State of Georgia

Department of Transportation

3D Modeling Best Practices & FAQ

3D Modeling Best Practices & FAQ

12/7/2018

Revision 0.0

Atlanta, Georgia 30308

GDOT Georgia Department of Transportation

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FREQUENTLY ASKED QUESTIONS

Overall 3D Modeling Initiative

Why is GDOT requiring 3D models?

The transportation industry is utilizing 3D data in a growing number of applications related to survey, design, and construction. State DOTs are implementing 3D modeling for design in various levels of depth, ranging from no requirements for 3D modeling to letting a construction project with a 3D model as the signed and sealed contract deliverable (no printed plan set). Georgia DOT's 3D modeling initiative is now entering its infancy stage where 3D surface model electronic files will be provided to contractors at the time of bidding for information only, and will not be considered contract documents.

Expected benefits of developing and delivering 3D models include:

- Better reflection of the engineer's design intent in areas traditionally not defined in plan sets (e.g. between cross sections, bridge endrolls, and intersections)
- Delivering a higher quality product to the contractor with an accurate project footprint related to earthwork and construction limits, with the goal of reduced supplemental agreements
- Ensuring a smooth transition from design to construction through the inclusion of a surface that communicates the design intent
- Creating a better visualization tool for engineering analysis (e.g. sight distance, clear zone) and coordination with other design disciplines
- Creating a product to facilitate communication within the project team, for example as an aide to avoidance and minimization discussions

What is the primary purpose/audience of the model?

The primary engineering objective of the 3D model is to convey the design intent, especially in areas traditionally not well-defined in plans or cross sections. The primary audience/customer for the 3D model is both the engineer on the design team (to define and validate design) and the contractor (to construct the proposed surface).

When will 3D models be required?

The Department will begin requiring electronic 3D model files to be included with final plans package submissions to the Office of Construction Bidding Administration beginning in January 2019, corresponding to the March 2019 letting.

What are some challenges related to implementation of 3D models?

3D modeling will come with the typical challenges of implementing new initiatives into the design process: time, money, and software. The Department recognizes that developing an accurate 3D model will require additional design effort and has updated the man-hour spreadsheet with a new final phase task called “Enhanced proposed surface for 3D modeling” so this can be discussed during consultant contract negotiations. This task should include all hours related to the 3D model effort, and assumptions should be noted accordingly (e.g. number of intersections to model, number of bridge endrolls to model, etc.). The additional design effort to develop an accurate 3D model should be related to cross section development and QA review and should not be related to the overall design effort for the project. The investment in developing a 3D model is expected to result in overall cost savings through the bidding and construction process. The implementation of Open Roads Designer (ORD) is expected to give designers greater flexibility and functionality regarding 3D modeling. A unique challenge of implementing the 3D modeling initiative, and likely the most difficult to overcome, will be the required change in the designer’s mindset from designing cross sections to designing a continuous surface.

Do I have to model my project?

3D model files will be required for projects that propose earthwork/grading operations, typically reflected in construction plan section 23 (Cross Sections) or 18 (Special Grading). Examples of such project types include, but are not limited to:

- New location roadways
- Widenings
- Bridge replacements
- Grade separations
- Interchange reconstructions
- Roundabouts
- Turn lanes
- Passing lanes

3D model files will not be required for projects that do not propose earthwork/grading operations; examples of such project types include:

- Lighting
- Maintenance
- Resurfacing without significant grading operations
- Landscaping
- Signal upgrades
- Signing/striping upgrades
- Streetscapes
- Drainage improvements
- ATMS/ITS
- Noise walls

3D model files are not required for MicroStation V7/CAiCE projects.

I'm turning in final plans in 2019, but completed my geometric design years ago. Am I expected to produce a 3D model at this late stage of the project?

Yes, but, due to the timing of the project, it will likely not be practical to implement any major improvements to the 3D model. It is expected that some of the projects submitted in the early phase of the initiative will be in this condition since preliminary design activities likely finished before GDOT announced its initiative. For these projects, 3D models should still be produced and reviewed to identify any major design or footprint concerns. If errors of this nature are found, the 3D model does not necessarily need to be fixed during the early phase of this initiative. However, the construction plans should be updated to resolve the issue(s), and a "lesson learned" should be carried into the next project when there is an opportunity to apply it during preliminary design.

A 3D model submission is not required if the project is designed in MicroStation V7/CAiCE; however, for projects designed in InRoads, the expectation is that the designer will turn in the surface used to create the cross sections. The Department does not view this task as additional effort.

Will the Department offer supplemental agreements to existing consultant contracts for 3D modeling?

No. Supplemental agreements will not be provided solely for the additional deliverable of a 3D model. For existing contracts or task orders approaching expiration near final plans submission, it is acceptable for the designer and reviewer to spend minimal time (8 hours maximum) creating and checking the proposed 3D surface. For the designer, the 3D surface is "automatically" created at the same time cross sections are being developed, so this should be an exercise in viewing all proposed surfaces and merging them into a single proposed surface. For the reviewer, the 3D surface should be checked with the mindset of looking for critical errors. If any critical errors are found, the plans should be corrected to ensure a higher quality bid; however, it is not necessary to update the model unless it provides significant value to the plans. For new contracts or task orders, this will be discussed during consultant contract negotiations using the new final phase task called "Enhanced proposed surface for 3D modeling".

Where will GDOT's 3D modeling initiative go in the future?

The next phases of implementation will likely include (for certain project types) modeling underground features such as drainage, utilities, foundations, etc., modeling each construction stage with a separate model, and using 3D models for quantity take-offs. 3D models could also be used in the future as a data source for asset management, maintenance, and operational decisions. The Department intends to establish a task force under the GPTQ Roadway Design Policy Subcommittee in order to discuss future phases of implementation and to have an ongoing open dialog with the consultant community about the progress, challenges, and best practices of 3D modeling in this initial stage.

3D Modeling Process

What is a 3D model?

With respect to this initiative, a 3D model is an electronic three dimensional proposed surface built within the design phase to reflect the engineer's design intent. During the design process, the 3D model takes the form of a proposed DTM (digital terrain model, .dtm file) within the design software (e.g. InRoads). After design is complete and final plans are ready to be submitted for letting, the designer will produce an electronic Land XML file (.XML) generated from the DTM to be included in the final plans package as the 3D model.

How is 3D modeling related to Bentley OpenRoads implementation at GDOT?

There is no direct relationship between these two initiatives; they are each moving forward independently from one another. 3D models can be produced from the InRoads software package, and OpenRoads is expected to provide additional functionality and flexibility to designers with respect to 3D modeling.

How will this initiative affect survey collection and processing?

Although there may be some changes with respect to software requirements (InRoads vs. OpenRoads), this initiative will have no direct effect on the collection and processing of survey data.

What specific deliverables make up a 3D model?

Two files (Land XML format) will be included:

1. 1234567_EXIST.XML (containing the complete existing ground surface)
2. 1234567_FINISH.XML (containing a single merged final finished grade of the proposed surface)

These files will be provided "for information only" and will not be considered contract documents. There are no changes to the required earthwork files to be submitted at final plans; earthwork quantities and files should be submitted using the average end area method/reports. Instructions for creating Land XML files can be found in Chapter 4 of the InRoads Workflow Processes available on GDOT's website at this link:

http://www.dot.ga.gov/PartnerSmart/DesignSoftware/INROADS/InRoads%20Workflow_Processes.pdf

When will I need to turn in my model?

3D model files will be submitted as part of the Final Plans Package submittal to the Office of Construction Bidding Administration to begin the letting process. At this time, 3D models will not be required as a part of any other submission, including field plan reviews.

Will GDOT review my model?

Not at this time. The reviewing engineer on the design team is expected to perform a high-level QA review of the model once in preliminary design (to verify the project footprint for Right of Way (ROW) acquisition and assessment of effects) and once in final design (to verify overall model including details). The Department expects the overall process for QC/QA to be defined in each consultant's specific quality assurance/control plan.

How do I perform a QA review of a 3D model?

For the reviewer on the design team, the focus should be to ensure the 3D model looks reasonable and that no major concerns are found, especially in areas traditionally not shown in the plans. The review may be accomplished through viewing proposed DTM surfaces electronically in 3D, rotating the surface in many different views and visually inspecting it for problem areas. This is largely a "manual" and visual process. Some techniques for performing a QA review include:

- Request files from designers:
  - 3D Microstation file (.dgn) of proposed surface showing proposed triangles and proposed surface features
  - Existing DTM file (.dtm)
  - Proposed DTM file (.dtm)
  - InRoads files (.alg, .ird, .itl, .xin)
  - Standard 2D DGN files to compare to model – MAIN, LIMIT, etc.
- Overlay 3D model with 2D design files to check for consistency (rotate view to "top")
- Rotate the proposed surface in 3D to review
  - Setting the Display Style (in "view attributes" dialog box) to wireframe, smooth, smooth with shadows, or illustration can help visibility when reviewing the 3D model.
- View proposed contours of the 3D surface using a small interval and check for continuity of surface
  - Surface → View Surface → Contours…
- View triangles of the 3D surface and check for good triangulation
  - Surface → View Surface → Triangles…
- Elevation label tool
  - Surface → View Surface → Single Point → Surface Elevation
- Color triangles by slope
  - Surface → View Surface → Color-Coded Slopes…
- Trickle Tool (shows flow path of any point on surface):
  - Tools →Application Add-ins… → Hydrology and Hydraulics Add-In (check box)
  - Evaluation → Hydrology and Hydraulics → Trickle…
- Display valleys and ridges
  - Evaluation → Hydrology and Hydraulics → Display Valleys and Ridges

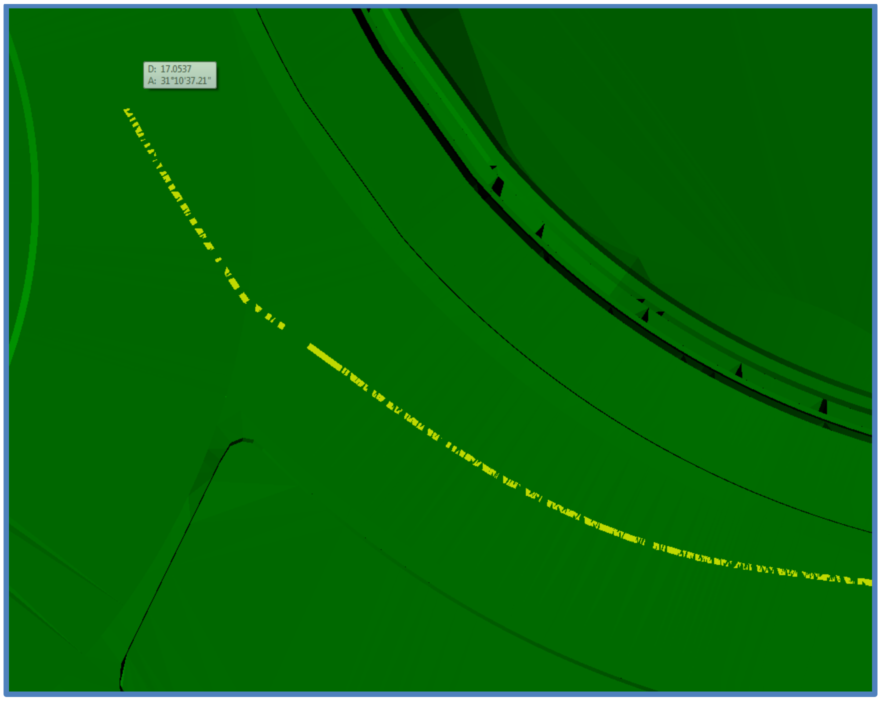

Figure 1: The trickle tool shows the flow path of a drop of water at any point on the proposed 3D surface.

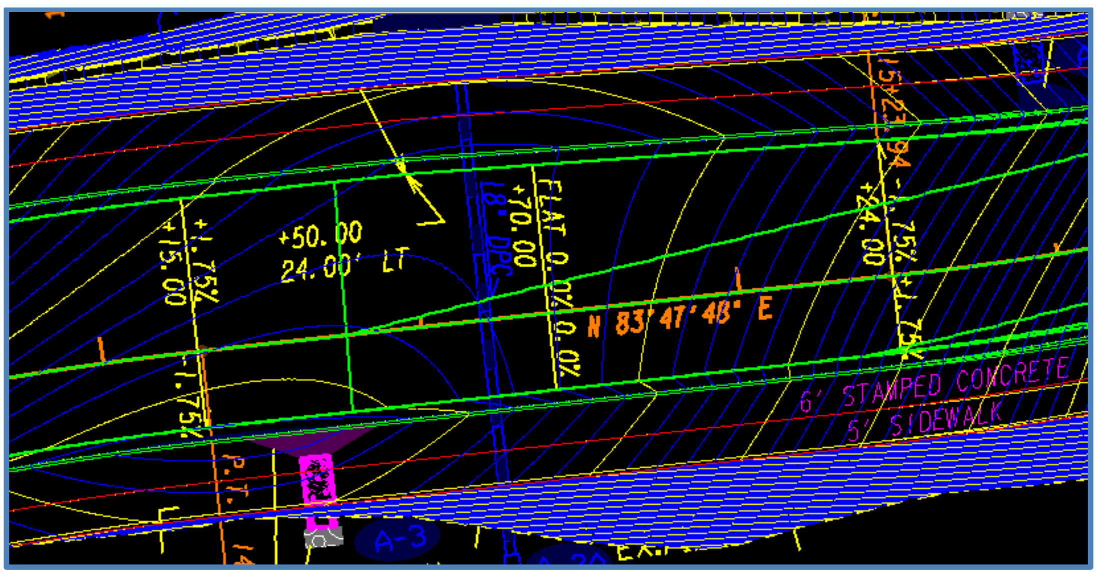

Figure 2: Viewing proposed contours of the 3D surface is helpful in reviewing the model and checking for consistency with the plans/DGNs. Note that proposed contours from the 3D model line up nicely with construction limits, ditches, and other features in the plans/DGNs.

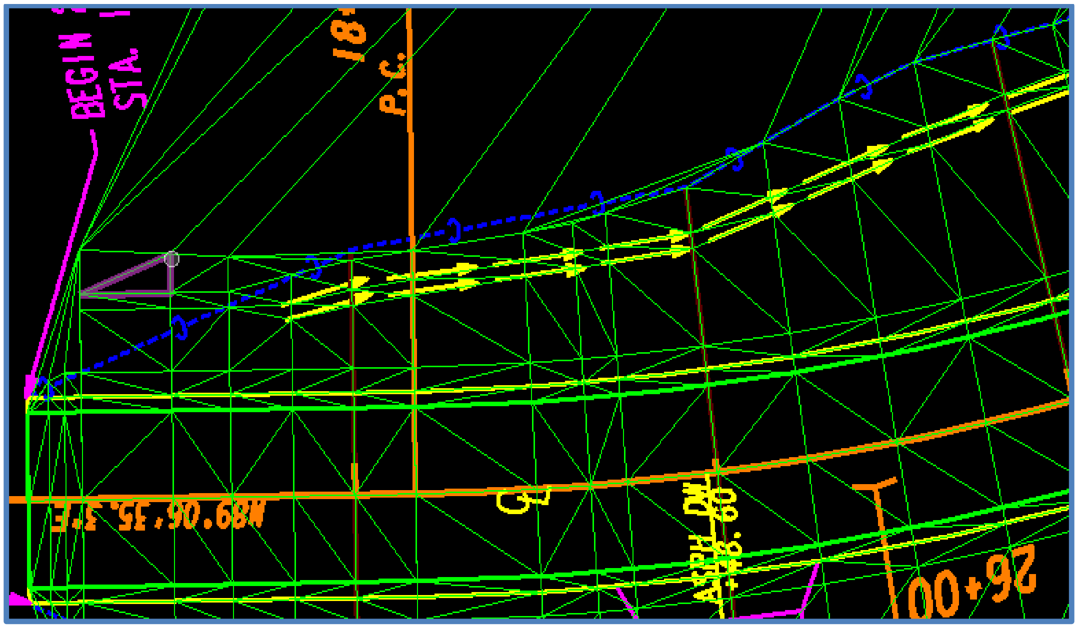

Figure 3: Viewing proposed triangles of the 3D surface is helpful in reviewing the model. Note that triangles line up nicely with the construction limits and ditch on the right side of the figure, but do not align on the left side of the figure.

Do I have to update the 3D model for every Use on Construction revision?

There are no requirements from the Department to update the model after submission. However, the 3D model may help identify certain areas of the project which need more explanation from the engineer. In these cases, plan revisions might be required.

3D Modeling Details

What do I have to model?

For this initial phase of implementation, the model should reflect the final finished surface of the project footprint. The mainline and sidestreet roadways (between shoulder break points) should be well-defined and accurate including intersections and median openings; this includes accurately defining the shoulder break point itself, especially in areas of guardrail and transitions to bridges. The roadside (outside shoulder break points to construction limits) should also be well thought out especially with respect to side slope transitions and roadside safety. The level of precision warranted on the roadside may be less than the roadway due to the nature of the roadside tying into existing ground, however, this is still a very important part of the model. Bridge endrolls should be modeled.

Walls should be modeled in the sense that there should be a “vertical” drop (avoid truly vertical elements in model by assigning an insignificant slope) in the proposed surface. Modeling the wall in 3D may illuminate to designers the need to extend or modify the wall based on a 3D evaluation, rather than only checking it at even cross section stations. However, detailing all of the cross sectional features such as barrier face, coping, footing, etc. is not required at this time. In future phases of this 3D modeling initiative, wall footings may be modeled in addition to drainage structures and utilities to evaluate for conflicts.

Sediment basins and permanent ponds/basins should be modeled with sufficient detail to verify the footprint for ROW and easement requirements, and to produce a grading plan for construction.

Raised islands should be modeled in cases where the edges of the island also serve as geometric controls, such as splitter islands on roundabout approaches. A right turn channelizing island which sits on top of the intersection geometry may provide no significant value to model.

Not all features are equally important, or provide the same value, to the 3D model. When developing a 3D model, especially during the early phase of implementation when time or resources are limited, this general hierarchy of importance should be used as a prioritization guideline:

1. Mainline roadway within shoulder break points including intersections
2. Mainline roadside
3. Side street roadways within shoulder break points including tie in to mainline
4. Side street roadsides
5. Bridge endrolls
6. Other miscellaneous model details

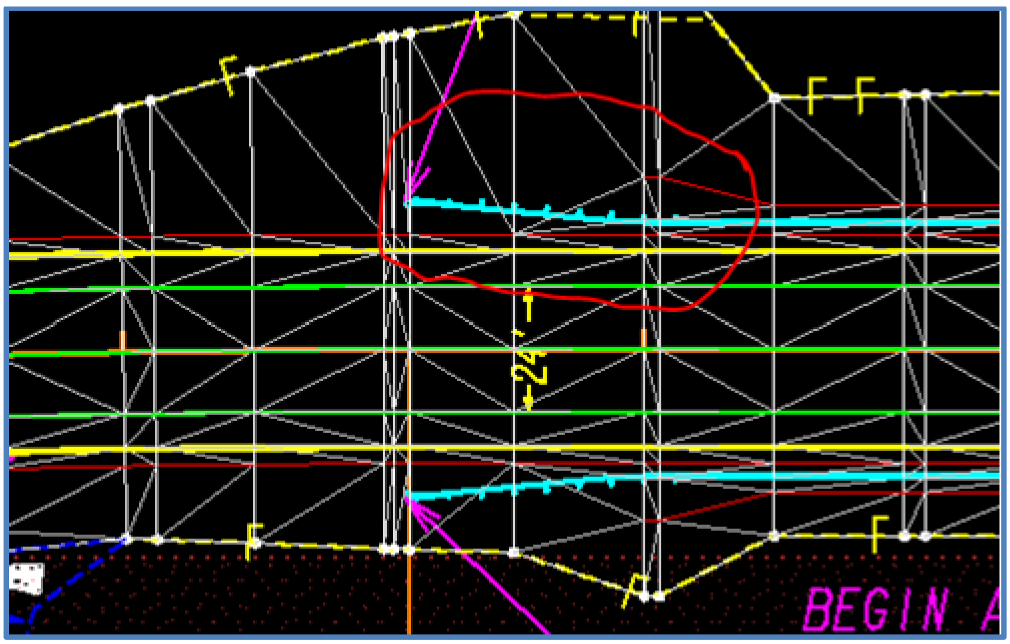

Figure 4: Overlaying the 2D DGN files with the triangulation from the 3D model shows that the 3D model triangles are not accounting for the guardrail terminal pad grading. The model should be updated to account for this grading, which will affect construction limits.

What do I not have to model?

For this phase of implementation, 3D models are not required to reflect anything below ground including drainage, pavement/base, utilities, etc. These items may be included in later phases of 3D modeling for certain project types.

Aboveground features that would not be triangulated into a surface do not need to be modeled. Such features include guardrail, sign poles or structures, signal poles, barrier wall, utilities, etc. These features would not typically be triangulated into the existing surface and, therefore, do not need to be modeled in the proposed surface at this time. Even though not required, modeling (even "roughly") guardrail and barrier walls adds additional value to the model with respect to sight distance checks. Additionally, while evaluating pilot projects, viewing the guardrail feature in the model and comparing it to the guardrail in the DGN file helped identify discrepancies in guardrail location, which can cause changes to the shoulder break point.

Driveways are not required to be modeled at this time; however, driveways should be modeled when engineering judgment dictates a benefit. For example, modeling may provide value for a commercial driveway in a tight urban environment where drainage and property impacts are likely, but not for a typical residential driveway in rural areas. Long, winding, rural driveways with significant grading should be modeled.

Bridges do not need to be modeled, but the bridge endrolls should be modeled. Proposed surface models will have a "gap" where the proposed bridge is located.

At this phase of implementation, culvert openings, culvert wing walls, and wheelchair ramps are not required to be modeled.

How does template drop frequency affect cross sections in plans?

Template drop frequency and plan set cross sections are different concepts and neither concept directly affects the other. The designer should make decisions about template drop frequency in order to accurately define the 3D model without any concern for which cross sections will eventually be shown in the plans. This mindset will help build an accurate 3D model, which can then be cut into cross sections, according to current Plan Presentation Guidelines (PPG) guidance.

This concept applies more broadly to the idea of 2D plans versus a 3D model, and the challenge of this change in mindset for designers. Drivers, pedestrians, and bicyclists experience and interact with the transportation facility as a continuous 3D surface, not as alignments/profiles/cross sections. The challenge for the designer is to attempt to visualize, develop, and define this 3D surface and to think of the project plans (plan/profile/cross sections) as "windows" into the 3D model.

Do I need to provide merged surfaces?

Yes. The "finish" Land XML file should include one surface comprised of the mainline, sidestreets, and any other surfaces (e.g. driveways, bridge endrolls) merged together. The "finish" surface, however, should not be merged with the existing ground surface which is provided as a separate file. General instructions for merging surfaces can be found in Chapter 1 of the InRoads Workflow Processes available on GDOT's website at this link:

http://www.dot.ga.gov/PartnerSmart/DesignSoftware/INROADS/InRoads%20Workflow_Processes.pdf

Do I need to show alignments and profiles for radius returns in the plans?

No. At this phase of implementation, no additional Plan Presentation Guideline (PPG) requirements are expected. As the Department gains more experience with 3D modeling, these types of requirements may be added to the PPG.

How do I model a bridge endroll?

Working with the bridge engineer, the roadway engineer should define and store geometry for the bridge endroll. This consists of storing a horizontal alignment around the end bents, storing a vertical alignment, and running a simplified template to approximate the bridge endroll.

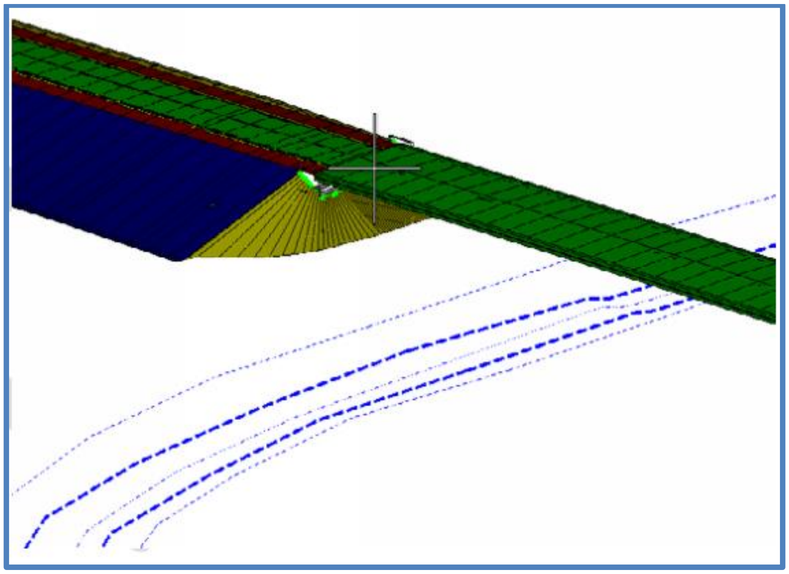

Figure 5: Bridge endroll modelled in 3D. Note that the bridge itself is also shown in this model, which is not required.

Does my model have to be "perfect"?

No. The designer should keep in mind that 3D models will be incomplete and imperfect by their nature but, in general, are sufficient for construction. The designer's goal should be to produce a practical and accurate 3D model, not a perfect 3D model. Not every triangulation issue needs to be resolved and not every transition needs to be smooth. Contractors and surveyors are often able to work out smaller problem areas in the model quickly and cheaply, especially if the surrounding areas in the model are accurate and well defined. Experiences from other State DOTs and the Federal Highway Administration (FHWA) show that designers can even "cloud" certain area of the 3D model file to indicate that the contractor should not rely on the model in these areas.

When is my model "good enough"?

When the model conveys the design intent, especially in areas traditionally not well-defined in plans or cross sections. Anecdotally, models which are about 80% complete/accurate can be developed without any significant additional design effort due to the 3D model being created "behind the scenes" while the designer is utilizing the traditional workflow of horizontal, vertical, and cross section design. However, taking the model from 80% to 100% can take many times more than the original effort. The intent of this initiative is not to get the models to 100%. Once, in the engineer's judgment, no substantial additional value would be added to the model, and the model conveys the design intent, the model is "good enough".

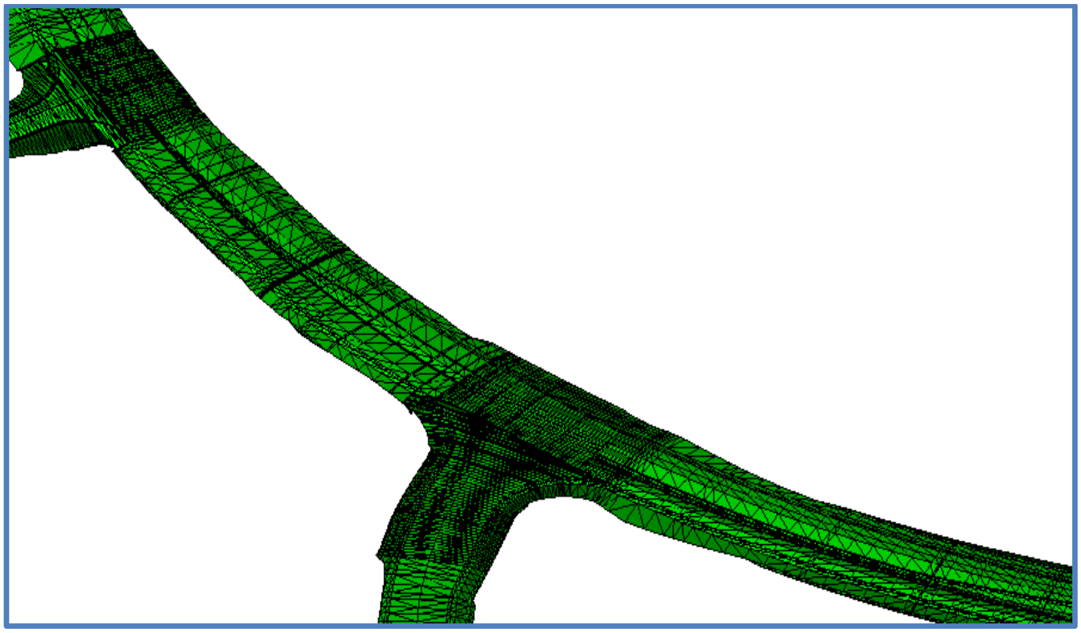

Figure 6: Proposed 3D surface model. This view of the model shows there are not any major gaps or busts, sidestreets tie in nicely to the mainline, and the designer used an increased template drop frequency within the intersection areas.

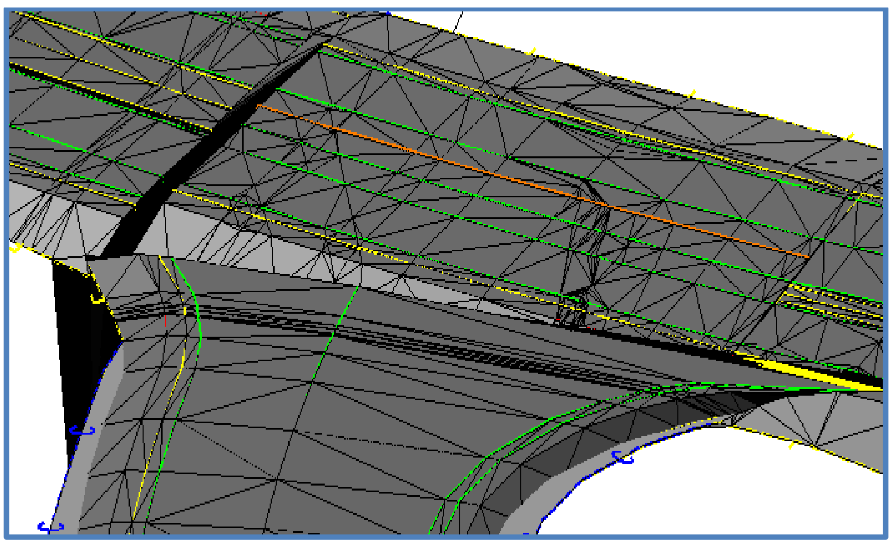

Figure 7: Proposed 3D surface model. This view of the model shows an elevation difference along the mainline, and where the sidestreet meets the mainline. Both of these areas should be "fixed" in the model to ensure the design intent is reflected.

BEST PRACTICES FOR 3D MODELING

Target Areas for Initial Phase of Implementation

During the early implementation of delivering 3D models, the focus will be on providing two Land XML files to contractors at the time of advertisement (for information only, not as contract documents):

1. 1234567_EXIST.XML (containing the complete existing ground surface)
2. 1234567_FINISH.XML (containing a single merged final finished grade of the proposed surface)

These files will be generated by the designer and submitted to the Office of Construction Bidding Administration as part of the final plans package. The over-arching goal of the proposed model is to reflect the design intent of the Engineer, especially in areas of the project typically not well defined in 2D plans. Examples of these areas include, but are not limited to, areas of transitions or changes between cross sections, mainline to side street transitions at intersections, and roadside transitions in shoulder break point and/or side slopes. In order to achieve this goal, three target areas have been identified as areas of focus:

1. Roads (mainline and side streets)
   - Roadway itself (between shoulder break points)
   - Roadside: including shoulder break points, side slopes, ditches, etc.
2. Intersections
   - Pavement warping
   - Radius returns
3. Bridge Endrolls

Approach to 3D modeling

When the final plans package is submitted, the goal is for the 3D model and the project plan set to be generally consistent with each other with respect to the target areas of this first phase of implementation. However, this does not mean designers should attempt to have a complete and perfect 3D model at all times throughout the design of the project. Instead, the development of the 3D model should mirror the development of the plans with limited modeling work to develop and vet alternative designs early in the project and with more detailed and complete modeling work later in the project when the overall footprint is established.

<u>Concept phase</u>: Generally, no 3D modeling is necessary during concept phase, since it is unlikely that 3D modeling would influence the selection of the preferred alternative.

<u>Preliminary Design Phase</u>: There are two primary objectives during the preliminary design phase:

1. The designer should lay out the roadway geometry with the end goal of a 3D model
2. The reviewing engineer should perform a high level check of the 3D model to ensure there are no major “busts” which would affect the footprint of the project.

For the designer, it is not critical to develop a perfect model during preliminary design; however, the “3D model mindset” should be present to build a solid model “behind the scenes” while still utilizing the traditional 2D workflow of horizontal alignment, vertical alignment, and cross sections. The 3D model should be used in conjunction with the traditional workflows to increase productivity and identify design issues more quickly. For example:

- In horizontal design, store alignments for inside and outside edge of pavements/shoulder break points and define the “seam” line between the mainline and sidestreet at intersections
- In vertical design, ensure sidestreet profiles match the mainline cross slope and consider skew, turn lanes, etc.
- In cross section design, consider the template drop frequency, add Key Stations where needed, and give no priority/special attention to even cross sections - all stations are equally important
- In preliminary design, model the bridge endrolls

For the reviewer, the focus should be to ensure the 3D model looks reasonable and that there are no major concerns, especially in areas traditionally not shown in the plans. View the proposed DTM surfaces electronically in 3D, rotate the surface in many different views and visually inspect for problem areas. The nature of the problem area will determine if the model needs to be altered during preliminary design, final design, or not at all. For example, if a sidestreet surface ties nicely into the mainline as expected, but the radius returns need adjusting, an alteration of the model could likely wait until final design since no significant footprint changes would be expected. On the other hand, if a review of the 3D model reveals that the design is not properly accounting for a turn lane taper or a guardrail anchor pad, addressing these concerns during preliminary design would be appropriate since they are more likely to affect the project footprint. Verifying the project footprint is the primary objective of reviewing the 3D model in preliminary design.

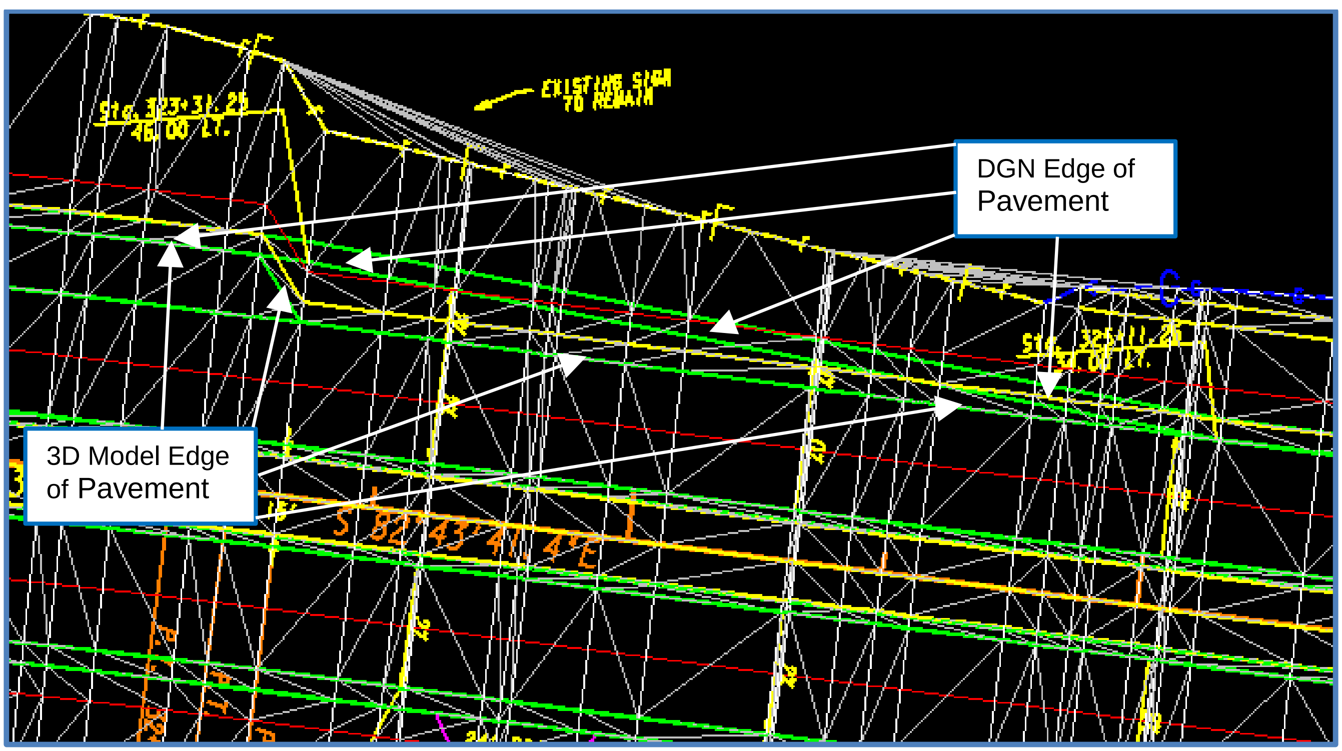

Figure 8: Overlaying 2D DGN files on top of triangles and surface features of the 3D model helps reveal discrepancies. In this case the 3D model (and construction limits) are not properly accounting for the turn lane taper.

<u>Final design phase:</u> The primary objective during the final design phase is the refinement of the 3D model in areas with less impact on project footprint but which are still necessary to reflect the design intent, such as refining radius returns. The purpose is to create a 3D model with very few or no areas where the design intent is unclear. For example, if the 3D model contains a few small gaps, point spikes, etc., but the surrounding areas clearly show the design intent, adjustment of these areas is unlikely to add significant value to the model. The model should be reviewed again during the final design phase prior to submission of the final plans package.

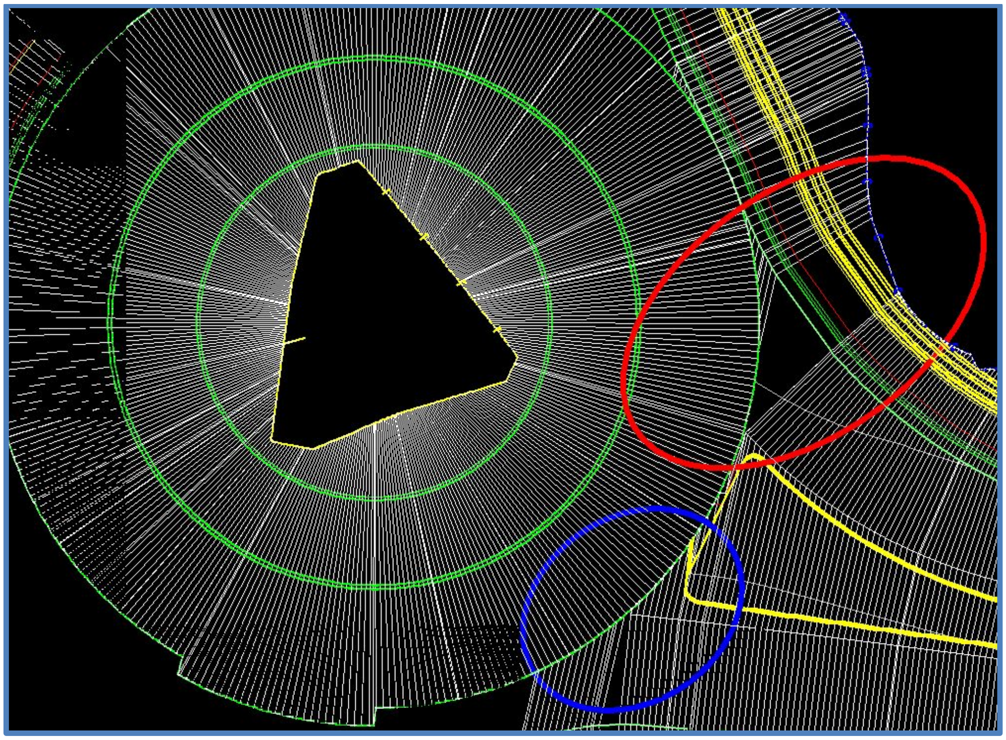

Figure 9: Proposed 3D model of a roundabout. The gap in the center represents the central island landscaping and does not need to be "fixed". The small gap within the blue circle likely does not need to be "fixed". The gap within the red circle should be examined to likely further define the design intent

Geometric Design Software Best Practices

- Utilize secondary alignments (horizontal/vertical) and point controls (in cross sections) to define edges of pavement, shoulder break points, medians/islands, or other elements varying in offset from the centerline
- Utilize parametric constraints
- Limit the number of cross section templates to a practical minimum
    - As a rough rule of thumb, the designer should strive to create one template for each typical section shown in the plans and utilize display rules and/or end condition exceptions when necessary to vary tie-ins
    - The designer is encouraged to think of a template as a typical section, and to think of an end condition exception as a typical section detail (guardrail or wall location, etc.)

- Utilize a logical and consistent naming convention for cross section elements, components, and points. Inconsistencies in point names at different cross sections can cause problems with the 3D model
- Do not use single station template drops
- Do not code in truly vertical surfaces in cross elements or 3D models. Always give vertical surfaces (e.g. walls) a very slight slope to avoid problems with the 3D model
  - This can be checked by toggling the “triangulated surface” in the roadway designer view

Template Drop Frequency / Model Density

The frequency of template drops should be a consideration throughout the geometric design of the project. In the conventional 2D approach, designers typically “automatically” run cross sections (or drop templates) every 50-ft and are finished. This method takes a somewhat random approach and is subject to missing important changes that occur between the cross sections. In the 3D approach, designers should proactively think about and “set” both the density (template drop frequency) and the location (Key Stations) of template drops so that the design intent is clearly present in the model. A paradigm shift may be required to change from a mindset that template drops must occur at even stations and at “regular” intervals (for example, starting at STA 10+00 and occurring every 50-ft) to an understanding that template drops should occur wherever necessary to design an accurate model. Increasing template drop frequency in the model is not equivalent to showing more cross sections in the plans.

The frequency of template drops should be an intentional design decision, and can vary along the same corridor. Designers should consider “what’s changing” in a particular area, keeping in mind both proposed and existing terrain, when making the decisions on template drop frequency. For example, consider the case of flat existing terrain, in a horizontal tangent, on a constant vertical grade, with no cross slope changes, no intersections, and no edge of pavement changes. In this simple case, little, if any, design intent will be lost between the cross sections. On the other hand, consider the case of rolling terrain, in a horizontal curve, within superelevation transitions, in the area of an intersection, and many auxiliary lanes with tapers. In this complex case, the use of 5-ft intervals may be needed to accurately reflect the design intent. In some cases, such as modeling radius returns or the circulatory roadway of a roundabout, the use of 1-ft template drops may be needed to accurately reflect the design intent. The following table summarizes template drop guidelines for a variety of situations:

Roadway Segment	Terrain		
	Flat	Rolling	Mount. or Irregular
Tangents	20-foot	10-foot	5-foot
Superelevation Transitions, Horizontal Curves, & Vertical Curves	5-foot	5-foot	5-foot
Intersections	5-foot	5-foot	5-foot
Roundabouts, Radius Returns, etc.	1-foot	1-foot	1-foot

Table 1: Guidelines for template drop frequency / model density

The template drop frequencies shown in the table above apply to the model submitted as part of the final plans package. During the preliminary design model development, the designer may use their judgment in selecting a lower model density.

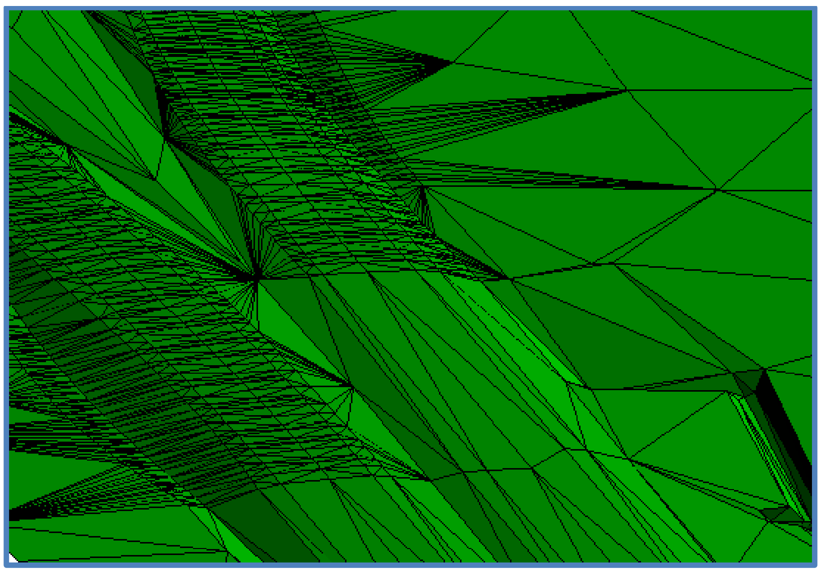

Figure 10: Existing surface 3D model. Just as surveyors collect existing data with varying densities for designers (curves vs. tangents), designers should likewise apply template drops at different densities and key stations to provide proposed data to contractors

Template Drops at Key Stations

In addition to the frequency of "typical" template drops, the designer should also proactively define the location of "special" template drops using Key Stations to help better define controlling sections/stations of the design. This does not entail creating separate templates for these locations, instead simply choosing key stations (outside the normal frequency drops) to apply a template which has already been created. Examples of these key stations include, but are not limited to:

- General:
  - Begin & End Project Stations
  - Begin & End Bridge Stations
  - Typical Section changes (excluding changes "below ground", e.g. pavement thickness)
    - Use a key station to ensure a template is dropped one hundredth of a foot before the typical section change to effectively remove any gap in the model
  - Sidestreet tie-ins to mainline
    - Use a key station to ensure a template is dropped at the station closest to the intersection where the design is controlled by sidestreet geometry
- Horizontal Alignment:
  - Horizontal alignment deflection points (PIs) without a horizontal curve
- Vertical Alignment:
  - Vertical alignment grade break points (PVIs) without a vertical curve
  - Controlling Minimum Vertical Clearance locations
- Edge of Pavement (EP) Layout / Shoulder Break Point Layout / Cross Section Design:
  - Superelevation transition stations
  - Begin/End tapers on edge of pavements (turn lane tapers, shifting tapers, lane addition tapers, lane drop tapers, etc.)
  - Shoulder break point at guardrail terminal pads (point controls, parametric constraints)
  - Other shoulder break point considerations:
    - Shoulder flaring at trailing anchor to transition back to normal shoulder width
    - Shoulder flaring approaching and trailing bridges
    - Transitions between rural and urban shoulders
    - Transitions between mainline and sidestreet shoulders

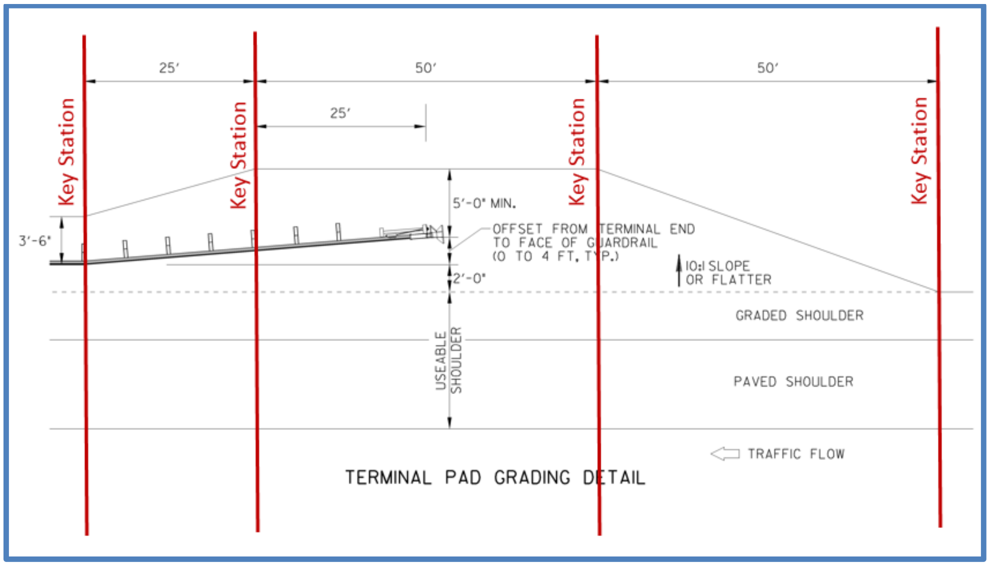

Figure 11: Typical guardrail terminal pad. Adding Key Stations as shown will ensure the model accurately reflects the design intent (and construction limits) in this area.