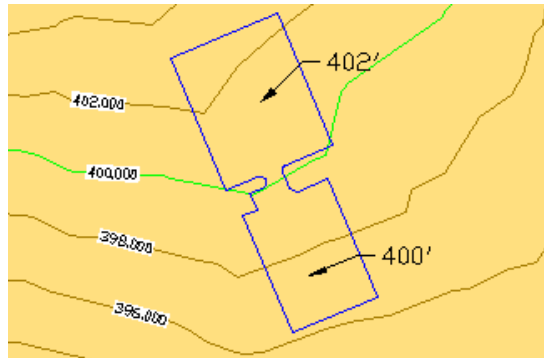


Figure 18: Building pad overview

In this case, let's assume that we want to create a 1.5-foot shoulder around the pad, and then grade into the existing ground surface at -1%. At first, it might seem like slope grading is the ideal choice for both of these tasks; however, the area around the ramp needs more control than slope grading alone can provide. Let's look at what happens when we try to apply the first criteria to this footprint, grading to a distance of 1.5 feet.

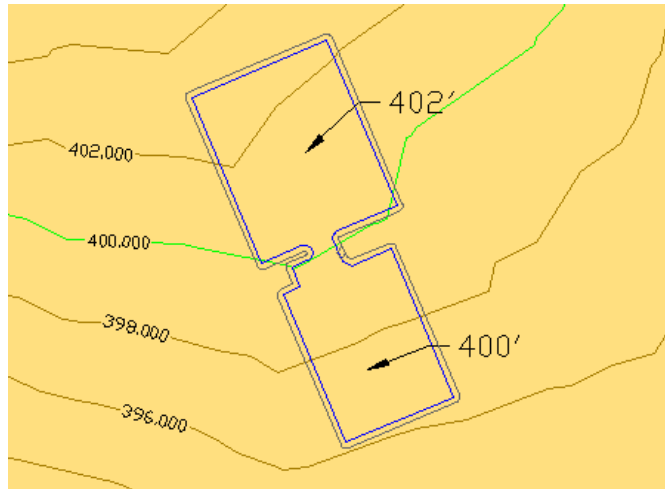


Figure 19: Building pad with slope grading

The 2D view in figure 19 looks fine, but notice in the 3D view of figure 20 how the grade twists in near the ramp:

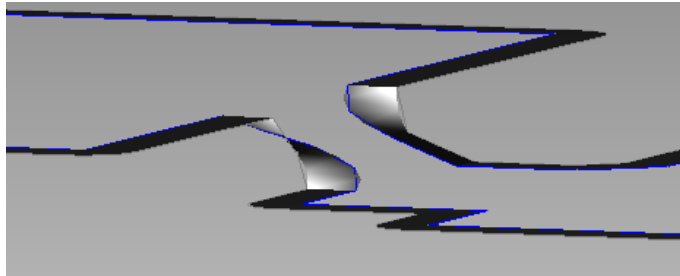


Figure 20: Grade twists beside the ramp

Because the ramp is steeper than the specified 1% cross-slope, there isn't a good way for slope grading to resolve this condition within the given constraints. More importantly, the inner portion of the shoulder is now substantially steeper than 2:1, so the problem will be exaggerated when we try to grade to the surface.

What we need is more detailed control of this region than slope grading allows. Because the daylight of a slope grading is controlled entirely by the criteria, it can't be edited other than by changing the criteria of the grading. Instead, we can use the Stepped Offset command to generate a daylight line that we can edit manually to resolve the area around the ramp. First, we run the

stepped offset command with the same parameters that were given to the slope grading (1.5' at -1%). This initial step yields essentially the same daylight solution as the slope graded version. However, because this is a stepped offset, we can use the full set of feature line editing tools to refine the solution. Next, we use the feature line Fillet command with a radius of 15' to create a smooth fillet between the corners of the two pads, as shown in figure 21.

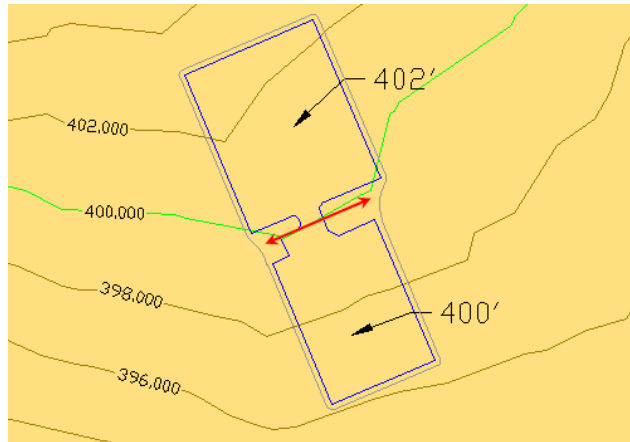


Figure 21: Fillets inserted on each side of the ramp

Notice that the feature line fillet uses the elevations from the existing feature line, and smoothly interpolates them across the length of the fillet, as shown in figure 22.

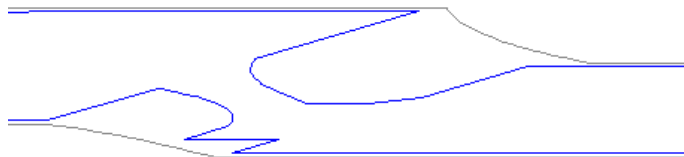


Figure 22: Fillet elevations

Several other feature line editing tools could also have been used to trim out this portion of the grading and set the desired elevations for the shoulder edge.

Now that we have a smoother feature line to grade from, we apply a 2:1 grade-to-surface criteria and create infill grading objects to handle the interior

parts. Each infill grading must be completely bounded by feature lines. Figure 23 clearly shows the diamond markers for the two infill grading objects: one for the building pads and the ramp between them, another for the perimeter of both pads and the area between the fillets and the ramp.

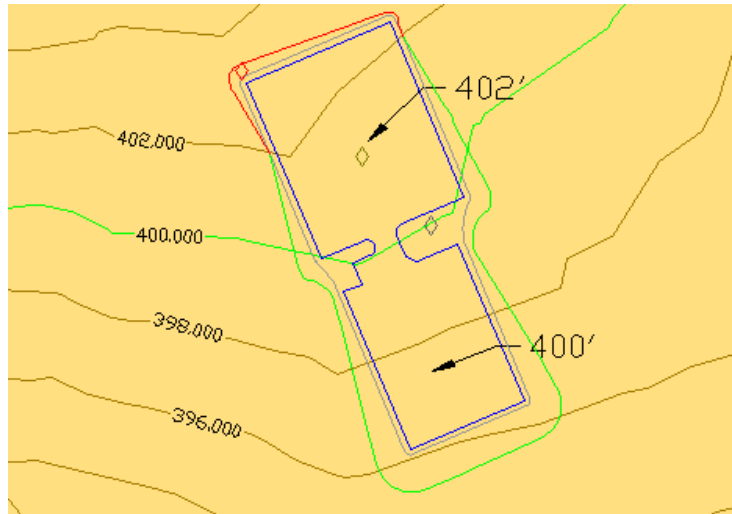


Figure 23: Project graded to the surface

Figure 24 shows the same grading in a 3D shaded view. The grey area (1) is the infill grading that represents the shoulder, the gold area (2) is the pad infill grading, and the green (3) is the slope grading to the surface.

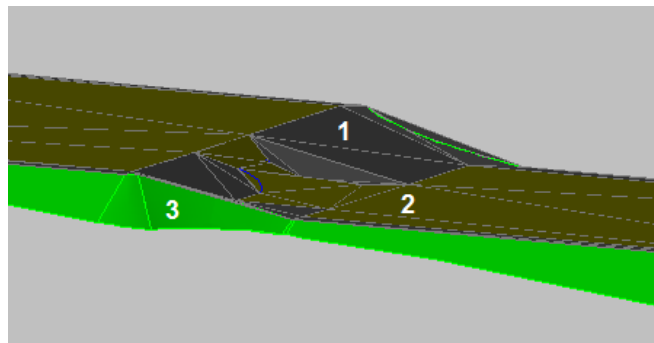


Figure 24: 3D grading

There are a couple of more details to clean up:

- The arc portion of our ramp (area 1 in figure 25) is not triangulated very well
- One of the triangles adjacent to the ramp (area 2) is steeper than we would like

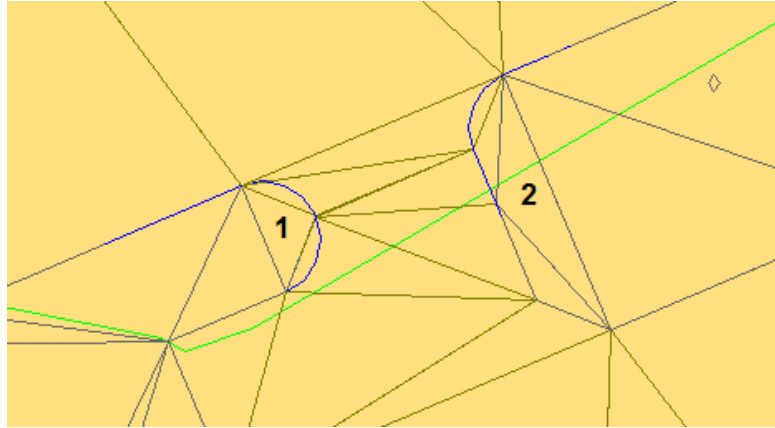


Figure 25: Triangulation issues

To fix the arc triangulation, we need to set a finer value for tessellation spacing in the grading group. As shown in figure 26, this can be difficult to find in the Grading Group Properties dialog box, because it can be set only when Automatic Surface Creation is enabled. However, this setting is also used for the Create Detached Surface command and infill grading triangulation. The trick is to turn on Automatic Surface Creation, change the tessellation spacing from the default value of 10 feet to 1 foot, then turn off Automatic Surface Creation again. You must click Apply after turning on Automatic Surface Creation in order to apply the changed settings.

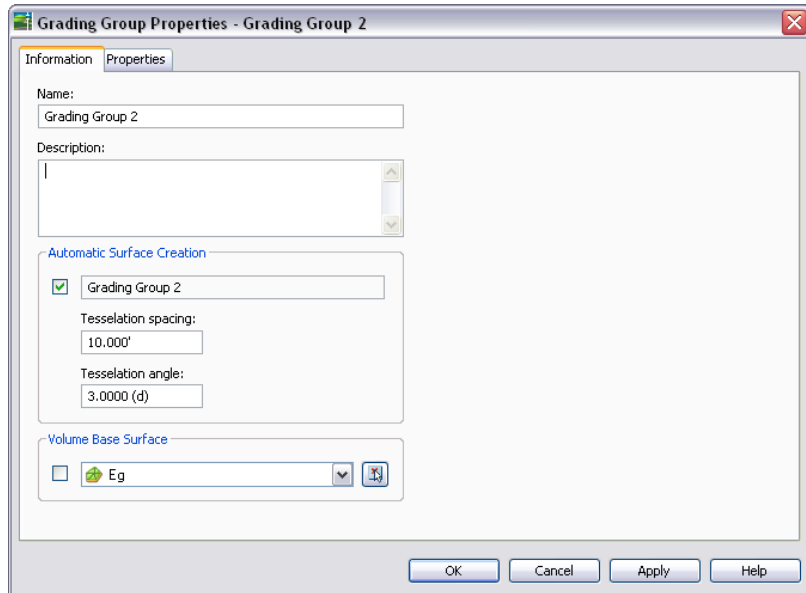


Figure 26: Changing tessellation spacing

With the tessellation spacing set correctly, you need to update the infill grading. The easiest way to do this is by selecting the interior feature line (the building pad), and using MOVE with a displacement of (0.0, 0.0, 0.0). The results are shown in figure 27.

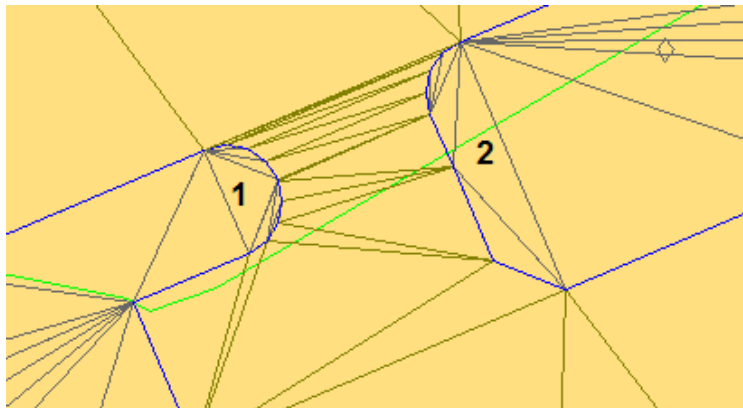


Figure 27: Improved triangulation on one side

The arcs in the ramp (area 1) are now triangulated better, but the triangles on the right side (2) are not well distributed. To handle this last issue, we will add another feature line to the infill to control the elevations in the same way that a breakline is used in a surface.

First, create a polyline in the area that needs to be fine-tuned.

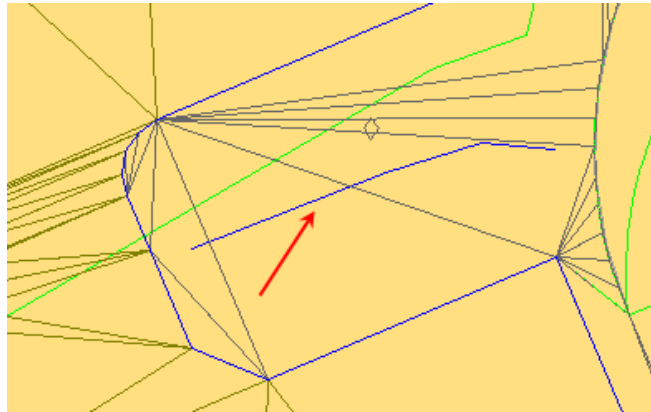


Figure 28: Feature line insertion

Then use the Create Feature Lines from Objects command. In this case, we want to assign elevations from grading objects so that the new feature line starts at reasonable elevations. There is no need to insert intermediate grade break points. The triangulation of the infill adjusts to accommodate the new feature line as shown in figure 29. Any of the feature line editing tools can now be used to precisely control this portion of the infill grading.

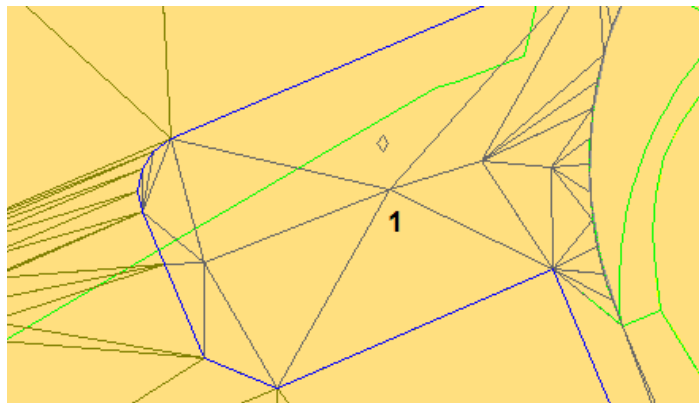


Figure 29: Resolved triangulation

Figure 30 shows the 3D view of our edited grading.

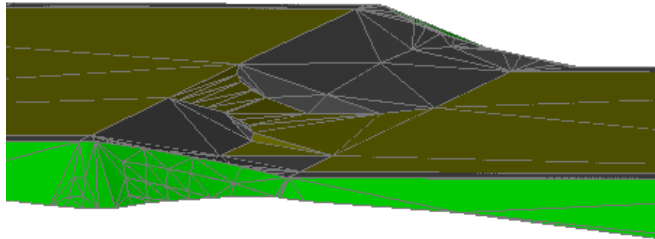


Figure 30: Final result in 3D

By using feature lines and projection grading skills together, we have demonstrated how to work through a typical design process, creating an initial grading, and then optimizing it for the specific project terrain.

Conclusion

The grading tools in AutoCAD Civil 3D software enable you to rapidly design graded surfaces, view the results in 3D, and refine the design, based on visual inspection and data analysis. The best way to get up to speed with these tools is to learn the basic operations in feature line grading and projection grading. When using feature lines, it is important to understand how they interact with other features in the same site, such as alignments and lot lines. In projection grading, best practices can involve manual editing of footprints and the regions where gradings intersect.

As demonstrated in this paper, once you understand the grading design concepts, and master the basic procedures, you can combine projections with feature lines, and use a range of operations to resolve the design challenges of a particular project.