AUTODESK®

AUTOCAD® CIVIL 2009 AND AUTOCAD® CIVIL 3D® 2009

Rule-Based Road Design using AutoCAD Civil and AutoCAD Civil 3D

Autodesk®

Contents

Introduction

AutoCAD Civil 2009 and AutoCAD Civil 3D 2009 possess the ability to analyze your road design as you work based on recognized industry standards or your own user-defined standards. As you build your design, the software will provide correction and/or notification whenever standards are not met. This capability helps provide many benefits including greater time savings, reduced rework due to fewer review comments, and more consistent quality designs. This is made possible through *design checks* and *design criteria files.*

Through design checks and design criteria files, you are able to construct dynamic criteria-based geometry. Beginning with the alignment, you can assign design criteria to the horizontal geometry of the centerline helping to ensure that minimum radius criteria are met based on design speed. Design criteria can then be assigned to superelevation settings, a property of the alignment—establishing cross-slopes throughout the design based on design speed and curve radii. Finally, design criteria can be assigned to the profile, also a child of the alignment—establishing minimum K values based on required stopping, passing, and headlight sight distance derived from design speed. These relationships and the associated design criteria result in a comprehensive, criteria-based model that will respond dynamically with each design change.

By leveraging these capabilities you will be able to produce sound designs more accurately and efficiently while helping to reduce the need for redesigns that address comments or design flaws. AutoCAD Civil and AutoCAD Civil 3D come equipped with AASHTO-based design criteria files and templates containing common design checks. For those working outside the United States, additional design criteria files can be obtained through country kits at www.autodesk.com/civil3d-countrykits. This content can be used as-is or modified to suit the needs of your designs.

The goal of this document is to help equip you with sufficient information about design criteria files and design checks so that you can begin creating your own criteria-based designs, and gaining the benefits of this powerful capability.

Design Criteria Files

As mentioned, AutoCAD Civil and AutoCAD Civil 3D come equipped with AASHTO-based design criteria files which can be used as-is, or copied and modified to suit your design needs. To create or modify design criteria files, you can use the Design Criteria Editor, which is accessible through the Alignments or Profiles menu.

The design criteria file is broken down into three major sections: Units, Alignments, and Profiles. The Units category is very straightforward, simply assigning specific units to different types of measurement such as linear, area, and speed. Alignments criteria are broken into two major categories: alignment geometry, and superelevation. The alignment geometry category is represented by the Minimum Radius Tables subsection of Alignments while Superelevation Attainment Methods and Superelevation Tables comprise the superelevation category. Profiles are addressed through the creation and application of Minimum K tables.

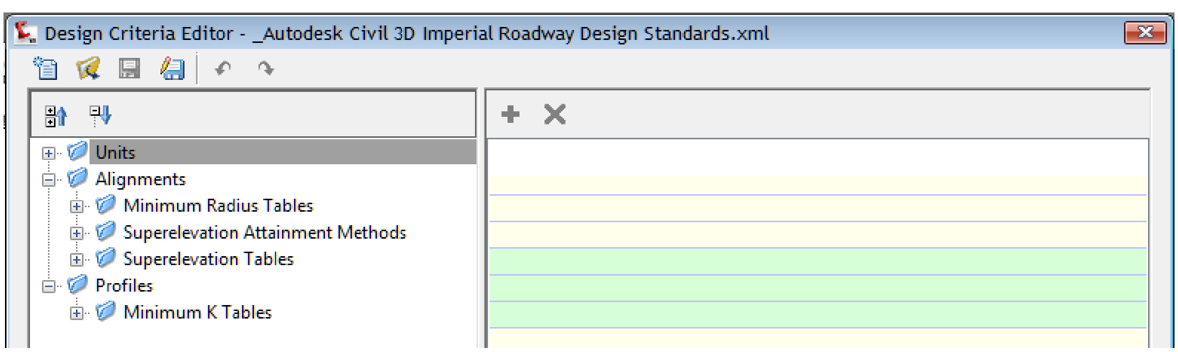


Figure 1: A view of the Design Criteria Editor showing the Units, Alignments, and Profiles sections and their associated subsections.

Based on this breakdown, the following sections will detail the three major categories of *Alignment Geometry*, *Superelevation*, and *Profile Geometry.*

Alignment Geometry

Alignment geometry is controlled through the use of Minimum Radius Tables. These tables simply establish a minimum curve radius based on design speed and maximum superelevation rates.

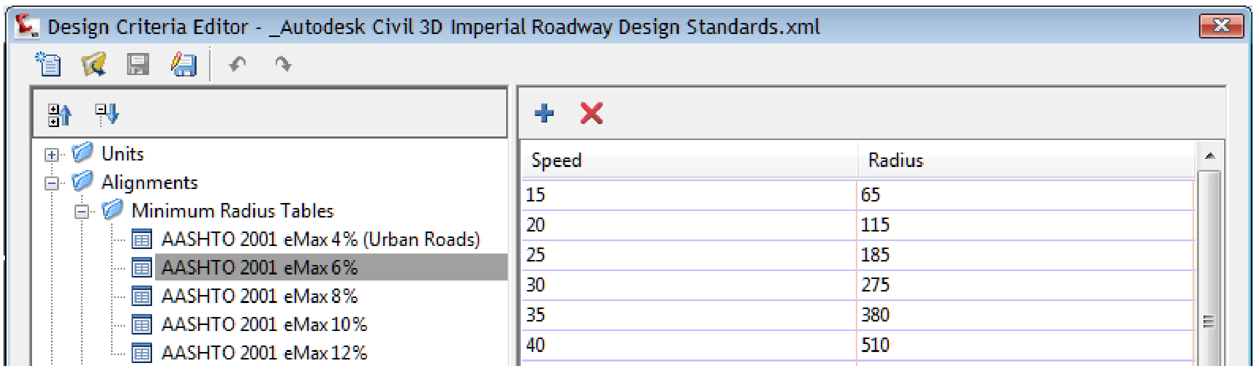


Figure 2: A view of the Design Criteria Editor showing design speeds and their associated minimum curve radii.

Applying Design Criteria Files to Alignment Geometry

To apply a design criteria file to an alignment you must first launch the Alignment Properties command and provide at least one design speed on the Design Criteria tab. Additional design speeds can be added as required by the design. Once design speeds have been established, the use of criteria-based design and the use of a design criteria file must be enabled using the appropriate check boxes. The appropriate minimum radius table is chosen to complete the process.

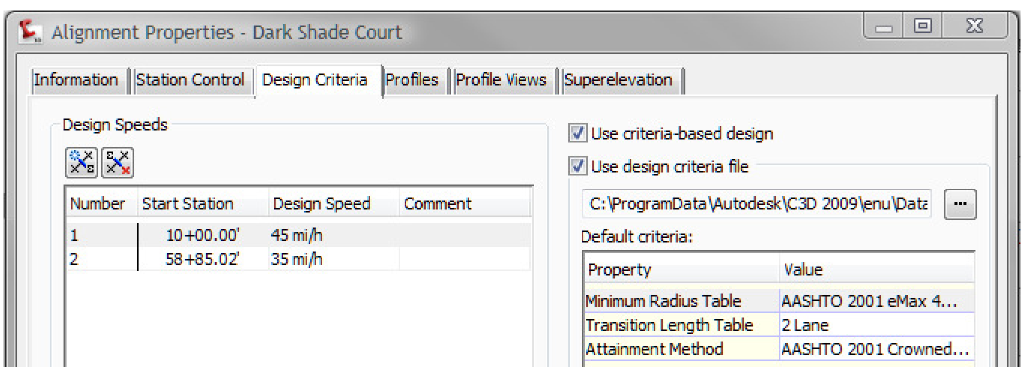


Figure 3: A view of the Design Criteria tab of the Alignment Properties dialog box. For this alignment there are two design speeds and the use of a design criteria file has been enabled by checking the two boxes at the top right.

Once the design criteria file has been assigned and enabled, there are several locations where its effects can be seen. In plan view a warning symbol will appear for any portion of the alignment that does not meet the criteria.

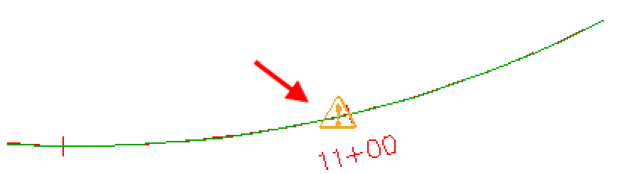


Figure 4: Warning symbol shown on an alignment indicating that one or more criteria have not been met.

In grid view, the Panorama will also display warning symbols where curve radii do not meet the criteria.

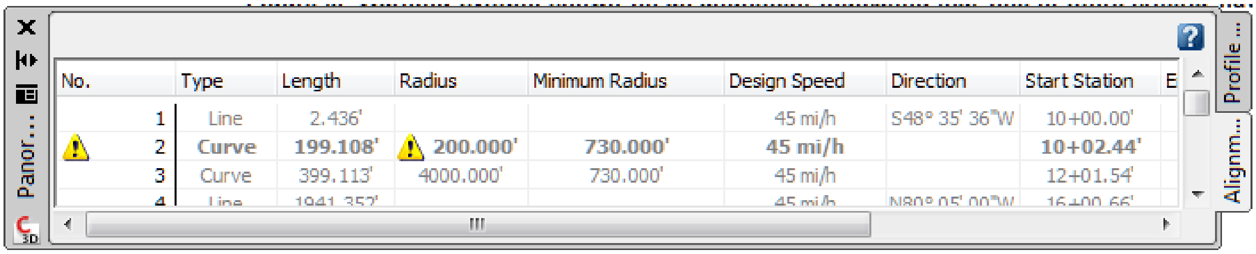


Figure 5: Warning symbols shown on the Panorama indicating that that the minimum radius criterion has not been met.

Once design issues are identified, they can quickly be resolved by the designer. When criteria are properly met, the warning symbols will disappear.

Superelevation

Superelevation is addressed in two subsections: Superelevation Attainment Methods and Superelevation Tables.

Superelevation Attainment Methods

There are two types of superelevation attainment methods; standard for crowned roadways and planar for non-crowned roadways. The attainment method uses a series of formulas to calculate the length of the transition regions that transform the road from normal crown to full superelevation. Specific variables are used to designate key values or lengths of specific regions. For example, {e} represents the full superelevation rate while NCtoLC represents the length of the transition region from normal crown (NC) to level crown (LC), a distance commonly referred to as tangent runout. {t} is a special value representing the runoff length, which is the length of roadway needed to accomplish the change in cross slope from a section with level crown to a fully superelevated section, or vice versa. This value is obtained from a table within the Superelevation Tables subsection of Alignments. Using formulas to establish relationships between {t}, {e}, and other variables, each specific transition region can be calculated.

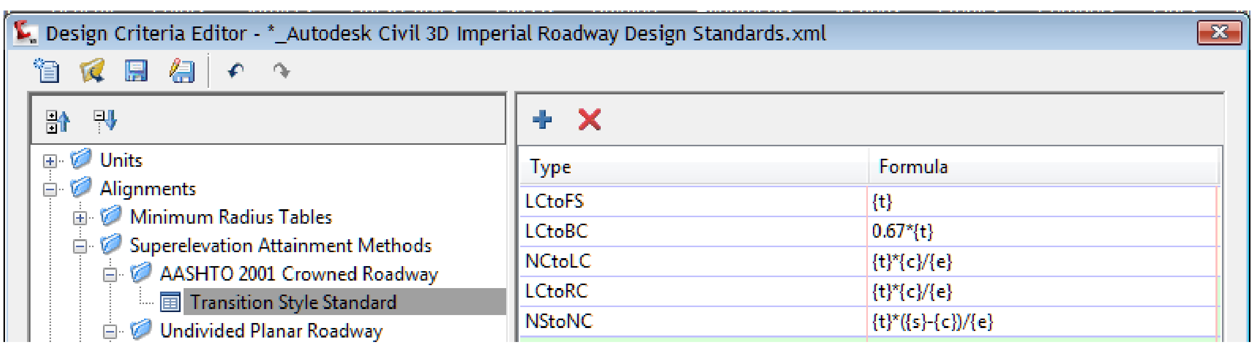


Figure 6: A view of the Design Criteria Editor showing a standard superelevation attainment method. The Type column contains a list of variables representing specific transition regions. For each region a formula is used to calculate the length.

Superelevation Tables

The Superelevation Tables section actually contains two types of tables. One contains the maximum superelevation rate {e} based on curve radius, and the other contains runoff length {t} based on curve radius. Both tables are dependent on design speed. These tables provide the {t} and {e} values needed to calculate transition lengths using the formulas provided under Superelevation Attainment Methods.

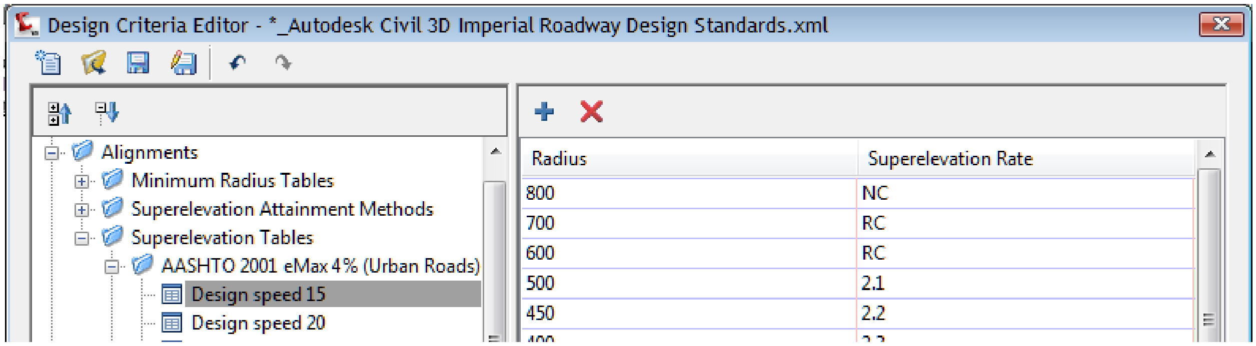


Figure 7: A view of the Design Criteria Editor showing a Superelevation Rate table. For each curve radius, a specific maximum superelevation rate {e} is assigned. NC and RC designate normal crown and reverse crown respectively.

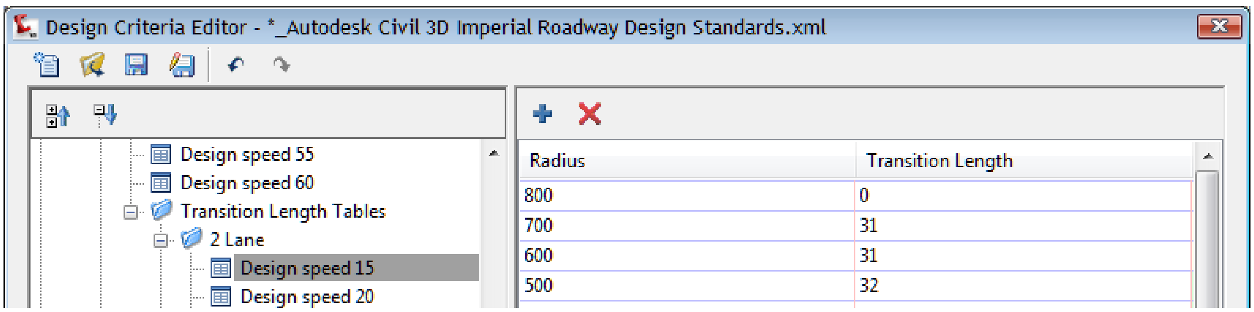


Figure 8: A view of the Design Criteria Editor showing a Transition Length Table. For each curve radius, a specific transition length {t} is assigned.

Applying Design Criteria Files to Superelevation

To apply a design criteria file to superelevation, you access the Superelevation tab of the Alignment Properties dialog box and click Set Superelevation Properties. This will launch the Superelevation Specification dialog box where you

Figure 9: A view of the Superelevation tab of the Alignment Properties dialog box as the user clicks Set Superelevation Properties.

will first notice that a superelevation region has been assigned for each curve in the alignment. Each region has a unique set of design rules allowing you to specify the design criteria file, attainment method, and tables separately. Additional default options must also be addressed such as nominal width, normal lane and shoulder slopes, various lookup methods, and shoulder superelevation method.

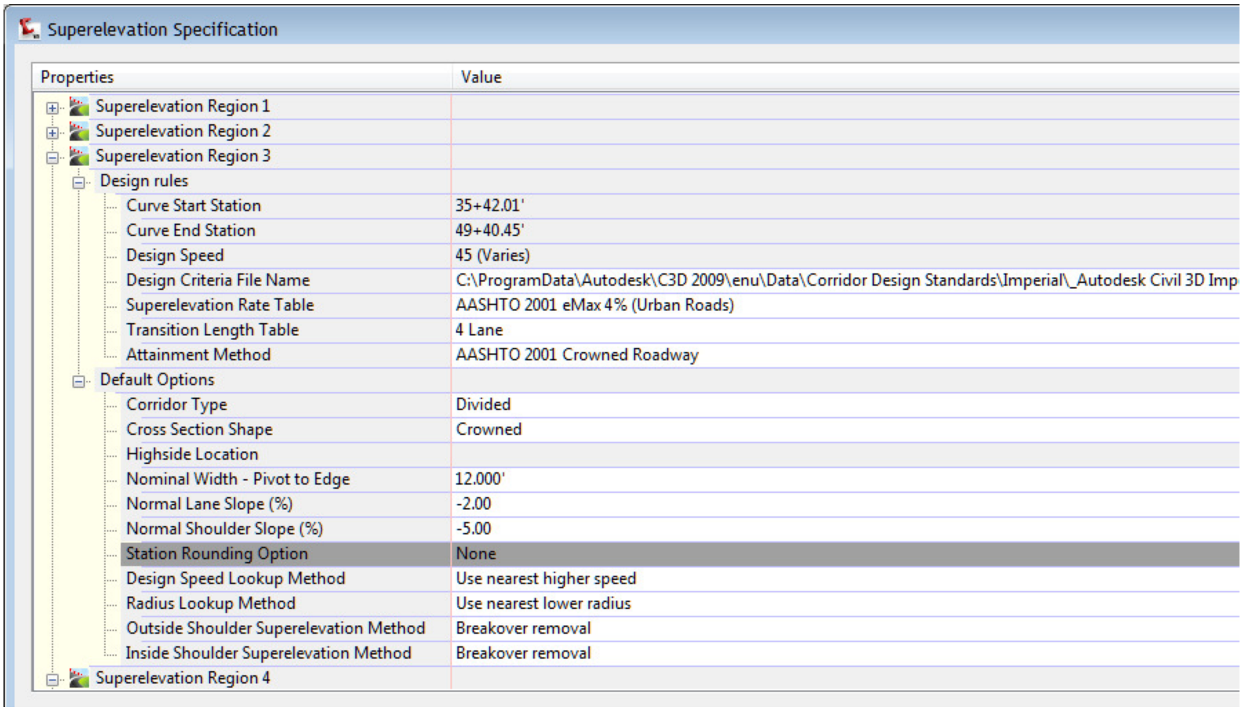


Figure 10: A view of the Superelevation Specification dialog for an alignment. Note how each superelevation region (each curve in the alignment) possesses its own configuration.

The design criteria file is applied by simply clicking OK after addressing all of the settings on the Superelevation Specification dialog box. Based on these settings, AutoCAD Civil and AutoCAD Civil 3D will automatically assign transition stations, lane slopes, and shoulder slopes, and list them on the Superelevation tab. These values can be modified once they are in place but each time the Superelevation Specification dialog is accessed, they will be overwritten with a full set of updated data.

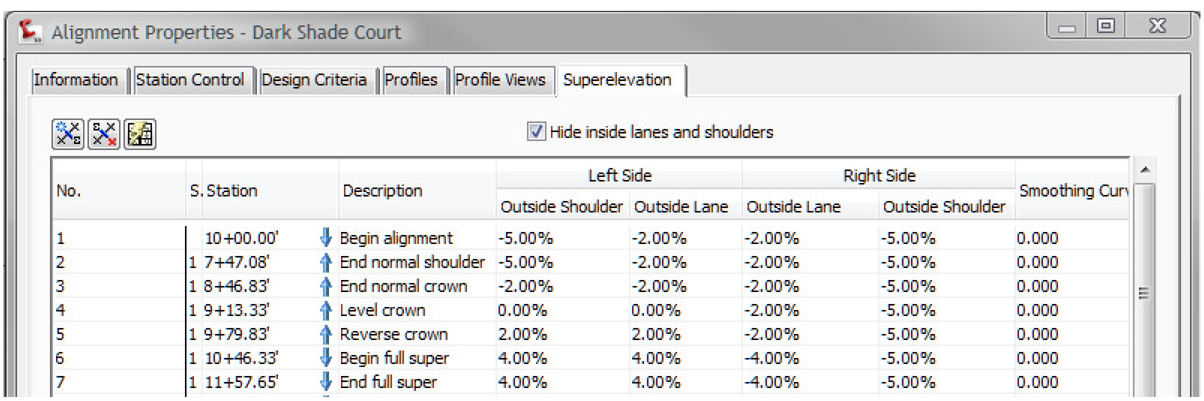


Figure 11: A view of the Superelevation tab of the Alignment Properties dialog box after accessing the Superelevation Specification dialog box.

These lane and shoulder slopes will be applied throughout the corridor for any subassemblies that are configured to respond to them.

Profile Geometry

Profile geometry is controlled through three types of minimum K tables based on stopping sight distance, passing sight distance, and headlight sight distance. K-value represents the horizontal distance along which a 1% change in grade occurs on the vertical curve.

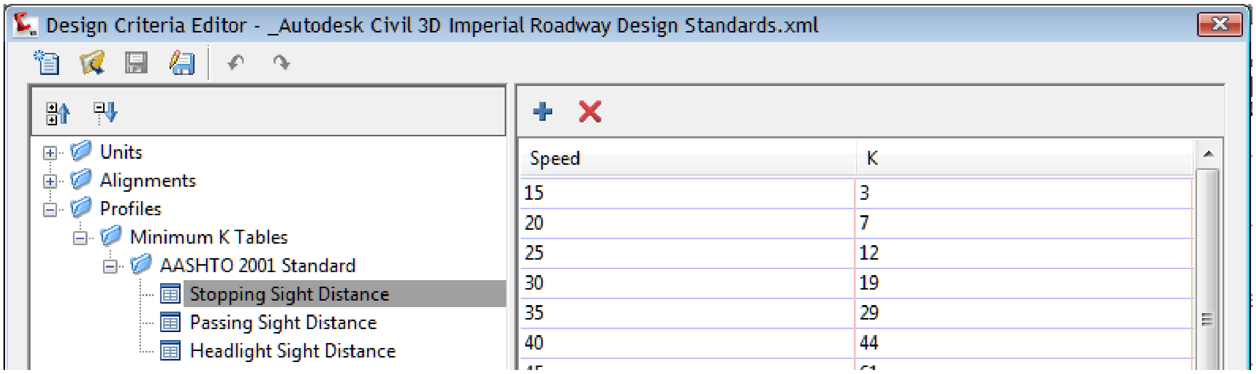


Figure 12: A view of the Design Criteria Editor showing a Minimum K Table for stopping sight distance. K values are assigned based on design speed.

Applying Design Criteria Files to Profile Geometry

To apply a design criteria file to a profile, you must access the Design Criteria tab of the Profile Properties dialog box. Here, in much the same way as for alignments, you enable criteria-based design and select the design criteria file.

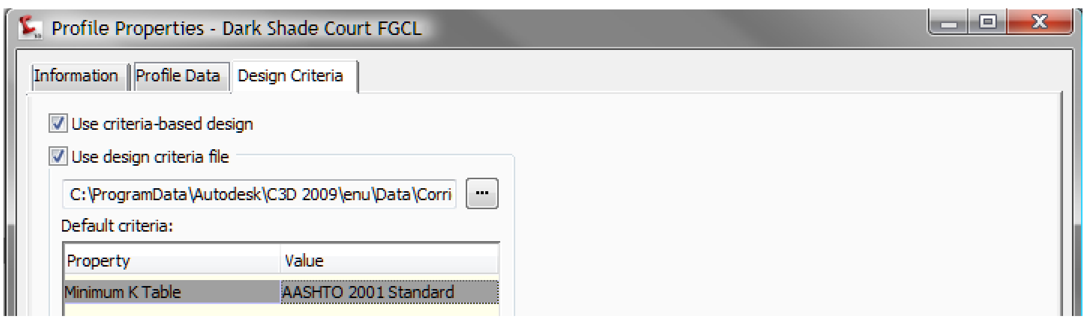


Figure 13: A view of the Design Criteria tab of the Profile Properties dialog in which a design criteria file has been enabled and chosen.

Once in place, the effects of the design criteria file can be seen in the drawing as well as in the grid view of the design as shown in Figure 14.

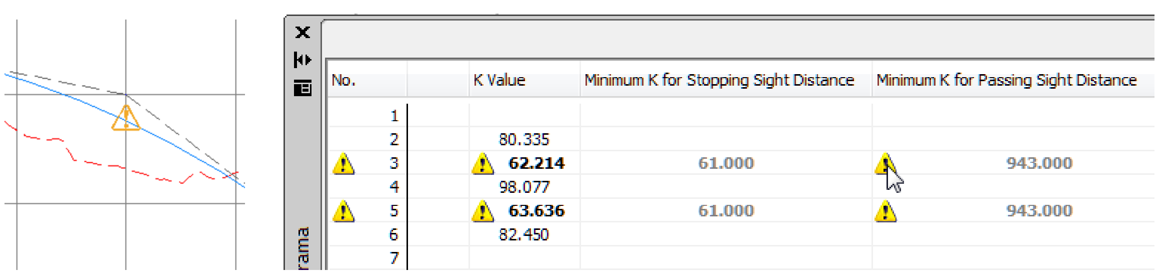


Figure 14: Warning symbol shown in profile view (left) at the location of a PVI which does not meet the criteria along with warning symbols in grid view (right) that also indicate criteria violations.

Once these issues are identified, they can be corrected by the designer. If all criteria have been met, the warning symbols will disappear. Some violations, such as passing sight distance can be ignored if they do not apply to the design.

Design Checks

Design checks are another way to track and control the road design in real-time and can be used by themselves or in conjunction with design criteria files. Design checks are managed through the Settings tab of the Toolspace and can be arranged into design check sets.

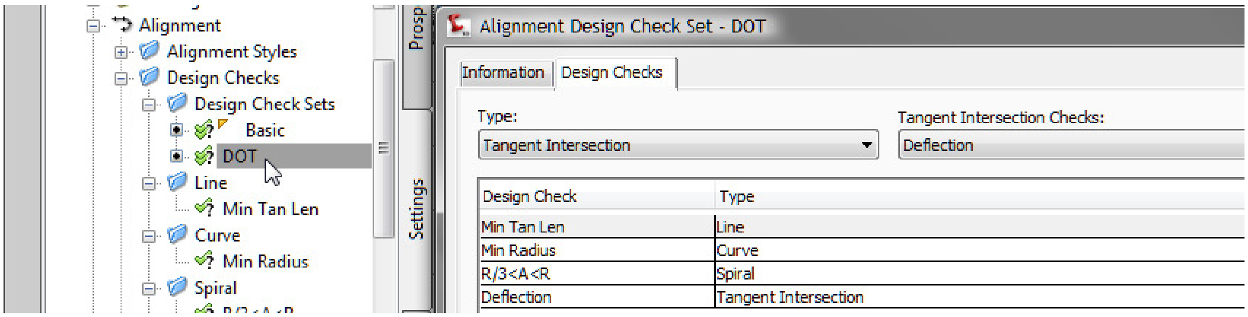


Figure 15: Settings tab of the Toolspace (left) showing design check sets and design checks. Alignment Design Check Set dialog box (right) showing the design checks that are contained within the DOT design check set.

A design check is actually a formula that compares a geometric property of an alignment or profile with another value. The second value can be another geometric property, a constant, or a calculated value. The figure below shows a simple design check formula which expresses that the length of a tangent must be greater than 100.

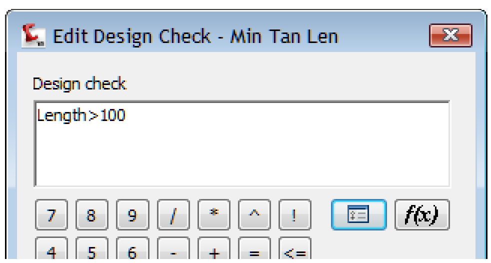


Figure 16: A simple design check formula expressing that tangent length must be greater than 100.

Alignments and profiles can each have their own collection of design checks. Each is addressed in detail in the following sections.

Alignment Design Checks

Alignment design checks fall under four types: line, curve, spiral, and tangent intersection. A new design check is created by launching the Edit Design Check dialog box from the Settings tab of the Toolspace. The user constructs a formula by first choosing a property of the alignment and then providing an operator (such as =, >, <, etc.) and a comparison value.

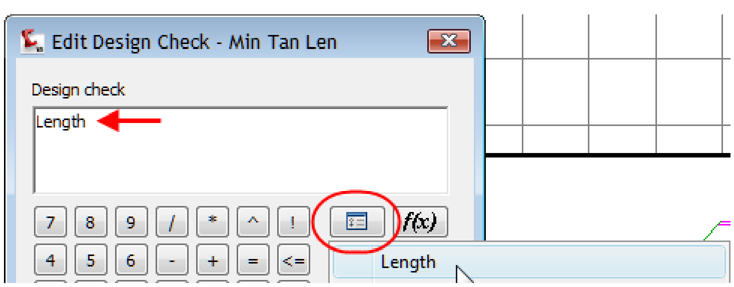


Figure 17: In the example above, the user is selecting the Length property of the alignment which is then copied into the formula window.

All of these values can be typed in directly from the computer keyboard or through the use of the specially designed keys on the Edit Design Check dialog box. Through this extremely flexible interface, nearly any geometric relationship can be established helping the designer to meet thousands of potential requirements.

Applying Alignment Design Checks

Like design criteria files, alignment design checks are assigned in the Alignment Properties dialog box on the Design Criteria tab. To accomplish this, the designer simply checks a box to enable the use of design check sets and chooses the appropriate check set.

Figure 18: A view of the Design Criteria tab of the Alignment Properties dialog box where design check sets have been enabled and the DOT check set has been chosen.

Violations of the design check set will appear in the same way as for design criteria files. Warning symbols will appear within the drawing at locations along the alignment where violations occur. Warning symbols will also display in grid view to notify the designer of any issues. The designer can choose to correct the issues or ignore them if the design requirements permit. If the criteria are met, the warning symbols will disappear.

Profile Design Checks

There are two types of profile design checks: line and curve. As with alignments, any combination of design checks can be organized into a check set.

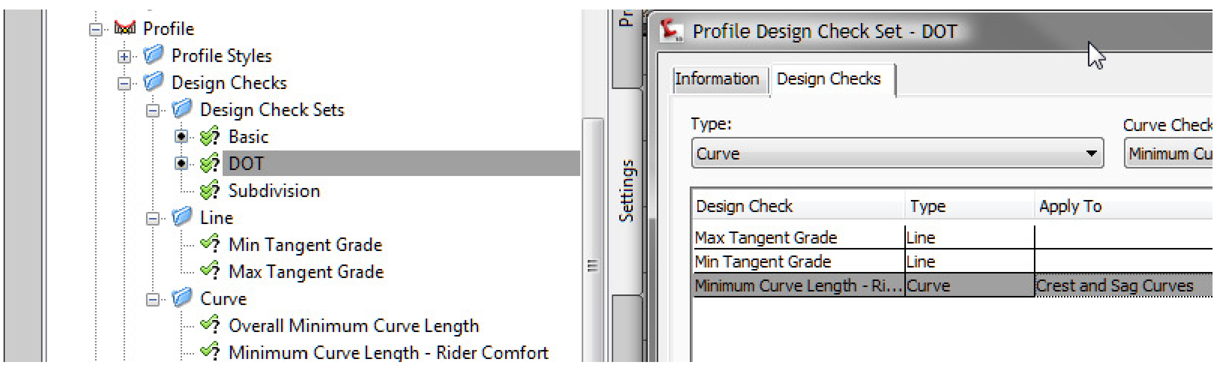


Figure 19: Settings tab of the Toolspace (left) showing design check sets and design checks along with the Profile Design Check Set dialog box (right) showing the design checks that are contained within the DOT design check set.

Applying Profile Design Checks

Like design criteria files, profile design checks are assigned in the Profile Properties dialog box on the Design Criteria tab. To accomplish this, the designer simply checks a box to enable the use of design check sets and chooses the appropriate check set.

Figure 20: A view of the Design Criteria tab of the Profile Properties dialog box where design check sets have been enabled and the DOT check set has been chosen.

Violations of the design check set will appear in the same way as for design criteria files. Warning symbols will appear within the drawing at locations along the profile where violations occur. Warning symbols will also display in grid view to notify the designer of any issues. The designer can choose to correct the issues or ignore them if the design requirements permit. If all criteria are met, the warning symbols will disappear.

Criteria-Based Design Example

To better understand the application of criteria-based design, we will study a design example involving a two-lane divided roadway to be constructed through a new commercial development. The design must adhere to AASHTO requirements as well as local design requirements. The first portion of the design is a rehabilitation involving overlay and widening with no change to the centerline geometry of the road. The second portion is new road construction to provide access to a new commercial area. The initial design speed is 45 mph which will change to 35 mph at station 54+00. In the area of the design we will be focusing on, the typical cross section consists of a 7 foot wide raised median, 12-foot lanes, and curb & gutter.

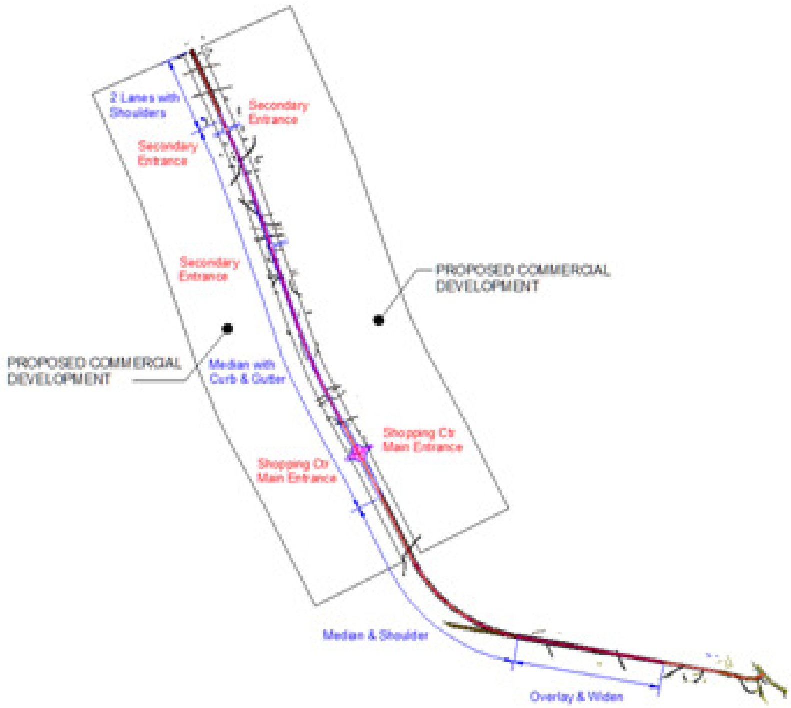


Figure 21: Conceptual layout of the proposed road design

Alignment Geometry

To address minimum curve radius, the AutoCAD Civil 3D Imperial (2004) Roadway Design Standards criteria design file will be assigned to the centerline alignment. The Minimum Radius Table will be set to AASHTO 2004 US Customary eMax 4%. Although it will not affect horizontal geometry, the appropriate choices will be made for the Transition Length Table and Attainment Method at this time. These settings will be addressed on the Design Criteria tab of the Alignment Properties dialog box.

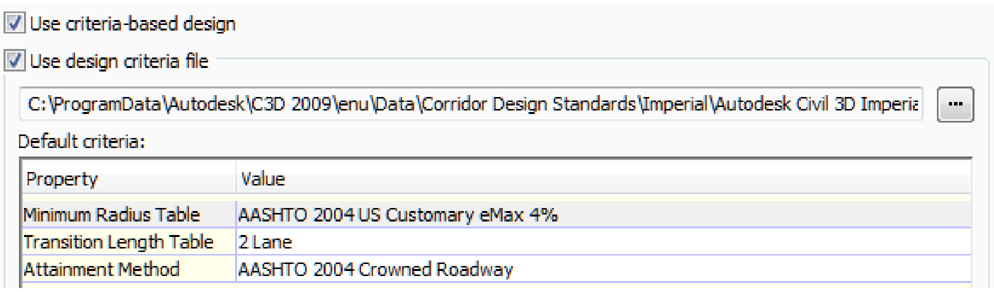


Figure 22: Design Criteria tab of the Alignment Properties dialog box showing that the design criteria file and associated minimum radius table have been chosen and enabled.

In addition, local requirements dictate that for this type of design there can be no curve radius less than 250 feet. This will be addressed through a design check.

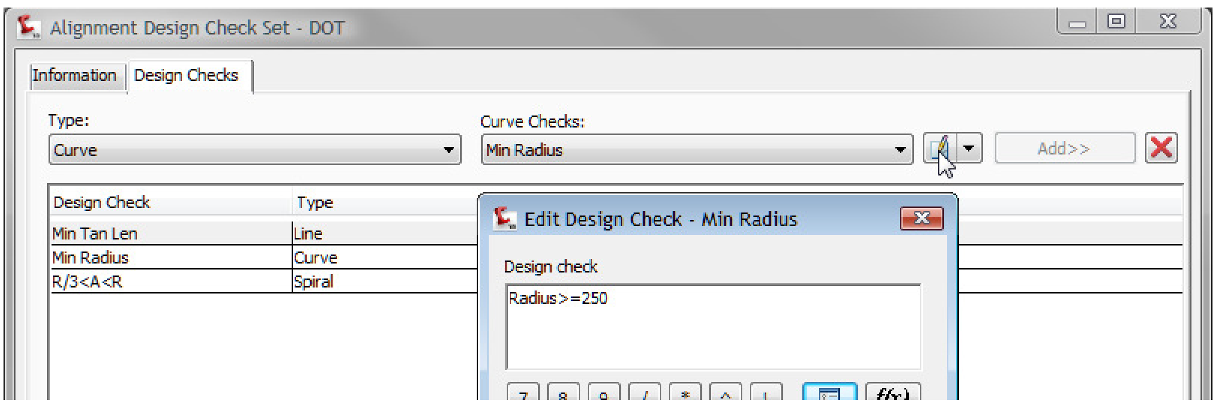


Figure 23: Design check formula to ensure that curve radii meet a minimum radius requirement of 250' (foreground) which will become part of the DOT design check set (background).

Once the design criteria file and design check set are enabled we immediately see a warning symbol on the first curve of the alignment. Investigation of the design using grid view shows that the first curve (radius = 200') does not meet AASHTO or local requirements. This will be ignored, however, since this portion of the design has already been approved as an overlay with no change to the road geometry. No other alignment warnings are present.

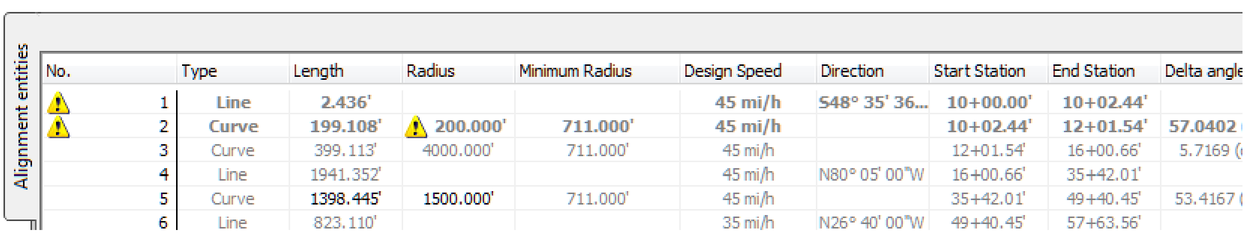


Figure 24: Warning symbols in grid view indicate a criteria violation.

Profile Geometry

The same design criteria file will be assigned to the profile via Profile Properties. In addition, local design requirements prohibit profile grades of less than 0.5% or greater than 12%. Design checks will be applied in this case.

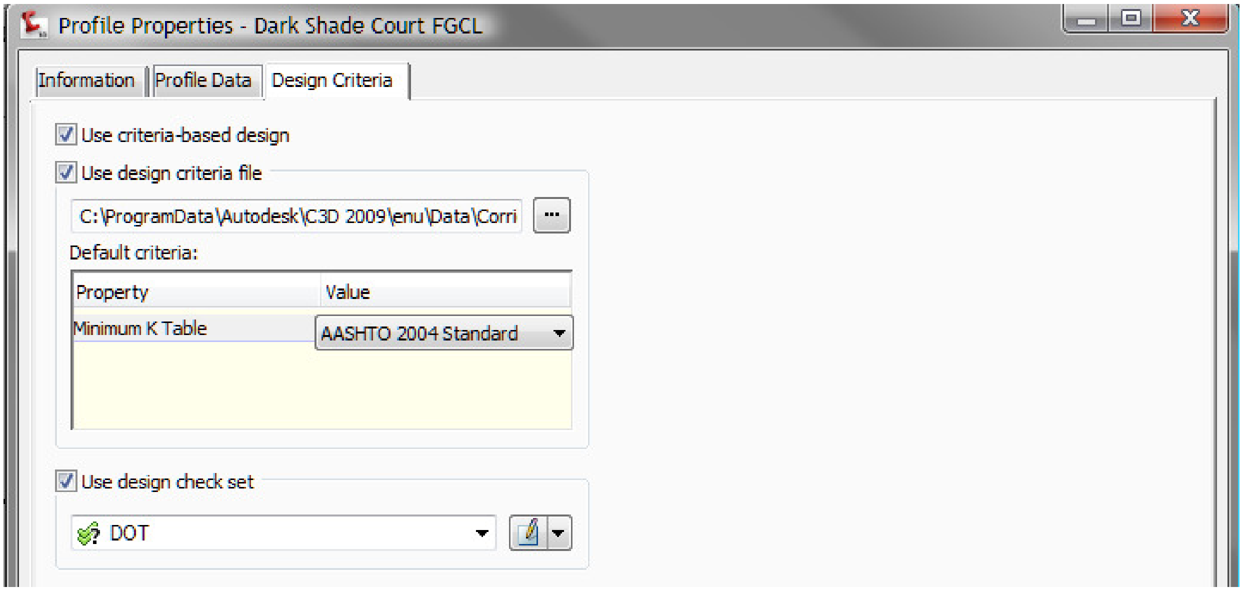


Figure 25: Design Criteria tab of Profile Properties dialog showing the application of a design criteria file and design check set.

Once the design criteria file and design check set are applied, many warning symbols appear. Violations based on minimum/maximum grades, stopping sight distance, or headlight sight distance are corrected by editing the profile. Violations based on passing sight distance are ignored since passing will not be permitted along this portion of the road.

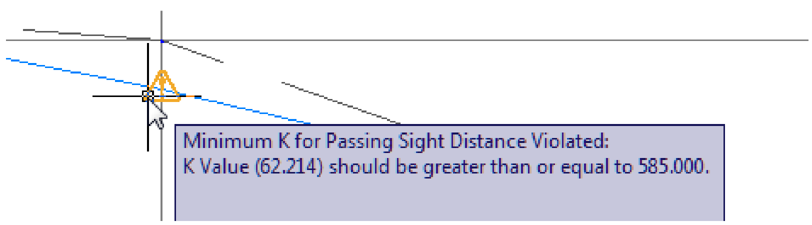
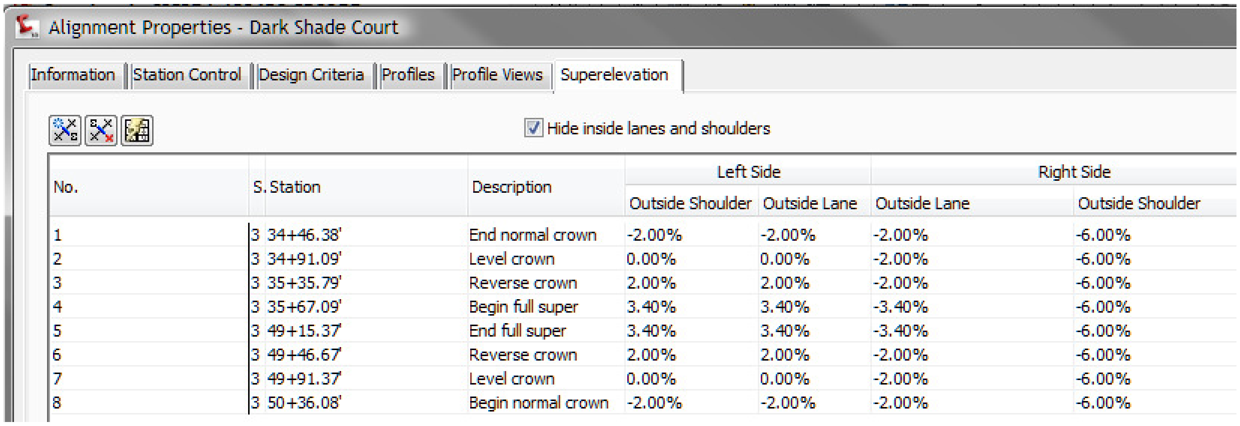


Figure 26: Warning symbol shown along the profile with a tooltip indicating that minimum K for passing sight distance has been violated.

Superelevation

To apply superelevation to the corridor, the Superelevation tab of Alignment Properties is accessed. Through the Superelevation Specification dialog, the AASHTO 2004-based design criteria file is chosen for superelevation region 3. Settings are configured for a maximum superelevation rate of 4%, divided road, with 6% slope on the shoulders. Another key setting is that the outside shoulder superelevation method will be set to Breakover Removal. All other regions represent very large radius curves that will not require superelevation.

These settings result in a series of transition stations and corresponding lane and shoulder slopes on the Superelevation tab. All superelevation transition stations are deleted except for those applying to region 3, since superelevation is not required in the other regions.


Alignment Properties - Dark Shade Court

Information | Station Control | Design Criteria | Profiles | Profile Views | Superelevation

Hide inside lanes and shoulders

No.	S.	Station	Description	Left Side		Right Side	
				Outside Shoulder	Outside Lane	Outside Lane	Outside Shoulder
1	3	34+46.38'	End normal crown	-2.00%	-2.00%	-2.00%	-6.00%
2	3	34+91.09'	Level crown	0.00%	0.00%	-2.00%	-6.00%
3	3	35+35.79'	Reverse crown	2.00%	2.00%	-2.00%	-6.00%
4	3	35+67.09'	Begin full super	3.40%	3.40%	-3.40%	-6.00%
5	3	49+15.37'	End full super	3.40%	3.40%	-3.40%	-6.00%
6	3	49+46.67'	Reverse crown	2.00%	2.00%	-2.00%	-6.00%
7	3	49+91.37'	Level crown	0.00%	0.00%	-2.00%	-6.00%
8	3	50+36.08'	Begin normal crown	-2.00%	-2.00%	-2.00%	-6.00%

Figure 27: Superelevation tab of the Alignment Properties dialog box showing the superelevation transition stations and associated lane and shoulder slopes.

After applying the superelevation settings to the alignment, the corridor is rebuilt and the region of superelevation is examined using the View/Edit Sections command. The superelevation has been applied according to the AASHTO standards contained within the design criteria file. Due to the breakover removal option, the cross-slope of the shoulder on the high side of superelevation has been set to match the cross-slope of the lane. On the low side, the shoulder is at a default slope of 6%.

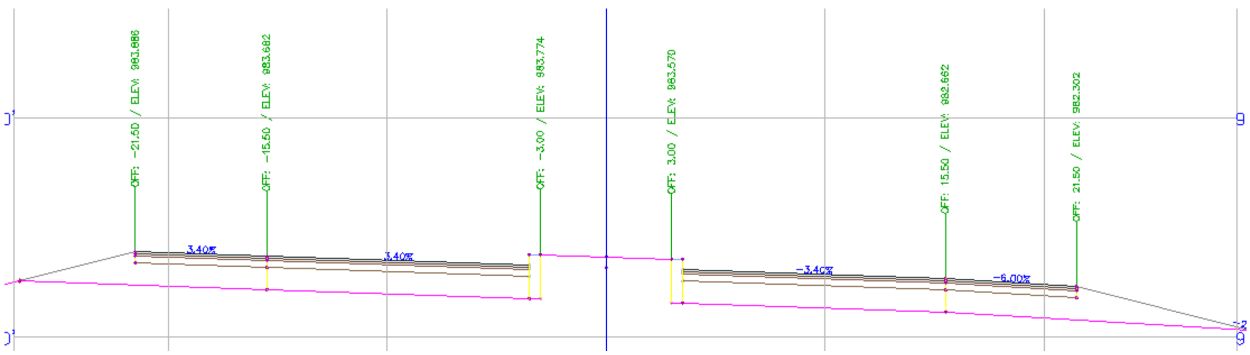


Figure 28: Corridor shown using View/Edit Corridor Section command indicating that superelevation has been applied according to the design criteria file.

Results

With the use of design checks and design criteria files, the geometric design of this road has been completed with greater adherence to local and state requirements. For this reason, the review cycle can be shortened and scheduling delays minimized. Even if this design were not under the scrutiny of local or state requirements, the designer can feel more confident that the geometric design is sound.

If changes require an update to the design such as a change in design speed or change in the geometry of the road, the criteria-based components are already in place. This means that the designer can quickly identify and correct any criteria violations resulting from the necessary changes.

More Criteria-Based Design Ideas

Build Your Own Design Criteria Files

Using the Design Criteria Editor, design criteria files can be built from scratch or created by modifying existing ones. With this capability you can construct highly customized design criteria files for many applications or design requirements. In the United States, many state highway design standards are some variation of AASHTO requirements—so you can start with the AASHTO files provided and quickly adjust them as needed to match state requirements. Local jurisdictions often employ simpler design standards which could be built as a new design criteria file.

Analyze the Designs of Others

The criteria-based design features of the AutoCAD Civil and Civil 3D software can be applied to any road design, regardless of the technology used to create it. If a design was created using a program other than AutoCAD Civil or AutoCAD Civil 3D, it could be exported from its native program as a LandXML file and then imported into AutoCAD Civil or AutoCAD Civil 3D. Once in place, you can assign the appropriate design criteria files, design check sets, and simply scan the design for warning symbols. If the design is not available in LandXML format, its framework could be reconstructed using AutoCAD Civil or AutoCAD Civil 3D and then analyzed using the same tools.

Conclusion

As you have seen in this document, criteria-based design is a powerful tool in roadway design, providing a more efficient means to help ensure that established design standards are met The capability of having real-time analysis and design checking as you work will help you avoid issues and potential review comments before drawings are ever plotted. This is all made possible through design criteria files, design checks, and the dynamic relationships between alignments, profiles, and corridors.

Using the criteria-based functions of AutoCAD Civil and AutoCAD Civil 3D, you can create dynamic corridor models that design and/or monitor their own horizontal geometry, vertical geometry, and superelevation. This helps you to design quickly knowing that minimum curve radii and K value requirements are met and that the superelevation design meets the required standards.

In addition to being very thorough and powerful, these criteria-based functions are also highly flexible. Out of the box, AutoCAD Civil and AutoCAD Civil 3D come equipped to handle AASHTO-based designs, but if your needs are different, you can quickly create your own design criteria files and design checks. For work outside the United States, you can also visit www.autodesk.com/civil3d-countrykits to see if a country kit is available for the location of your project.

After reading this document, you should be able to begin building your own dynamic, criteria-based road designs so that you, your company or organization, and your clients can start to see the benefits of this powerful design approach.

Engineered Efficiency, Inc. is a CAD consultancy and software vendor that has been involved in the testing, training, and implementation of AutoCAD Civil 3D since its initial release in 2003. EE has worked with end-users across North America to successfully implement Civil 3D and regularly presents at Autodesk University. EE has authored several works on Civil 3D, including *Mastering AutoCAD Civil 3D 2009*; AOTC Civil 3D *Solution Series* courseware including *Residential Grading*, *Designing Intersections and Cul-de-Sacs*, and *Creating and Managing Plan Sets*; and several AutoCAD Civil 3D whitepapers. Engineered Efficiency, Inc. can be reached online at www.eng-eff.com.