TunnelCAD User Manual

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TunnelCAD is a professional tunnel cross-section monitoring and analysis application. It provides engineers, surveyors, and project managers with tools to import, visualize, and analyze tunnel excavation data against theoretical design profiles.

CHAPTER

ONE

GETTING STARTED

TunnelCAD is a professional tunnel cross-section monitoring and analysis application built for engineers, surveyors, and project managers. It lets you import, visualize, and compare measured tunnel profiles against theoretical design templates, compute volumes (overbreak, underbreak, shotcrete), process point cloud data, and generate analytics reports.

1.1 Key capabilities

- Cross-section monitoring – overlay measured profiles on design templates to visualize deviations
- Volume calculations – compute overbreak, underbreak, and custom volume formulas along the alignment
- Point cloud processing – import LAS/LAZ/E57 files and extract cross-sections from scan data
- Analytics and compliance – quality grading, clearance checks, deviation statistics
- Import/Export – LandXML 1.2/2.0, DXF templates, CSV/XLS mass tables, legacy TCM conversion

1.2 System requirements

Operating system
: Windows 10 or later (x86_64)

  Linux x86_64 with GTK2 widget set

Graphics
: OpenGL support required for the point cloud viewer

Disk space
: Approximately 50 MB for the application and resources

1.3 Installation

TunnelCAD is distributed as a portable application. No installer is needed.

1. Extract the archive to a folder of your choice.

2. Ensure the `resources/` folder sits next to the `TunnelCAD` executable. This folder contains hatch patterns (`.pat`), linetypes (`.lin`), plot styles (`.ctb`), and fonts (`.shx`) that the application loads at startup.
3. Run the executable: `TunnelCAD` on Linux, `TunnelCAD.exe` on Windows.

> **Note**
>
> On Linux you may need to install OpenGL libraries if they are not already present:
>
> ```
> sudo apt install libgl1-mesa-dev libglu1-mesa
> ```

1.4 Settings file

TunnelCAD stores its settings in a JSON file that is created automatically on first launch:

Linux
: `~/.config/TunnelCAD/settings.json`

Windows
: `%APPDATA%\TunnelCAD\settings.json`

The settings file stores canvas background color, window position and size, recent file list, and debug logging preferences. You can also edit settings from within the application via File > Settings.

1.5 First launch

When you start TunnelCAD for the first time, it creates a default settings file and displays an empty workspace. From here you can create a new project, open an existing `.tun` file, or convert a legacy `.tcm` file.

> **Tip**
>
> If the application window appears but hatch fills or linetypes are missing, verify that the `resources/` folder is in the same directory as the executable.

1.5.1 Interface Overview

This page describes the main elements of the TunnelCAD window and where to find the tools you need.

Title bar

The title bar shows the application name followed by the current project file name. If the project has unsaved changes, an asterisk (*) is appended to the name. When no project is open the title bar shows only “TunnelCAD”.

Menu bar

The menu bar provides access to all commands organized into the following menus:

File
: New Project, Open, Save, Save As, Convert TCM, Export/Import LandXML, Recent Files, Close, Settings, Exit.

Tunnel
: Add Tunnel, Delete Tunnel, Import Geometry (load an `.alm` alignment file).

View
: Toggle visibility of the Command Line panel and Properties panel.

Section
: Section-related commands (also accessible from the ribbon).

Template
: Edit Templates – opens the template editor dialog.

Volume
: Volume definition and computation commands.

Point Cloud
: Import point cloud files (LAS/LAZ/E57), Attach pre-processed `.iqpc` files, Section Viewer.

Test
: Diagnostic tools including Volume Calc Test.

Reports
: Line Data, Line vs Theoretical, DR Trend / Stats. See *Reports*.

Help
: Manual (F1 — opens `TunnelCAD_Manual.pdf` from the executable directory), License Manager, About dialog.

> **Tip**
>
> Keyboard shortcuts are shown next to menu items. Common ones include Ctrl+N (New), Ctrl+O (Open), Ctrl+S (Save), Ctrl+W (Close), Ctrl+Q (Exit), and F1 (Manual).

Ribbon toolbar

The ribbon toolbar sits below the menu bar and provides quick access to the most frequently used operations. It is organized into tabs, each containing grouped buttons.

Sections tab

The default ribbon tab, divided into four panes:

Navigation
: Prev / Next – step through cross-sections one at a time.

Section
: Add – add a new section (single station or range). Delete – delete the current section. Del Range – delete multiple sections by station range.

Template
: Assign – open the template editor to define and assign design profiles. Copy – copy template definitions between tunnels in the same project.

Section Edit
: Sort – sort measured points within section lines. Filter Elev – delete points above or below an elevation threshold. Filter DR – delete points by deviation ratio. Closed – batch toggle open/closed override on section lines. Close to Lvl – extend line ends to a target elevation. Close Invert – add invert closure points near the tunnel axis.

Home tab

Always visible. Holds project-level and help commands:

Project
: New / Open / Save / Save As / Close.

Settings
: Settings – opens the Application Settings dialog.

Help
: Help – opens `TunnelCAD_Manual.pdf` from the executable directory (same as the Help menu entry, and F1). License – opens the License Manager dialog where users can activate/deactivate a serial, edit the Server URL that points to the activation server, or use Clear License to remove the license file from this PC without a server round-trip (with confirmation). About – shows the About dialog with the version, build date, copyright and licensed modules.

Point Cloud tab

Contains a single pane:

Import
: Load – import a point cloud file. Clear – remove the loaded point cloud from memory.

Analytics tab

Visible when the Analytics view is active. Contains:

Parameters
: Mode (Measured vs Template / Measured vs Measured), Measured and Reference combo boxes. These stay synchronised with the active tunnel (see *Active-tunnel synchronisation*).

Station Range
: From and To text boxes accepting chainage values. Filled on activation with the tunnel's chainage range.

Analysis
: Analyze – run the analytics pipeline. Settings – open the Analytics Configuration dialog.

Export
: XLSX – workbook with per-section metrics and grading criteria. PDF – per-section PDF. DXF – annotated section drawings.

Reports
: Grade – Grade quality PDF report. Clearance – Clearance PDF report (with the new clearance heatmap page and critical-only filter that now applies to the details table too). Tolerance – Tolerance PDF report with methodology pages, tolerance heatmap and USL/LSL corridor sketches.

Workspace area

The central area of the window is occupied by the project workspace. Each open project appears as a tab in a page control, allowing you to work with multiple projects simultaneously. Within each project tab, the workspace is divided into three canvas tabs along the bottom edge:

Sections
: Displays the current cross-section in local coordinates (offset vs. elevation relative to the alignment axis). Measured lines are overlaid on template lines so you can visually assess deviations.

Alignment
: Shows the tunnel alignment in world coordinates (Easting/Northing). Useful for viewing the overall geometry and section locations along the route.

Point Cloud
: Renders imported point cloud data using OpenGL. Requires a graphics card with OpenGL support.

> **Note**
>
> The Sections canvas is where most day-to-day monitoring work happens. Use Prev/Next on the ribbon or the section details grid to navigate between stations.

Project tree

The left side of the workspace contains the project tree, which gives a hierarchical view of the tunnel project structure:

```
Project Name
  +-- Tunnel 1
  |     +-- Line Definitions
  |     +-- Template Lines
  |     +-- Templates
  |     +-- Sections
  |     +-- Volumes
  +-- Tunnel 2
        +-- ...
```

Line Definitions
: Named measured-data line types (e.g., “Excavation”, “Final Lining”, “Shotcrete”).

Template Lines
: Named design-profile line types used in templates.

Templates
: Design profiles that define the theoretical tunnel shape at a given station.

Sections
: The list of measured cross-sections along the alignment.

Volumes
: Volume definitions that pair measured and template lines for overbreak/underbreak calculations.

Clicking an item in the tree navigates to that element and updates the canvas and detail panels.

Right-side panel

The right side of the window contains a panel with two tabs, separated from the workspace by a draggable splitter:

Properties
: An object inspector that shows the properties of the currently selected entity on the canvas. You can edit values directly in this grid.

Section Details
: A read-only grid showing key data for the current cross-section, including station chainage, section name, bearing, assigned template, axis elevation, gradient, and lateral offsets.

> **Tip**
>
> You can toggle the right panel on or off via View > Properties. Drag the splitter to resize it.

Command line panel

A resizable panel at the bottom of the window (below the canvas area) provides a command line interface. Toggle it via View > Command Line.

The command line displays feedback messages from operations (import results, computation summaries, errors) and accepts typed commands.

Status bar

The status bar at the very bottom of the window has two sections:

- Coordinate display (left) – shows the current cursor position in canvas coordinates as you move the mouse.
- Status text (right) – shows “Ready” or contextual messages during operations.

1.5.2 Quick Start Tutorial

This tutorial walks you through creating a basic tunnel monitoring project from scratch. By the end you will have a project with an alignment, design templates, measured cross-sections, and volume results.

1. Launch TunnelCAD

Run the `TunnelCAD` executable. On first launch the application creates a default settings file and opens with an empty workspace.

2. Create a new project

Go to File > New Project (or press Ctrl+N). A new project tab appears in the workspace with the name “Untitled”.

3. Add a tunnel

Go to Tunnel > Add Tunnel. In the dialog that appears, enter:

- Name – a descriptive name for the tunnel (e.g., “Main Bore”)
- Start Chainage – the starting station of the tunnel (e.g., 0.000)
- End Chainage – the ending station (e.g., 500.000)

Click OK. The tunnel appears in the project tree on the left.

> **Tip**
>
> You can import an existing horizontal and vertical alignment from an `.alm` file via Tunnel > Import Geometry. This defines the 3D centreline of the tunnel.

4. Define line definitions

Line definitions describe the types of measured data lines you will use (e.g., “Excavation”, “Final Lining”, “Shotcrete”). Each line definition has a name and a display style (color, linetype, weight).

1. Go to File > Settings (or click the Settings button) to open the Tunnel Settings dialog.
2. Navigate to the Line Definitions section.
3. Add entries for each type of measured line your project requires.
4. Assign a color and linetype to each so they are visually distinct on the canvas.

> **Note**
>
> Line definitions are per-tunnel. If your project has multiple tunnels, define them for each one.

5. Define template line definitions

Template line definitions work the same way as measured-line definitions, but they describe the lines used in design templates (e.g., “Design Profile”, “Clearance Envelope”).

Configure these in the same Tunnel Settings dialog under the Template Line Definitions section.

6. Create a design template

A template defines the theoretical cross-section shape of the tunnel at a given location. Templates are made up of template lines, each referencing a template line definition.

1. Go to Template > Edit Templates (or click the Assign button on the ribbon).
2. In the Template Editor, click Add to create a new template.

3. Draw the design profile by adding points. For arcs, set the bulge value on the relevant segment.
4. Assign each line segment to a template line definition.

> **Warning**
>
> When defining arcs, always add the end point first, then set the bulge value on that segment. The bulge array requires at least two points to be present.

7. Assign templates to station ranges

Templates are applied to specific chainage ranges via station definitions. This tells TunnelCAD which design profile to use at each cross-section location.

In the Template Editor, use the Station Definitions panel to assign your template to a start and end chainage. You can assign different templates to different ranges along the tunnel.

8. Add cross-sections

Cross-sections represent the measured tunnel profile at a specific station.

1. Click Add on the Section pane of the ribbon.
2. In the Add Section dialog, choose:
   - Single mode to add one section at a specified station, or
   - Range mode to add sections at regular intervals over a chainage range.
3. Enter the station chainage and section name.
4. Click OK.

The new section appears in the Sections canvas showing the assigned template overlay.

9. Import measured data

You have several options for getting measured data into your sections:

- LandXML import – go to File > Import LandXML to import cross-section data from a LandXML 1.2 or 2.0 file.
- DXF import – import measured profiles from DXF template files.
- Point cloud extraction – load a point cloud via Point Cloud > Import, then use the Section Viewer to extract profiles at each station.
- Manual entry – add individual points directly on the Sections canvas.

> **Tip**
>
> When importing from LandXML, TunnelCAD auto-detects the schema version (1.2 or 2.0) and maps cross-section offset/elevation data to the correct line definitions.

10. Review deviation analysis

Switch to the Sections canvas tab. The current cross-section displays measured lines overlaid on the design template. Deviations between measured and design profiles are immediately visible.

Use the ribbon Prev/Next buttons to step through sections and review each station. The Section Details tab on the right panel shows numerical data including bearing, elevation, gradient, and offsets.

Section Edit tools on the ribbon help clean up measured data:

- Sort reorders points within each line
- Filter Elev removes outlier points by elevation
- Filter DR removes points exceeding a deviation threshold
- Closed / Close to Lvl / Close Invert help close open profiles for accurate area calculations

11. Define volumes

Volume definitions pair a measured line with a template line to compute overbreak, underbreak, or material quantities between them.

1. Go to the Volume menu or expand the Volumes node in the project tree.
2. Open the Volume Editor to create a new volume definition.
3. Select the measured line (e.g., “Excavation”) and the template line (e.g., “Design Profile”).
4. Choose the calculation type (overbreak, underbreak, or a custom formula).

12. View the mass table

After defining volumes, compute results and view them in the mass table:

1. Click Compute to calculate volumes across all sections.
2. Open the Mass Table to see a tabulated summary of areas and volumes for each section interval.
3. Export results to CSV or spreadsheet format for reporting.

> **Note**
>
> Volume calculations use the area between measured and template polylines at each section, then integrate along the alignment between stations. Results are displayed in the project’s configured units.

13. Save the project

Go to File > Save (or press Ctrl+S) to save the project as a `.tun` file. TunnelCAD uses an XML-based format that stores all alignment data, templates, sections, volume definitions, and style libraries in a single file.

If this is a new project, you will be prompted to choose a file name and location.

Tip

TunnelCAD tracks unsaved changes and will prompt you to save when closing a project or exiting the application. Look for the * in the title bar to see if there are pending changes.

Next steps

With the basics covered, explore these areas to get more from TunnelCAD:

- *Templates* – advanced template design with arcs, multi-line profiles, and superelevation
- *Volumes* – custom volume formulas, volume reports, and mass table export
- *Point Cloud* – importing scan data and extracting cross-sections
- *Analytics* – quality grading, clearance reports, and statistical analysis
- *Import/Export* – LandXML workflows, DXF templates, and legacy TCM conversion

CHAPTER

TWO

PROJECTS

A TunnelCAD project is the top-level container for all tunnel monitoring data. Each project is stored as a single `.tun` file (XML-based) and contains one or more tunnel alignments, plus shared style libraries for section lines and alignment display.

2.1 Project structure

Every project holds:

- Tunnel alignments – each alignment is fully self-contained with its own alignment geometry, line definitions, template line definitions, templates, station definitions, cross-sections, and volume definitions.
- Section line style library – shared styles that control how measured and template lines are drawn across all tunnels.
- Alignment style library – shared styles for alignment display on the alignment canvas.
- Project-level units – angular units, station format, and decimal-place settings that apply to the entire project.

2.2 Creating and opening projects

2.2.1 New project

Select File > New Project (or press `Ctrl+N`) to create a blank project. The new project opens in a new tab with a default empty tunnel alignment ready for configuration.

2.2.2 Open existing project

Select File > Open… (or press `Ctrl+0`) to browse for a `.tun` file. TunnelCAD also supports importing legacy `.tcm` files via File > Convert TCM…, which converts the old format into the current `.tun` format.

2.2.3 Recent files

The File > Recent Files submenu lists previously opened projects for quick access. Click any entry to reopen that project.

2.3 Saving projects

- File > Save (`Ctrl+S`) – saves the current project to its existing file path. If the project has not been saved before, this behaves like Save As.
- File > Save As… – prompts for a new file name and location.

2.4 Modified indicator

When a project has unsaved changes, an asterisk (*) appears in the tab caption next to the project name. Closing a modified project (via File > Close, `Ctrl+W`, or exiting the application) triggers a save prompt asking whether to save, discard, or cancel.

2.5 Multi-project tabs

Multiple projects can be open simultaneously, each in its own tab. Use File > Close (`Ctrl+W`) to close the active project tab, or File > Close All to close every open project. Each tab independently tracks its own modified state.

2.6 Activity log / Calendar

Each project carries its own audit log and lightweight task tracker. The Calendar workspace tab records system events (saves, edits, imports, exports, analytics runs) automatically and lets the user add status-tagged notes alongside them. The log is persisted in the `.tun` file. See *Calendar / Activity Log*.

2.7 File format

TunnelCAD projects use the `.tun` extension. The file is XML-based and contains all project data: alignment geometry, line definitions, templates, cross-sections, volume definitions, style libraries, and unit settings. See *TUN File Format Reference* for the full schema reference.

2.7.1 Tunnel Alignments

Each tunnel alignment in a TunnelCAD project represents an independent tunnel with its own 3D geometry path, line definitions, templates, cross-sections, and volume definitions. A project can contain multiple tunnel alignments, and each is fully self-contained.

Adding a tunnel

Select Tunnel > Add Tunnel… to open the new tunnel dialog. Provide:

- Name – a unique identifier for the tunnel within the project.
- Description – optional metadata text.
- Start Chainage – the chainage value at the beginning of the tunnel.
- End Chainage – the chainage value at the end of the tunnel.
- Style – the alignment display style to use.

The new tunnel appears in the project tree and becomes the active alignment.

Deleting a tunnel

Select Tunnel > Delete Tunnel to remove the currently selected tunnel alignment from the project. This operation deletes all associated data (sections, templates, volumes) and cannot be undone.

> **Warning**
>
> Deleting a tunnel permanently removes all its cross-sections, templates, and volume definitions. Make sure to save a backup before deleting.

Importing alignment geometry

Select Tunnel > Import Geometry… to import alignment geometry from external sources:

- ALM files – TunnelCAD's native alignment format, containing horizontal elements (lines, arcs, spirals) and vertical PVIs.
- LandXML files – industry-standard exchange format (versions 1.2 and 2.0 are supported).

The imported geometry replaces the current tunnel's alignment engine data.

Editing alignment geometry

The Alignment tab lists the alignment the same way SurveyTools Alignment Solver does (`scr / alignsolver`): a category tree (horizontal elements, vertical profile, station equations, superelevation, widenings, offsets, transition offsets, cant, rail) and a read-only grid. The plan drawing stays on the right. The header shows whether 3D mode is on and, when it is, the section azimuth.

Alignment tree, next to Edit Alignment on the alignment toolbar, shows or hides that tree and its grid. The button stays down while they are on screen. While they are hidden, the plan drawing fills the view. Showing them again restores the width they had.

Edit Alignment… on the tunnel's project-tree menu, Edit on the Alignment ribbon, and the alignment-view toolbar open the alignment editor. It is the Alignment Solver editor:

- Horizontal — PI easting, northing, radius, spiral in/out (clothoid or cubic) and start station. Solve builds the element chain. Apply writes it onto the tunnel.
- Vertical Profile — VPI station, elevation and curve length.
- Station Equations — station back and station ahead.
- Superelevation, widening, offsets, transition offsets and cant — chainage ramps.

3D mode and Section reference azimuth are on the same dialog. 3D mode stations the tunnel along the 3D centreline (a vertical shaft also needs a vertical profile). The section reference azimuth is the horizontal direction of the section axis when that centreline is vertical: 0 is East, counter-clockwise, in the project angle unit (a DMS project edits decimal degrees). Turning 3D mode off keeps the stored azimuth.

Apply recomputes each section's insertion point, bearing and grade from the new geometry and redraws the alignment.

Tunnel components

Each tunnel alignment contains the following components, visible in the project tree:

Alignment engine

The alignment engine defines the 3D path of the tunnel. It consists of:

- Horizontal geometry – a sequence of elements: straight lines, circular arcs, and transition spirals (clothoids). Arc/spiral sign convention: positive (+) = right (clockwise), negative (-) = left (counter-clockwise).
- Vertical geometry – a series of PVIs (Points of Vertical Intersection) defining the vertical profile along the alignment.

The horizontal and vertical geometry together define the station, offset, and elevation reference for all cross-sections.

Line definitions

Measured line definitions describe the lines that are recorded at each cross-section. Each definition has:

Property	Description
Name	Unique identifier for the line
Layer	Drawing layer assignment
Color	Display color
Deviation Line	Reference line for deviation calculations (can reference another measured or template line)
Style	Section line style from the shared style library
Draw	Whether the line is visible on the section canvas
Closed	Whether the line forms a closed polygon

Manage line definitions through the Tunnel Settings dialog (Line Definitions tab). See *Settings* for details.

Template line definitions

Template line definitions describe the theoretical/design lines. Each definition has a name, layer, color, and draw visibility flag. The closed property is determined by the template geometry itself.

Templates

Templates define the theoretical cross-section shape at specific stations. Each template contains geometry for the template lines defined above, using polylines with optional arc segments (bulge values). Templates are assigned to station ranges via station definitions.

Station definitions

Station definitions map templates to chainage ranges, controlling which theoretical shape applies at each station along the tunnel.

Cross-sections

Cross-sections contain the actual measured data at specific chainages. Each section stores measured points for every line definition, along with computed setout offsets and elevations relative to the alignment axis.

Volume definitions

Volume definitions specify how volumes are calculated between pairs of lines (measured vs. template) across a range of stations.

Forepoling umbrellas

Forepoling umbrellas are fans of pipes drilled from a collar chainage. The alignment stores the design inputs. Stakeout coordinates are calculated from the template and the alignment. See *Forepoling Umbrellas*.

Start and end chainage

The start and end chainage values define the valid station range for the tunnel. These are set when creating the tunnel and can be modified later through the Tunnel Settings dialog. Chainages are displayed according to the project's station format setting (e.g., `0+100.000`).

Tunnel description

The description field stores free-text metadata about the tunnel. Edit it through the Tunnel Settings dialog (General tab).

Building a DTM from a measured line

The alignment toolbar Build DTM button produces a 3D triangulated surface (TAECC_SURFACE) by sweeping one chosen measured line across a chainage range. This is useful for visualising a continuous as-built feature – for example, the excavation surface, the lining intrados, or any other line you've sampled across many sections.

Click Build DTM on the alignment toolbar to open the dialog:

Field	Description
Line	Drop-down listing the active alignment's line definitions. Pick the one whose sampled polylines should be threaded into the mesh.
From	Start chainage of the range to mesh. Defaults to the alignment's start chainage.
To	End chainage. Defaults to the alignment's end chainage.

Click OK to build. TunnelCAD walks the cross-sections in the range, collects the chosen line's per-section polyline (in world XYZ), and feeds the chainage-ordered list to `TAECC_SURFACE.BuildSweptSectionMesh`. Each section becomes one cross-rib of the mesh; consecutive ribs are stitched into triangles to form the surface.

Validation

The dialog enforces these checks before producing a mesh:

- The active alignment must have at least one line definition.
- From must be less than or equal to To (an inverted range produces an information dialog, not a mesh).
- At least two cross-sections in the chainage range must have data on the chosen line; otherwise an information dialog explains the gap.

Sections in the range that have no data on the chosen line (or fewer than 2 points) are passed through as explicit gaps: `BuildSweptSectionMesh` bridges them by interpolating between the nearest non-empty neighbours, so a single missing section does not break the mesh.

Output

The resulting mesh is added to the alignment's drawing canvas:

- Name: `DTM-<line name>`
- Layer: `DTM` (created automatically if absent)
- Color: inherits the line definition's color (or `clByLayer` if the definition is not found)

Each Build DTM run replaces any prior DTM surface on the alignment – the design is "one DTM at a time" per alignment. To remove the current DTM without rebuilding, use the Clear DTM toolbar button.

> **Tip**
>
> The DTM is built from the persisted cross-section line data, not from the in-memory section-viewer preview. Any manual edits made in the section viewer must be committed via Sample Current before they show up in the next Build DTM run.

Tunnel Statistics report

Right-click a tunnel in the project tree and pick Tunnel Statistics… to open an HTML report describing the tunnel. The report contains:

1. Summary – tunnel name, chainage range, total length, cross-section count, line-definition counts, template count.
2. Template assignments along the tunnel – a horizontal coloured bar showing each consecutive run of cross-sections sharing a template. Hover any band for from/to/section-count details. Below the bar, a table with the same data.
3. Per-line totals – for each measured line definition: how many cross-sections have data on that line, total point count, average points per section. Template lines are listed below with their colour and layer name.
4. Per-template stats – for each unique template name: section count, total measured points, average density, station range.
5. Per-section detail – collapsed by default; click "Show per-section detail" to expand a table with one row per cross-section (sorted by chainage) and one column per measured line.

The report is a static HTML file, so use the browser's print-to-PDF feature for archiving.

Export Sections

The Export Sections… command is reachable from three places:

- Project tree – right-click a tunnel and pick Export Sections….
- Top main menu – File > Export > Export Sections….
- Ribbon Sections tab – Export > Sections.

All three open the same dialog. While the export runs, a progress bar and a one-line status label at the bottom of the dialog show the current section (or the current phase, in the combined-world mode), and the OK/Cancel buttons are disabled until the export finishes.

File format is DXF, DWG 2018, or IQZ. DWG is written by the native writer as AutoCAD 2018. IQZ is the compressed drawing. A per-section export uses the chosen extension on every file. The combined and atlas browse dialogs offer all three formats.

The dialog has three output modes:

- One file per section (local offset/elevation plane) – writes one file per cross-section in the chosen range. Each file is in the section's local plane (X = offset, Y = elevation). Useful for review or sending individual sections to a reviewer.
- Single combined file (3D world coordinates) – writes one file with every cross-section's polylines transformed to world XYZ via the alignment engine. Useful for BIM / Civil3D / surface-comparison workflows. Bulges and closed-state are dropped because 3D POLYLINE entities do not carry them.
- Sections Atlas (2D sheet layout) – writes a single file where each section is drawn in its own cell of a Columns x auto-rows grid. Each cell may include a frame rectangle and station + name labels. Cell width/height defaults are sized from the largest cross-section in range so geometry never touches the frame; you can override these in the dialog.

What is exported follows the Draw=Yes flag on each line definition in Tunnel Settings: lines hidden in the section editor are not exported. Layer name matches the line definition name; layer colour matches the line definition colour.

The Range section selects either the active cross-section only or an inclusive chainage range from `From` to To.

Templates and DR labels (v2)

In all three modes, template-line polylines are exported when their definition has `Draw = Yes`. Templates are resolved per section the same way the section editor canvas resolves them – via the alignment's station-range mapping (Station Definitions, including transition-zone interpolation), with a fallback to the section's own assigned `TemplateName` for legacy data without station defs. For every visible template line, the polyline is emitted on a layer named after the template-line definition (colour from the definition).

In per-section and atlas modes, measured lines whose section line style has `Show DR = Yes` get deviation lines and DR labels at every point selected by the style's DR Display Mode – the same setting that drives DR rendering in the section editor canvas. Smart, Threshold, Interval, Extremes, Zone Extremes, All, and None all work as on screen. The label shows the deviation in the unit (mm/cm/m) and decimal places set on the style.

DXF and DWG write that measured curve, the deviation lines, and the DR text as ordinary CAD entities. IQZ stores the tunnel section line, links it to the reference line (the deviation line drawn on the section), and stores the section-line styles, so opening the file draws the DR the way the section view does.

Mode B (combined world coordinates) does not emit DR labels – they would float in 3D space, illegible.

In per-section and atlas modes, Tunnel Settings → Section Draw → Draw Forepoling Piles adds a circle of the pipe diameter wherever a forepoling pipe crosses that section. The circles go on the layer `Forepoling`, named with the umbrella and the pipe number, and View Along Decreasing Chainage mirrors them with the section. Mode B does not include these circles. See *Forepoling Umbrellas*.

> **Note**
>
> Mode B requires the alignment to have an engine geometry (horizontal + vertical) for any geometry to be exported. Sections in a tunnel without an alignment engine, or with an empty horizontal geometry, are silently skipped in Mode B for both measured and template lines. Use Mode A (per-section local plane) or Mode C (atlas) when the alignment has not yet been imported.

2.7.2 Forepoling Umbrellas

A forepoling umbrella is a fan of pipes drilled ahead of the face from one collar chainage. TunnelCAD stores the design on the tunnel alignment and calculates stakeout coordinates from the template and the alignment. Each pipe is a straight line in project coordinates, from its collar to its tip.

One entry is one umbrella. To cover a drive with several overlapping fans, add one umbrella at each collar chainage. The list is ordered by collar chainage, lowest first. Two umbrellas at the same chainage keep the order they already had.

Opening the editor

Open Forepoling Umbrellas in either of these ways:

- On the Alignment view, click Forepoling umbrellas on the alignment toolbar.
- In the project tree, right-click the tunnel and choose Forepoling Umbrellas….

The command uses the tunnel selected in the tree, or the active tunnel when the selection is not a tunnel. The alignment needs horizontal geometry, and a template must cover the collar chainage.

The editor has the umbrella list on the left and the inputs across the top. Add creates an umbrella. Delete removes the selected one. Calculate fills the stakeout table. Export CSV writes that table. Export PDF writes the stakeout report. Draw axes puts the pipes on the alignment view. Close returns to the project. Edits are kept when the dialog closes.

What you enter

The `.tun` file stores these inputs. Collar and tip coordinates are calculated again whenever you calculate, draw, or open the sketch, so they follow the alignment if the geometry changes.

Angles in the form use the project angular unit (degrees, DMS, gradians, or radians). The file stores degrees.

Input	Meaning
Name	Name of this umbrella. It becomes the alignment layer `Umbrella-<name>`.
Collar chainage	Station where every pipe of this umbrella starts.
Template line	Design line the collars are measured from, usually the excavation outline. The line must exist on the template that covers the collar chainage, and the arch window must lie on that outline.
From crown	Left-hand limit of the fan, in degrees from the crown. Negative is left.
To crown	Right-hand limit. Positive is right. From crown must be the left-hand limit, so it is smaller than To crown.
Spacing	Largest gap allowed between pipes, measured along the template line.
Radial standoff	Distance from the template line out to the pipe axis, away from the alignment axis.
Pipe length	Length of each pipe, measured along the pipe from collar to tip.
Lookout	Angle between the pipe and the alignment tangent, outward toward the collar.
Diameter	Pipe diameter. The stakeout sheet records it, and the section view draws a circle of this diameter where the pipe crosses the section. It does not move the collar and it does not change the spacing.
Decreasing station	Drill the pipes back down the chainage. Leave it off to drill toward increasing chainage.

A new umbrella starts from −60° to +60°, with spacing 0.40 m, radial standoff 0.15 m, length 12 m, lookout 6°, and diameter 0.114 m. Decreasing station is off. The collar chainage starts at the tunnel's start chainage.

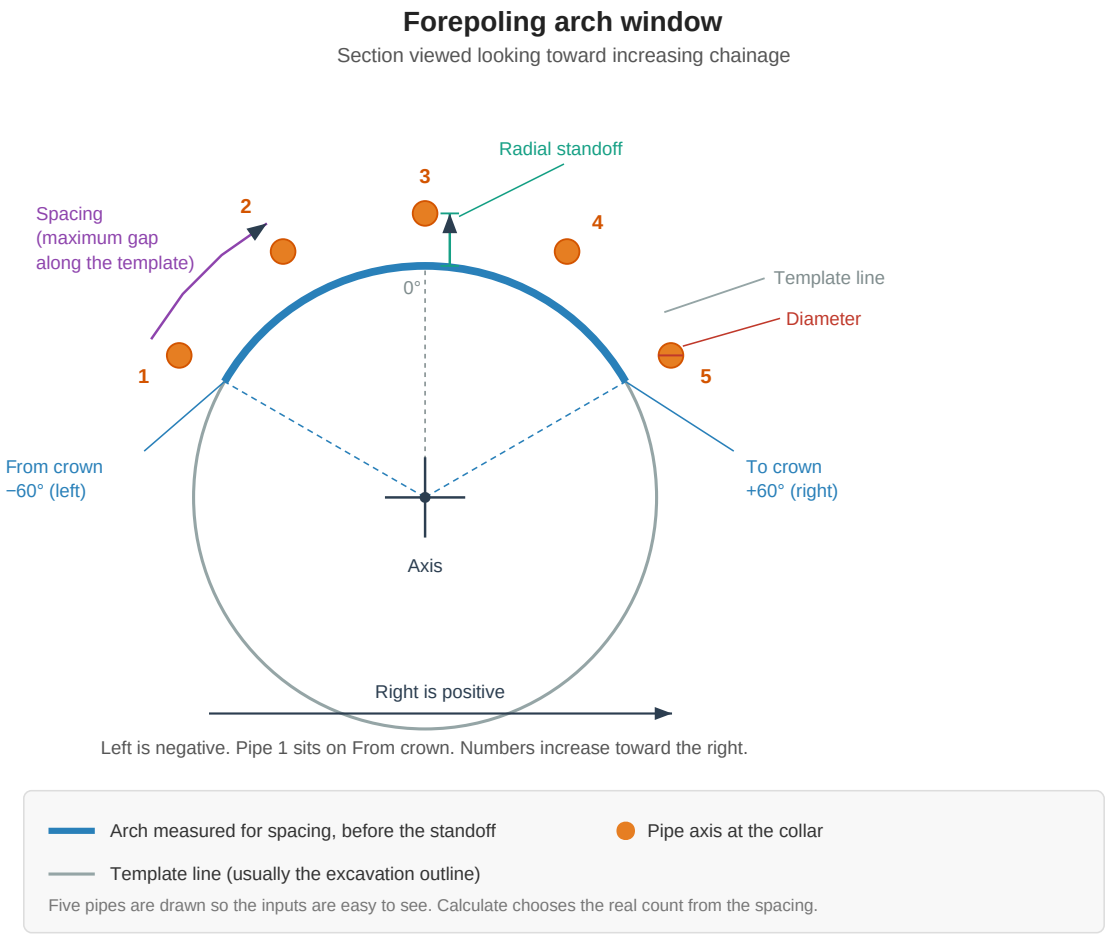


Fig. 1: Arch window on the section. Left is negative and right is positive, looking toward increasing chainage. Spacing is measured on the template line. The radial standoff then moves each pipe axis outward.

Crown angles

Zero is the crown. The sign is the same as every other offset in TunnelCAD: looking toward increasing chainage, left is negative and right is positive. From crown is the left limit and To crown is the right limit.

Pipe 1 sits on From crown. The numbers increase toward the right, and the last pipe sits on To crown. Decreasing station does not swap left and right. The fan is still described looking toward increasing chainage.

Set From crown and To crown to the same angle to place a single pipe, for example `0` and `0` for one crown pipe.

Spacing

Spacing is the largest gap you will accept, measured along the template line before the radial standoff is applied. TunnelCAD measures that arch, then chooses the smallest number of equal gaps that stay at or under the spacing:

- Gaps = the arch length divided by the spacing, rounded up.

- Pipes = gaps + 1.
- Actual spacing = arch length / gaps.

The end pipes stay on the two limits. The status line reports the pipe count and the arch length.

Example. A circular excavation of radius 5.00 m, from −60° to +60°, spacing 0.40 m. The arch is 120° of that circle:

`120 / 360 × 2 × π × 5.00 = 10.472 m`

`10.472 / 0.40 = 26.18`, which rounds up to 27 gaps, so 28 pipes. The actual spacing is `10.472 / 27 = 0.388 m`. A radial standoff of 0.15 m puts the pipe axes on a radius of 5.15 m. That standoff is applied after the arch is measured, so it does not change the pipe count.

Radial standoff and diameter

The radial standoff is the distance from the template line to the axis of the pipe, measured away from the alignment axis in the section. The collar in the stakeout table is that point. The diameter is recorded beside it so the stakeout sheet can show the pipe size. The drawn axis is the centreline.

Lookout

Lookout is the angle between the pipe and the alignment tangent. The tangent includes the grade. Each pipe leaves that tangent in the plane that contains the tangent and the outward radial of its own collar.

- At the crown the radial is upward, so the pipe rises above the alignment.
- At a shoulder the same angle also carries the pipe outward, away from the axis.

The stakeout inclination is a different angle: it is the pipe above the horizontal. On a level tunnel, at the crown, the inclination equals the lookout. On a grade, or away from the crown, the two numbers differ. A climbing crown pipe has a larger inclination than its lookout, because the lookout is measured from the rising tangent and the inclination is measured from the horizontal.

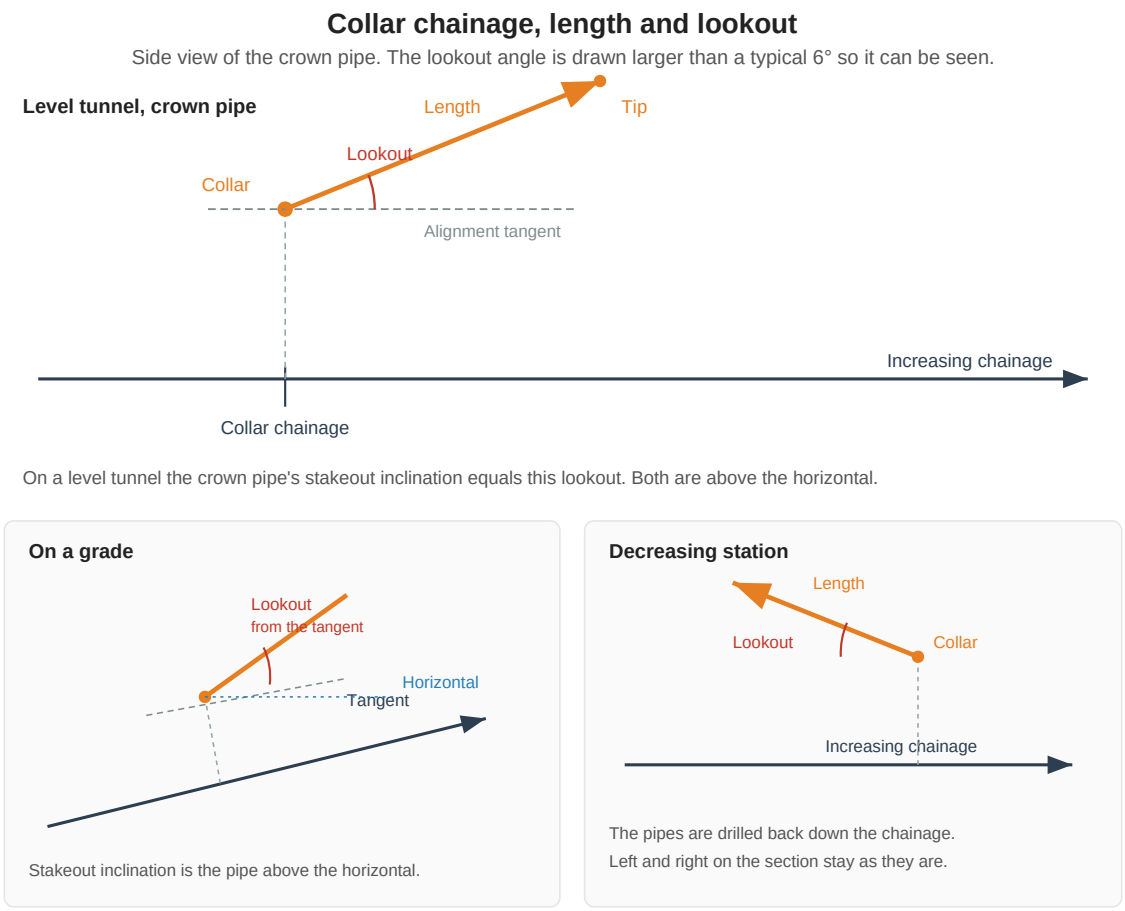


Fig. 2: Collar chainage, pipe length, and lookout. Lookout is measured from the alignment tangent. The stakeout inclination is the same pipe measured from the horizontal. Decreasing station drills back down the chainage.

Decreasing station reverses the drilling direction. The pipes leave the collar toward decreasing chainage, and the lookout is measured from that reversed tangent. The section window is unchanged. On a level crown, a 6° lookout is still a 6° inclination, and the survey bearing turns by 180°.

Length is the distance from collar to tip along the pipe. The tip is not one length further along the chainage: on a curve, and whenever the pipe has a lookout, the chainage of the tip is shorter than collar chainage plus length.

Stakeout

Calculate checks the inputs and fills the Stakeout tab. The table has one row per pipe:

Column	Meaning
Pipe	Pipe number. 1 is the left limit.
Offset	Collar offset from the alignment axis. Right is positive.
Height	Collar height above the alignment axis.
Collar E, N, Z	Collar easting, northing, and elevation.
Tip E, N, Z	Tip easting, northing, and elevation.
Bearing	Survey bearing of the pipe, clockwise from north, in the project angular unit.
Inclination	Angle of the pipe above the horizontal, in the project angular unit.
Length	Pipe length, in metres.
Diameter	Pipe diameter, in metres.

Export CSV writes the same rows, plus the umbrella name and the collar chainage. Bearings and inclinations use the project angular unit, and the column title carries the unit (deg, gon, or rad).

PDF report

Export PDF writes a report in the same family as the Analytics reports. The cover is the TunnelCAD Analytics cover, the footer is the Analytics footer, and each later page uses the same title and subtitle. The default file name is `<TunnelName>_Umbrella_<Name>.pdf`.

The report has these pages:

- Cover. Project, tunnel, and the chainage from the collar out to the tips along the alignment tangent. The count on the cover is the number of pipes. On a curve that chainage span is shorter than the pipe length, and it is not a chainage measured around the curve.
- Design inputs. Every value from the dialog, in the project angular unit, plus the arch length, the number of gaps, the pipe count, and the actual spacing.
- Collar section. The template line, the arch the spacing was measured on, and a circle at each pipe axis. Pipe 1 is the left limit. Left is negative, looking toward increasing chainage. Decreasing station does not swap the two sides.
- Lookout. A side view at equal scale. The alignment tangent is drawn through the crown collar and includes the grade. Lookout is the angle off that tangent. A dashed line marks the horizontal when the tunnel is on a grade. The heavier line is the pipe nearest the crown. Decreasing station draws the pipes back down the chainage.
- Stakeout. The same columns as the table, on a landscape page. Bearing is clockwise from north. Inclination is above the horizontal.

Chainages use the project station format. Coordinates use the project decimals.

The status line names the problem when a calculation cannot run. Typical causes are: the alignment has no horizontal geometry, no template covers the collar chainage, the chosen template line is missing or has no outline, the outline does not cover the whole arch window, From crown is to the right of To crown, or the spacing or the pipe length is not positive.

Sketch

The Sketch tab draws this umbrella in 3D, together with the alignment along the drilled length. A decreasing-station umbrella shows the alignment back down the chainage. Chainage labels sit on the alignment, and each pipe is numbered at its collar.

- Drag to turn the view.
- The wheel zooms.
- The middle button pans.
- Zoom extents fits the umbrella without changing the viewing angle.

A new calculation resets the view to a three-quarter view. Switching back to the Sketch tab keeps the view you had turned.

Draw axes

Draw axes switches to the Alignment view and draws one straight polyline per pipe, from collar to tip. The polylines go on a layer named `Umbrella-<name>`. Drawing the same umbrella again replaces that layer. The lines follow the current inputs, including Decreasing station.

Section view

Tunnel Settings → Section Draw → Draw Forepoling Piles draws the pipes on the section you are viewing. The setting is on for a new tunnel. Turn it off to leave the section picture without the piles.

Each pile is a circle of the pipe diameter. The centre is the point where that pipe's axis crosses the section, so a section between the collar and the tip shows the pipes that are still in the ground there. Overlapping umbrellas are all drawn. A pipe that does not cross the section is omitted, and an umbrella that cannot be calculated is skipped. The circles go on a layer named `Forepoling`, in the same orange as the stakeout sheet. The circle's name is the umbrella name and the pipe number.

Left and right follow the section. View Along Decreasing Chainage mirrors the piles with the rest of the section. Opening the section draws the circles again from the current design. They are not stored as measured lines. Closing the umbrella editor refreshes the section when that tunnel is the one on screen.

The same circles are written into a per-section export and into a sections atlas, in DXF, DWG 2018, or IQZ. The combined world-coordinate file does not include them.

The choice is stored on the tunnel as `drawForepolingPiles` (`1` or `0`). A file that has no such attribute draws the piles.

Saved design

Each umbrella is stored inside its tunnel:

```
<Umbrellas>
  <Umbrella name="Umbrella 487" collarChainage="487.05"
            templateLine="Line B" fromCrownDeg="-60" toCrownDeg="60"
            spacing="0.4" radialOffset="0.15" length="12"
            lookoutDeg="6" diameter="0.114" decreasingStation="0" />
</Umbrellas>
```

`fromCrownDeg`, `toCrownDeg`, and `lookoutDeg` are degrees. `decreasingStation` is `1` when the pipes are drilled toward decreasing chainage, and `0` otherwise. A file written by an older build has no `decreasingStation` attribute; those umbrellas drill toward increasing chainage.

A realignment proposal copies these inputs onto the new alignment. Coordinates are not copied, because they are calculated from the alignment the umbrella belongs to.

2.7.3 Realignment Proposal

For tunnels where the final lining has been cast with locally-deficient thickness, the Realignment Proposal tool computes a corrected alignment that, when used, would shift the design template enough to restore the required thickness across all measured points.

The original tunnel is never modified. The tool clones the active tunnel into a new sibling tunnel under the project tree, with the computed horizontal/vertical offset profile baked into its alignment engine. You review by switching active tunnel between the original and the proposal — DR, clearance, and tolerance reports work against either. You keep what you want, delete the rest.

When to use

- The final lining survey shows points inside the design template (negative DR — the lining is too thin).
- You want to know whether shifting the alignment would let the design template "lean into" the deficient region and recover the required thickness, without re-pouring the lining.

How to use

1. Right-click the tunnel in the project tree → Realignment Proposal….
2. Measured line: pick the line that represents the as-built inner face of the final lining (e.g. *MeasuredFinalLiningInside*).
3. Template line: pick the design template line that represents the theoretical inner face (e.g. *FinalLiningInside*).
4. Required thickness (m): the minimum allowable clearance between the measured polyline and the (shifted) template at every point. E.g. `0.300` for 30 cm minimum.
5. Bounds — `|dh|`, `|dv|`: the maximum lateral / vertical shift you allow per station. Caps the LP search range. E.g. `0.200` m.
6. Smoothing — Window: rolling-mean window length in metres. `0` disables smoothing. E.g. `50.0` m.
7. Smoothing — Max gradient: maximum gradient (%) of the offset profile. The constructibility safety net. E.g. `0.500` % = 5 mm/m.
8. The preview charts update live. The top chart is dh (horizontal shift in metres) vs station; the bottom chart is dv. Grey = raw per-section LP output; blue = smoothed and gradient-capped (this is what gets baked into the proposal). Red dashed lines mark the ±bounds. Red triangle markers mark residual-deficit stations.
9. Review the warnings list. Each row is one of:

- `Sta X — residual deficit Y mm at Z°` — LP couldn't fully satisfy the required thickness with the available shift bounds.
- `Sta X — gradient clip dh: Y mm -> Z mm` — smoothing pass clipped a section's shift to enforce the constructibility limit.
- `Sta X — skipped (no measured points / template missing)` — section excluded from the LP entirely.

10. Generate Proposal: clones the tunnel + applies the smoothed offset profile + appends to the project's alignment list + activity log + Modified flag, then closes. The new tunnel becomes active so you immediately see the canvas re-render against it.
11. Cancel: discards everything; no project mutation.

Reading the result

The proposal tunnel appears in the project tree with the suffix *(Realignment proposal)*. Toggle between the original and the proposal via the tree popup *Set Active*; the canvas, DR column, clearance report, and tolerance report all switch between them. To accept the proposal, delete the original (or rename the proposal). To reject it, just delete the proposal. The project file isn't saved until you save it — until then everything is in memory and discardable.

What happens behind the scenes

For each cross-section the tool resolves the measured polyline + the template polyline (template-line first, then a measured-line fallback matching `DeviationLine`) and runs `Engine.ComputePointInfos` to derive the per-point clearance + outward unit normal. It then solves a small LP per section:

```
maximise z
subject to c_i - dh*nx_i - dv*ny_i >= z + RequiredThickness
           |dh| <= DhMax, |dv| <= DvMax
```

`z >= 0` means the section is satisfied; `z < 0` means residual deficit `|z|` (warning). The per-section `(dh, dv)` series is then smoothed (rolling mean) and clipped (forward + backward gradient cap) and written as one piecewise-linear segment per pair of adjacent valid sections into the new alignment's HorizontalOffset / VerticalOffset chainage collections.

Limitations

- One (measured, template) line pair per run.
- The math is one-shot: it does not iteratively re-project measured points onto the proposal alignment. For cm-scale shifts on realistic tunnel curvature, the second-order projection error is sub-mm and well below survey noise; if you ever see evidence the second-order effect matters, run the tool a second time against the proposal — each round corrects relative to its current state.
- A section that is wildly inside the design (deficit > available bounds) cannot be fixed by any (dh, dv); the LP returns the bound-corner solution and flags a residual-deficit warning. The user decides whether to proceed.

Save Report

The Save Report… button on the Realignment Proposal dialog exports a PDF deliverable showing the full realignment analysis without having to first commit the proposal. The report can be emailed to a senior reviewer; once they approve, you come back to the dialog and click *Generate Proposal* (or pick different inputs and try again).

The report contains:

1. Cover page — project, tunnel, proposal name, generation date.
2. Parameters & headline stats — every input that drove the math (lines, threshold, bounds, smoothing knobs) plus aggregated counts (sections analysed, satisfied, residual, skipped, gradient clips, max residual mm, max applied dh/dv mm). One paragraph explains the LP and smoothing pipeline.
3. Longitudinal charts — separate full-page charts of dh and dv versus station. Raw per-section LP output (grey, thin) is overlaid by the smoothed series (blue, thicker). Red dashed lines mark `±DhMax` / `±DvMax`. Red triangles at the top axis mark sections that ended up with residual deficits.
4. Per-section adjustments table — every analysed section, with raw and smoothed dh/dv (mm), residual mm if any, and a status badge (precedence: skipped > residual > clipped > satisfied).
5. Offset profile segments table — the `(StartSta, EndSta, dh start, dh end, dv start, dv end)` tuples being written to the new alignment's `HOffset` / `VOffset` chainage collections.
6. Warnings list — grouped by kind: residual deficits, gradient clips, skipped sections.
7. Per-deficient-section pages — for each section with residual deficit > 0, a page showing:
    - The section sketch: original template (dashed grey), shifted template (solid blue), measured polyline (orange), the worst 10 deficient measured points (red filled circles, 1-based index labels), the shift vector arrow from origin to `(dh, dv)` with its mm label, and origin crosshatch.
    - A constraint table with the same 10 points: angle, original clearance (mm), `c after shift` (mm), and a per-point status (`deficient` / ok).

Save Report does not modify the project — it is a read-only export. You can run it any number of times with different inputs without losing the option to Cancel or Generate the proposal.

2.7.4 Cross-section line edits

The Sections-view toolbar in the project frame includes six commands for editing the polyline data of a single line definition within a cross-section. Each command works either on the active section only or across a chainage range (batch mode). Both modes share the same dialog; selecting the chainage-range radio button enables the From/To fields.

Toolbar button	Effect
Copy Line	Copies the source line's points + bulges + closed-state into the target line.
Move Line	Same as Copy, then clears the source line's data — a cut-and-paste between line slots.
Offset Line	Computes a parallel offset of the source line and writes it into the target. Distance is signed: + moves outside (away from the alignment axis); – moves inside (toward the axis).
Delete Line	Clears all points of one line.
Remove Duplicates	Drops consecutive points whose 2D distance from the previous kept point is below a tolerance (metres). Preserves bulges of kept points and the line's closed-state.
Translate Line	Shifts every point of one line by `(dX, dY)` in metres. Z, bulges, and closed-state unchanged.

Common dialog elements

- Source line / Target line — dropdowns of all measured line definitions in the active alignment. For Move and Copy, source and target must be different. For Offset, source = target is permitted (in-place offset). For Delete, Remove Duplicates and Translate Line there is only one Line dropdown.
- Apply to
  - Active section only — runs on the currently selected section in the Sections view.
  - Chainage range — iterates every cross-section whose station falls in the inclusive range. The From/To fields default to the alignment's first and last stations.
- Skip sections where target already has data (Copy / Move / Offset) — when checked, sections whose target slot already has points are left untouched and counted in the post-run summary as "skipped".

After OK, a summary box reports `Visited N section(s). Applied: M. Skipped: K (target had data) / L (source empty).` Counts equal `Visited` (every visited section is either applied or skipped).

When the run touches the active cross-section, the section canvas reloads from the updated model immediately — no manual refresh, no need to switch sections and back.

Offset side rule

For each segment of the source polyline, "outside" is the perpendicular direction whose midpoint moves *farther* from the alignment axis (the `(0, 0)` point in the section's offset/elevation plane). For a tunnel polyline that wraps around the section interior, this consistently means away from the tunnel axis. For unusual line shapes (e.g., a short measured line off to one side) the rule may pick a counterintuitive side; in that case use a negative distance to flip.

Behavior matrix

Pre-condition	Copy	Move	Offset	Delete
Source has no points	Skipped: source empty	Skipped: source empty	Skipped: source empty	Skipped: line already empty
Target already has data, “Skip” checkbox on	Skipped: target had data	Skipped: target had data	Skipped: target had data	n/a
Source = target	Rejected (OK disabled)	Rejected	In-place offset (allowed)	n/a

Remove Duplicates dialog

- Tolerance (m) — the maximum 2D distance between consecutive points that still counts as a duplicate. Defaults to `0.005` (5 mm). The first point is always kept; subsequent points whose distance from the most recent kept point is at or below the tolerance are dropped. The bulge that travels with each kept point is preserved.
- The summary reports `Visited N section(s). Modified: M. Skipped: K (line empty).` Sections where the scan finds no duplicates are counted as visited but not modified.

Translate Line dialog

- dX (m) / dY (m) — translation vector in the section’s local offset/elevation plane. X follows the line-definition’s offset axis (right-positive), Y follows elevation. Both can be negative. Translating by `(0, 0)` is rejected at the dialog (OK button stays disabled).
- Every point of the chosen line is shifted by `(dX, dY)`; Z is preserved. Bulges and closed-state are unchanged.
- The summary reports `Visited N section(s). Modified: M. Skipped: K (line empty).`

Notes

- Bulges: Copy, Move, Remove Duplicates, and Translate Line preserve bulges exactly. Offset drops bulges (output polyline is straight-segment only). Acceptable accuracy for tunnel measured lines; revisit if exact-arc lines start using these commands.
- Closed state: Copy and Move mirror the source’s `coDefault` / `coForceClosed` / `coForceOpen` override. Offset, Remove Duplicates, and Translate Line preserve the source’s closed state.
- Self-intersection: A closed polyline offset inward beyond its inradius will self-intersect. v1 emits the raw self-intersecting polyline; clean it up by hand or undo.
- Undo: Batch operations are not undoable as a single transaction. Confirm the summary box’s counts before continuing.

Section metadata

Each tunnel can declare a set of metadata fields (excavation date, blast number, crew name, free-form notes…). Field schema is defined per tunnel; values are entered per cross-section.

Defining the schema

1. Open *Tunnel Settings…* on the active alignment.
2. Switch to the Metadata Fields tab.
3. Click Add Field, enter a name (`[A-Za-z0-9_]`), pick a Type. Optionally tick *Required* and fill *Default* / *Description*.
4. For *Enum* type, click Edit Enum Values… to add the allowed choices.
5. Buttons Move Up / Move Down reorder the schema; Remove Field drops a definition (with a confirm prompt that names how many sections have values to clear).

New tunnels start with three example fields: `ExcavationDate` (date), `BlastNumber` (integer), `Notes` (text). Delete what you don't need.

Entering values per section

Right-click a cross-section in the project tree → Edit Metadata… to open the per-section editor. Each field renders its own widget:

Field type	Widget
Text	text edit
Integer	number-only edit with up/down arrows
Number	floating-point edit
Date	date picker (`yyyy-mm-dd`)
Boolean	checkbox
Enum	dropdown of the allowed values

OK commits; *Cancel* discards every change made in the dialog.

Using metadata in layouts

Layout TEXT entities can inject metadata via the `META` field:

ProviderArgs	Result
`field=META, meta=ExcavationDate`	`2026-04-15` (default `yyyy-mm-dd`)
`field=META, meta=ExcavationDate, fmt=dd/mm/yyyy`	`15/04/2026`
`field=META, meta=BlastNumber, prefix=Blast #`	`Blast #42`
`field=META, meta=Crew`	`Alpha` (the canonical case from the schema)

Activity log

Schema mutations (add/rename/type-change/remove) and per-section value commits land in the project's activity log under the `metadata` category, viewable in the Calendar workspace.

Round-tripping with LandXML

Both the schema and the per-section values round-trip through LandXML import/export. The export dialog has an opt-out "Include section metadata" checkbox under TunnelCAD Extension Details (default on). Old LandXML files without metadata extensions load with the alignment's seeded defaults.

Bulk editing (matrix view)

For long station lists, the per-section editor is slow. Right-click a tunnel in the project tree → Edit Metadata Matrix… to open a spreadsheet-style grid: rows are sections in chainage order; columns are Station / Name / one per metadata field. Per-column editors switch automatically (text / number / date / checkbox / dropdown). Three helpers above the grid:

- Fill Down copies the active cell's value into every selected row below it (single column at a time).
- Clear wipes selected metadata cells back to empty.
- Paste drops a tab-separated rectangular block from the clipboard — works for paste-from-Excel.

OK commits; Cancel restores the snapshot taken when the dialog opened.

The Metadata Fields tab in *Tunnel Settings* also has an Edit Matrix… button so you can jump straight from defining a new field to filling values across every section.

Including metadata in DXF exports

The Sections-to-DXF export dialog has a per-mode checkbox:

- Mode A (per-section local plane) → captions appear on a `METADATA` layer below each section's bounding box.
- Mode C (atlas / sheet layout) → captions appear inside each cell, stacked below the title line.
- Mode B (combined world XYZ) does not offer the option — 3D-stacked text labels are illegible.

Each non-empty metadata value emits one `Field: Value` line. Empty values are skipped. Off by default.

Including metadata in PDF reports

The three section-level PDF reports (Line Data / Line vs Theoretical / DR Trend) have a per-dialog checkbox Include section metadata (default off). When on:

- The PDF gains a small two-column metadata table at the top of each per-section detail page (one row per non-empty value).

- The XLSX export adds one column per metadata field at the right end of the per-section sheet — handy for pivot tables.

Mass Table

The Mass Table dialog has its own Show metadata columns checkbox. When on, the grid + every export (CSV / XLSX / PDF) gain one column per defined metadata field, formatted per the field's type.

Edit Line Data

For typing-based corrections to measured-line points (paste from Excel, fix a bad offset by typing, reorder rows), open the Edit Line Data… dialog from the section toolbar or the project-tree right-click on a cross-section.

The dialog shows one cross-section's chosen line as a grid:

Column	Meaning	Editable
`#`	Point index (auto-numbered).	no
`Offset (m)`	Lateral offset from the alignment axis.	yes
`Elevation (m)`	Vertical position on the section's local plane.	yes
`DR (mm)`	Computed deviation from the line's reference (template or measured). `--` when no reference is configured. Recomputes live as you type Offset/Elevation.	no

The `#` and `DR` columns are read-only — the in-cell editor will not open for them.

Switch lines via the Line combo at the top — pending edits to the previous line are kept until you click OK or Cancel. Buttons on the right add/delete rows, move the active row up/down, reverse the whole point order, sort all rows by ascending Offset (Sort by X), or toggle the line's Closed flag.

OK commits all changes; Cancel restores every line modified during the dialog session, including pre-existing bulges that the dialog doesn't surface as columns.

Pasted values follow the standard `TStringGrid` paste path — copy a 2-column block from Excel and paste into the Offset/Elevation pair to bulk-update points.

2.7.5 Settings

TunnelCAD has two levels of settings: project settings that are stored in the `.tun` file, and application settings that persist across sessions in a local configuration file.

Project settings dialog

Open the project settings dialog via File > Settings…. The dialog has a category list on the left and an editor panel on the right.

Project Settings page

- Project Name – the display name for the project, shown in the tab caption.
- Tunnels – a read-only grid listing all tunnel alignments in the project. Tunnel names can be edited directly in this grid.

Units page

See *Units* for the full description of unit settings available on this page.

Tunnel settings dialog

Open the tunnel settings dialog by double-clicking a tunnel in the project tree, or by right-clicking a tunnel and selecting Settings…. The dialog groups the tunnel settings on separate tabs.

General tab

Field	Description
Name	Tunnel name (unique within the project)
Description	Free-text metadata
Start Chainage	Beginning station value
End Chainage	Ending station value
Style	Alignment display style name

Line Definitions tab

A grid for managing measured line definitions. Each row represents one line definition with the following columns:

Column	Description
Name	Line identifier (used in cross-sections)
Layer	Drawing layer assignment
Color	Display color (double-click to open the color picker)
Dev. Line	Deviation reference line (dropdown of all measured and template lines)
Style	Section line style (dropdown from the shared style library)
Draw	Visibility toggle (checkbox — single-click to toggle)
Closed	Whether the line forms a closed polygon (checkbox — single-click to toggle)

Use the toolbar buttons to manage definitions:

- Add – creates a new measured line definition (prompts for name).
- Delete – removes the selected definition and all its data from every cross-section.
- Rename – changes the name of the selected definition across all cross-sections.
- Style Editor – opens the section line style editor to create or modify styles in the shared library.

> **Warning**
>
> Deleting a line definition removes all measured data for that line from every cross-section in the tunnel. This cannot be undone.

Template Lines tab

A grid for managing template line definitions with the following columns:

Column	Description
Name	Line identifier (used in templates)
Layer	Drawing layer assignment
Color	Display color (double-click to open the color picker)
Draw	Visibility toggle (checkbox — single-click to toggle)
Closed	Read-only checkbox, mirrors the template geometry's closed state

Use the Add and Delete buttons to manage template line definitions. Deleting a template line removes its geometry from all templates.

Section Draw tab

These settings control what the section view adds around the measured lines and the template. Each one is saved with the tunnel.

Setting	Description
Draw Alignment	Axis cross and the CL label. On by default.
Draw Offset Axis	The OL line, when the alignment has a horizontal offset. Drawn together with the axis cross. On by default.
Draw Tunnel Axis Height	Leader that states the axis elevation. On by default.
Draw Forepoling Piles	A circle of the pipe diameter where each forepoling pipe crosses the section. See *Forepoling Umbrellas*. On by default.
View Along Decreasing Chainage	Look at the section from the falling-chainage side, so left and right swap. Off by default.

Application settings

Application-level settings are stored in a JSON configuration file:

- Linux: `~/.config/TunnelCAD/settings.json`
- Windows: `%APPDATA%\TunnelCAD\settings.json`

These settings include:

- Canvas background color – the background color of the drawing canvases.
- Window position and size – restored on next launch.
- Recent files list – the most recently opened project files.

Debug logging

TunnelCAD includes a built-in debug logging system for troubleshooting. To enable it, add `"debugLog": true` to the `settings.json` file:

```
{
  "debugLog": true
}
```

When enabled, timestamped log entries are written to `iqcad_debug.log` in the application directory. The log uses flush-per-write, so entries survive crashes. Logging is always compiled into the application but remains dormant until explicitly enabled.

2.7.6 Units

Each TunnelCAD project stores its own unit settings, controlling how angles, coordinates, and stations are displayed throughout the application. Configure units via File > Settings… > Units.

Angular units

TunnelCAD supports four angular unit systems:

Unit	Display example	Description
Degrees	`45.0000` followed by degree symbol	Decimal degrees
DMS	`45deg00'00.0000"`	Degrees, minutes, seconds
Gradians	`50.0000g`	Gradians (gon), where 400 gon = 360 degrees
Radians	`0.7854 rad`	Radians

The default angular unit is Gradians.

> **Note**
>
> All angles are stored internally in radians regardless of the display unit. The angular unit setting only affects how values are presented in the interface.

Station format

Chainages (stations) can be displayed in two formats:

Format	Example	Grouping
`0+000`	`1+250.000`	Groups of 1000
`00+00`	`12+50.000`	Groups of 100

The default station format is `0+000`.

Decimal places

Separate decimal-place settings control the precision of displayed values in different contexts. All values range from 0 to 6 decimal places:

Setting	Default	Applies to
Coordinates	3	Northing and Easting values
Elevations	3	Height / elevation values
Angles	4	Angle and bearing displays
Stations	3	Chainage / station values
Offsets	3	Lateral offset values

Coordinate system

TunnelCAD uses a standard surveying coordinate system:

- Northing (Y) – north-south position, increasing northward.
- Easting (X) – east-west position, increasing eastward.
- Elevation (Z) – vertical position, increasing upward.

Offset convention

Cross-section offsets are measured laterally from the alignment axis:

- Positive (+) values are to the right of the alignment direction.
- Negative (-) values are to the left of the alignment direction.

This convention applies to both setout offsets and measured offsets in cross-section data.

Bearings

Bearings are displayed as surveying bearings measured clockwise from north. Internally, angles are stored as mathematical angles (measured counter-clockwise from east). The conversion is performed automatically:

> Bearing = 90 degrees - mathematical angle

Bearings are formatted using the project's angular unit and angle decimal-place settings.

Gradient

Gradient values are stored and displayed directly in percent (%). A gradient of `2.5` means a 2.5% slope. The values are not multiplied by 100 for display – they are already in the correct unit.

2.7.7 Calendar / Activity Log

The Calendar workspace tab is a project-level audit log and lightweight task tracker. It records both system events (auto-generated when something changes in the project) and user notes (manually authored, with a status tag).

Opening the Calendar

The Calendar tab appears in the project's workspace alongside Sections, Alignment, Templates, Volumes, Analytics, etc. Each open project has its own scoped Calendar. Switching projects switches the visible activity log.

What is recorded

System events

Auto-recorded entries are produced for actions that change the project's structure or state. The categories include:

- Project lifecycle – new project, open, save, save-as, close
- Structural edits – adding, editing, or deleting sections, line definitions, template line definitions, templates, station definitions, alignments, section line styles, and volume definitions
- Imports – LandXML import, measurement import, point cloud attachments, DXF template imports
- Exports – LandXML export, measurement export, PDF export, mass-table export, analytics report export
- Conversions – legacy `.tcm` → `.tun` conversions
- Analytics runs – compliance, geometry, statistics, longitudinal, clearance reports

> **Note**
>
> Granularity is per-action, not per-edit. A long template edit session that changes multiple points in one dialog produces a single "template edited" event rather than one per edit.

User notes

Notes are authored manually via Add Note in the detail pane. Each note has:

- A title (one line) and free-form body
- A category (chosen from the same set as system events, or "Note" for general entries)
- A status: Open, Done, or Cancelled
- A scope: project-wide, alignment, section, template, etc.

User notes are editable; system events are read-only. The status of a user note can be toggled directly from the detail pane without reopening the Edit dialog.

The interface

The tab is split into three regions:

Filter strip (top)
: Date range picker, category dropdown, status filter, and scope filter. Filters are AND-combined; clearing a filter widens the result set.

Timeline list (left)
: Chronological list of entries that match the filters. Each row is colour-coded by status (system events use a neutral colour; user notes are tinted by their status).

Detail pane (right)
: Shows the selected entry's full body, metadata, and – for user notes – Edit, Delete, and status-toggle buttons.

Persistence

The activity log is stored in the project's `.tun` file as XML. Each entry has a stable GUID so cross-references survive saves and reloads. Closing and reopening the project preserves the entire log.

Privacy

The activity log lives only in the `.tun` file; nothing is sent to a remote server. Sharing a `.tun` file shares the activity log with it. If you need to scrub history before sharing, delete user notes individually (system events cannot be deleted, but you can save a fresh copy of the project to start a new log).

Tips

- Use Open notes as a tunnel-scoped TODO list. Toggle them to Done as work is completed – the timeline view shows the original creation date and the close date.
- Filter by category Import or Export before sharing a `.tun` to see exactly what data has flowed in or out.
- The same activity log records analytics runs, so you can answer "when was the last clearance report generated for this project?" directly from the Calendar.

CHAPTER

THREE

SECTIONS

Cross-sections are the core data in TunnelCAD. A cross-section represents a measured tunnel profile at a specific chainage (station) along the alignment. Together, the collection of cross-sections forms a complete picture of the as-built tunnel geometry, which can be compared against the design template for deviation analysis and volume computation.

3.1 What is a cross-section?

Each cross-section captures the tunnel profile at a single point along the alignment and carries the following properties:

- Station – the chainage (distance along the alignment) where the section is located
- Name – a user-assigned identifier (e.g., “Sec 1” or “Sta 0+100”)
- Bearing – the surveying bearing of the alignment at that station
- Template – the design template assigned to the section, used as the theoretical reference
- Insertion Point – the world-coordinate position computed from the alignment engine
- Elevation – the alignment elevation at the station
- Grade – the longitudinal gradient (%) at the station
- Superelevation – cross-fall applied at the station

3.2 Line data

Each section contains multiple line data entries, one per line definition. Line definitions describe the types of lines measured or designed at each section – for example, an “Excavation” line, a “Final Lining” line, or a “Shotcrete” line. Each line data entry is a polyline: an array of 3D points with optional bulge values to represent arcs.

> **Note**
>
> Line definitions are configured per tunnel. See *Line definitions* for details on creating and managing them.

3.3 Viewing sections

Sections are displayed on two canvas tabs:

- Sections tab – shows the current section in local coordinates, where X represents the horizontal offset from the alignment axis and Y represents elevation. This is the primary view for inspecting and editing individual profiles.
- Alignment tab – shows all sections in world coordinates, positioned along the alignment path. This view provides the overall tunnel context.

3.4 Navigating between sections

There are several ways to move between sections:

- Ribbon navigation buttons – use the Prev and Next buttons in the ribbon Navigation pane to step through sections sequentially.
- Section Details grid – double-click any row in the Section Details panel to jump directly to that section. See *Section Details panel* for more information.

> **Tip**
>
> Use the Section Details grid for quick random access to any section, and the Prev/Next buttons when reviewing sections in order along the alignment.

3.5 Chapter contents

3.5.1 Adding and deleting sections

Adding sections

To add sections, click the Add button in the Ribbon > Section pane. This opens the Add Section dialog, which supports two modes.

Single mode

Add one section at a specific station. Enter the desired chainage and the section is created at that location.

Range mode

Create multiple sections at once by specifying:

- Start station – the chainage of the first section
- End station – the chainage of the last section
- Interval – the spacing between consecutive sections

All sections between the start and end stations (inclusive) are created at the given interval.

Station naming

The Add Section dialog offers two naming conventions:

- Sequential – sections are named with a running counter: Sec 1, Sec 2, Sec 3, and so on.
- By Station – sections are named after their chainage: Sta 0+100, Sta 0+200, etc.

> **Tip**
>
> Use “By Station” naming when working with large projects where you need to identify sections by their position along the alignment at a glance.

What happens when a section is added

When a new section is created, TunnelCAD automatically:

1. Assigns a template based on the TemplateStationDefs configured for the tunnel. The template that covers the new section’s chainage is applied.
2. Computes the setout offset from the alignment engine, which determines the section’s world-coordinate position, bearing, elevation, grade, and superelevation.

> **Note**
>
> The setout offset computation depends on a valid alignment being loaded. If no alignment is defined, sections can still be created but will lack positioning data.

Deleting sections

Delete current section

Click the Delete button in the Ribbon > Section pane to delete the currently displayed section.

Delete range

Click the Del Range button in the Ribbon > Section pane to open the Delete Range dialog. Specify:

- Start station – the beginning of the range
- End station – the end of the range

All sections whose chainage falls within the specified range are deleted.

> **Warning**
>
> Deleting sections cannot be undone. When using Del Range, verify the start and end stations carefully before confirming.

3.5.2 Line definitions

Line definitions describe the types of lines that appear in each cross-section. There are two categories: measured line definitions for surveyed data, and template line definitions for design profiles. Both are configured per tunnel – each alignment has its own independent set.

Line definitions are managed in the Tunnel Settings dialog, accessible from the ribbon.

Measured line definitions

Measured line definitions (`TSectionLineDefinition`) describe the types of surveyed lines recorded at each section. Common examples include "Excavation", "Final Lining", and "Shotcrete".

Each measured line definition has the following properties:

Property	Description
Name	Identifier for the line type (e.g., "Excavation")
Layer	CAD layer assignment for display
Color	Display color of the line
Style	Section line style, selected from the SectionLineStyleLibrary
Closed	Whether the polyline is drawn as a closed polygon
Draw	Whether to render this line on the canvas
Deviation Line	If checked, this line is used for deviation analysis against the template

> **Note**
>
> Only one measured line should typically be marked as the Deviation Line. This is the line compared against the template when computing deviations and generating clearance reports.

Template line definitions

Template line definitions (`TTemplateLineDefinition`) describe the types of theoretical/design profiles. These represent the intended tunnel geometry at each section.

Template line definitions share the same properties as measured line definitions:

Property	Description
Name	Identifier for the template line type
Layer	CAD layer assignment
Color	Display color
Style	Section line style from the style library
Closed	Whether to draw as a closed polygon
Draw	Whether to render this line

How line definitions relate to sections

Each cross-section contains one `TSectionLineData` entry per line definition. This means:

- When you add a new line definition, every existing section gains an empty line data slot for that definition.
- When you add a new section, it automatically gets one line data entry per existing line definition.

The line data itself is a polyline – an ordered array of 3D points with optional bulge values for arcs.

> **Tip**
>
> Plan your line definitions before importing survey data. Having the correct definitions in place ensures that imported points map to the right line types.

Configuring line definitions

1. Open Tunnel Settings from the ribbon.
2. Select the Line Definitions tab for measured lines, or the Template Lines tab for template lines.
3. Add, edit, or remove definitions as needed.
4. Click OK to apply.

> **Warning**
>
> Removing a line definition deletes all associated line data from every section in the tunnel. This action cannot be undone.

3.5.3 Editing sections

The Ribbon > Section Edit pane provides batch-editing tools for modifying section line data across one or more sections. Each tool opens a dialog where you select the target line definition and station range before applying the operation.

Sort

Reorders section points radially. Points are sorted clockwise starting from the -Y axis (bottom of the section).

Dialog options:

- Line definition to sort
- Station range (start and end chainage)

> **Tip**
>
> Use Sort after importing survey data where point order is not guaranteed. Radial sorting ensures the polyline traces the tunnel profile smoothly without crossing itself.

Filter Elev

Deletes points that fall within a specified elevation range.

Dialog options:

- Line definition to filter
- Station range
- Minimum elevation
- Maximum elevation

All points whose elevation falls within the min/max range are removed from the selected line data.

> **Note**
>
> This tool is useful for removing survey artifacts that appear above or below the actual tunnel profile – for example, reflections from the tunnel floor or ceiling that produce erroneous points.

Filter DR

Deletes points whose deviation from the template exceeds a specified threshold.

Dialog options:

- Measured line definition (the surveyed data)
- Template reference line (the design profile to compare against)
- Station range
- DR range (minimum and maximum deviation radial)

Points whose radial deviation from the template falls outside the specified range are removed.

> **Tip**
>
> Filter DR is particularly effective for cleaning up point cloud-derived sections where outlier points may be far from the expected tunnel surface.

Closed

Sets the open/closed drawing mode for a line across a range of sections.

Dialog options:

- Line definition
- Station range
- Override value: Default, Force Closed, or Force Open

Override	Behavior
Default	Uses the setting from the line definition
Force Closed	Draws the polyline as a closed polygon regardless of the line definition setting
Force Open	Draws the polyline as an open polyline regardless of the line definition setting

> **Note**
>
> This override is per-section. It does not change the line definition itself, only how individual sections render that line.

Close to Lvl

Extends or truncates line endpoints to reach a target elevation.

Dialog options:

- Line definition
- Station range
- Target Y level (elevation)

The first and last points of the polyline are projected to the specified elevation, ensuring the line starts and ends at a consistent reference level.

> **Tip**
>
> Use Close to Lvl when sections need to connect to a common reference elevation, such as the road surface or a construction joint level.

Close Invert

Automatically adds closing points at the bottom of the section near the alignment axis.

Dialog options:

- Line definition
- Station range

This tool inserts invert points to close open profiles at the bottom, bridging the gap between the last point on one side and the first point on the other side of the tunnel.

> **Tip**
>
> Close Invert is helpful when survey data covers the tunnel walls and crown but not the invert (floor). Adding closing points produces a complete closed profile for area and volume calculations.

3.5.4 Section Details panel

The Section Details panel provides a tabular overview of all sections in the current tunnel and displays properties for the active section. It is located in the right-side panel of the application window.

Section Details tab

The Section Details tab contains a grid listing every section in the tunnel with the following columns:

Column	Description
Station	Chainage along the alignment
Name	Section identifier
Bearing	Surveying bearing at the station
Template	Name of the assigned design template
Elevation	Alignment elevation at the station
Grade	Longitudinal gradient in percent
Offsets	Horizontal and vertical offset from the alignment axis
Superelevation	Cross-fall value at the station

Navigating with the grid

Double-click any row in the grid to navigate directly to that section. The Sections canvas tab updates to display the selected section, and the alignment canvas highlights the corresponding station.

> **Tip**
>
> The Section Details grid is the fastest way to jump to a specific section when you know its station or name. Combine it with the Prev/Next ribbon buttons for sequential review.

Properties tab

The Properties tab shows the CAD object inspector for the currently selected entity on the canvas. When an entity is selected (such as a section line or template line), its geometric and display properties appear here for review.

> **Note**
>
> The Properties tab reflects the canvas selection. If no entity is selected, the tab is empty. Click on a line or point on the Sections canvas to populate it.

Status bar

The status bar at the bottom of the application window shows the cursor coordinates in the local section coordinate system:

- X – horizontal offset from the alignment axis (positive = right, negative = left)
- Y – elevation

Note

These coordinates match the section's local system, not world coordinates. The offset convention follows TunnelCAD's standard: positive offsets are to the right of the alignment axis, negative offsets are to the left.

CHAPTER

FOUR

TEMPLATES

Templates define the theoretical (design) tunnel cross-section shape. Every measured section in TunnelCAD is compared against a template to determine how closely the as-built excavation matches the intended geometry. Deviations from the template produce overbreak and underbreak values that drive volume calculations and compliance analysis.

4.1 What is a template?

A template is a named collection of one or more template lines, each represented as a polyline with optional arc segments (bulge values). Template lines correspond to Template Line Definitions – named categories such as “Theoretical Excavation”, “Theoretical Lining”, or “Design Invert”. While measured sections use Line Definitions, the design counterpart uses Template Line Definitions to keep the two concepts distinct.

For example, a tunnel design might specify two template lines:

- Theoretical Excavation – the outer excavation boundary
- Theoretical Lining – the inner finished surface

Each template line is a closed or open polyline that traces the design profile in local section coordinates, where X is the horizontal offset from the alignment axis and Y is the elevation.

4.2 Multiple templates per tunnel

A single tunnel alignment can contain multiple templates. This is common when the design profile changes along the route – for instance, a wider cross-section in zones of poor geology, a reduced profile in stable rock, or a different shape at portal areas. Each template is a self-contained profile that can be assigned to a chainage range.

4.3 Template assignment via Station Definitions

Templates are linked to the alignment through Station Definitions, which map chainage ranges to specific templates. When a new cross-section is added at a given station, TunnelCAD looks up the matching station definition and automatically assigns the correct template.

4.4 Template transformations

Station definitions can specify transitions between two templates over a given length. When a cross-section falls within a transition zone, the template transformation engine automatically computes an interpolated profile by blending the source and destination templates point-by-point.

Two interpolation types are supported:

- Linear – uniform blending from source to destination.
- Cubic – smoothstep easing (zero velocity at boundaries) for smoother transitions.

The Template Editor includes a transformation preview with a slider to visualize the interpolated profile at any point in the transition zone, and a Check report that diagnoses compatibility issues between the two templates.

See *Station Definitions* for full details on configuring transitions, and *Template Editor* for the transformation preview.

4.5 Template lines and template line definitions

Each template line within a template carries the name of a Template Line Definition. These definitions are configured per tunnel and control the display color and layer of template lines on the canvas. When the Template Editor opens, it automatically synchronizes template lines so that every template contains an entry for every defined Template Line Definition.

> **Note**
>
> Template Line Definitions are separate from the (measured) Line Definitions used for section line data. They are managed in the project tree under each tunnel's "Template Lines" node.

4.6 Arc segments via bulge values

Template lines support curved segments through bulge values on individual points. A bulge value of 0 produces a straight segment to the next point, while non-zero values create circular arcs. Positive bulge curves to the right (clockwise) and negative bulge curves to the left (counter-clockwise). The magnitude equals the tangent of one-quarter of the included arc angle.

Important

When editing template points, always set the bulge value after adding the endpoint. The internal bulge array requires at least two points to exist before bulge values can be assigned.

4.7 Chapter contents

4.7.1 Template Editor

The Template Editor is the primary dialog for creating, viewing, and modifying templates. Open it from the ribbon via Template > Assign, or from the menu via Template > Edit Templates.

Dialog layout

The Template Editor is divided into several areas:

- Toolbar (top) – buttons for New, Delete, Duplicate, Import DXF, Export, Import, Export DXF, Test Transform, Apply, and Close.
- Tree panel (left) – hierarchical view of all templates and their template lines.
- Properties panel (left, below tree) – name, description, and display options for the selected template or line.
- Points grid (left, below properties) – coordinate editor for the selected template line's vertices, with Add, Delete, Insert, and Reverse buttons.
- Preview area (center) – visual display of the current template with zoom/pan navigation.
- Station Definitions grid (bottom) – chainage-to-template assignments. See *Station Definitions*.
- Station strip (below grid) – a longitudinal color bar showing template zones along the alignment, with template names and transition zone markers.
- Status bar (bottom) – shows the cursor position in world coordinates.

Tree panel

The tree shows all templates in the current tunnel alignment. Each template node expands to reveal its template lines. Selecting a template node shows all of its lines overlaid in the preview. Selecting a specific line node shows only that line, with vertex dots highlighted.

Template lines are color-coded according to their Template Line Definition color, making it easy to distinguish between different design layers.

Properties

When a template is selected in the tree, the properties panel shows:

- Name – the template identifier, used in station definitions and reports.
- Description – free-text field for notes (e.g., "Standard section - good rock").

When a specific template line is selected:

- Closed – whether the polyline is drawn as a closed shape (last point connects back to first).
- Show Direction – toggles direction arrows on the preview, showing point order and winding direction (CW/CCW label).

> **Tip**
>
> Use “Show Direction” to verify the winding order of your template lines. Consistent winding direction matters for correct area and overbreak/underbreak calculations.

Points grid

The points grid is enabled when a template line is selected in the tree. It displays one row per vertex with the following columns:

Column	Description
#	Point index (zero-based)
X	Horizontal offset from the section axis (positive = right, negative = left)
Y	Elevation value
Bulge	Arc bulge factor (0 = straight segment to next point)

Adding points

Click the Add button below the grid to append a new point. The new point is added at (0, 0) with zero bulge and can then be edited in the grid cells.

Inserting points

Select a row in the grid and click Insert Point to add a new point after the selected row. The new point is inserted at (0, 0) with zero bulge. All point indices are renumbered automatically.

Deleting points

Select a row in the grid and click Delete to remove that vertex.

Reversing point order

Click Reverse to reverse the order of all points in the current template line. This also negates all bulge values to maintain the correct arc direction. Use this when the winding direction (CW/CCW) needs to be flipped — enable “Show Direction” to verify the result.

Applying changes

After editing point coordinates or bulge values in the grid, click Apply in the toolbar to commit the changes to the template. The preview updates immediately to reflect the new geometry.

Important

Bulge values are applied after all points have been added to the internal polyline. When entering bulge values, make sure the endpoint of the arc segment already exists in the grid before setting a non-zero bulge.

Preview area

The preview renders the template geometry on a dark background with a coordinate grid and center marker (red crosshair at the origin). Navigation:

- Drag (any mouse button) – pan the view.
- Mouse wheel – zoom in/out, centered on the cursor position.
- The preview auto-zooms to fit the template extents when a new template or line is selected.

When all lines are shown (template node selected), each line is drawn in its definition color. When a single line is selected, it is drawn with highlighted vertex dots showing the control points.

Creating a new template

1. Click New in the toolbar.
2. Enter a unique name in the input dialog and confirm.
3. The new template is created with template lines matching all existing Template Line Definitions (auto-synchronized), but the lines have no geometry yet.
4. Select each template line in the tree and add points via the points grid, or use *DXF Import* to import geometry from a DXF file.

Duplicating a template

Select an existing template in the tree and click Duplic. to create a copy. You will be prompted for a new name. The duplicate includes all template line geometry (points and bulge values), making it useful when a new zone needs a profile similar to an existing one with minor modifications.

Deleting a template

Select a template in the tree and click Delete. A confirmation dialog appears before the template is removed. Deleting a template does not affect cross-sections that already reference it, but those sections will no longer have a valid template for future deviation analysis.

Exporting templates

Export to XML (.tcx)

Click Export in the toolbar to save all templates, template line definitions, and station definitions to a `.tcx` file (TunnelCAD Template XML). This portable file can be imported into any other tunnel alignment.

Export to DXF

Select a template in the tree and click Export DXF to save it as a DXF file. Each template line is written as a LWPOLYLINE on its own layer, using the Template Line Definition layer name and color. Lines with no geometry are skipped.

Importing templates

Click Import in the toolbar to load templates from a `.tcx` file. The import wizard shows:

- Template Line Definitions – checkbox list of definitions in the file. New definitions (not in the current alignment) are marked "(new)".
- Templates – checkbox list with line count and point count for each template. Templates that already exist are marked "[exists]".
- Import Station Definitions – optional checkbox to also import chainage ranges (unchecked by default since chainages are alignment-specific).

When importing a template whose name already exists, you are prompted to Skip, Overwrite, or Rename (imported as "Name (imported)"). The "Apply to all" checkbox applies your choice to all remaining conflicts.

Transformation preview

The Test Transform button in the toolbar activates the transformation preview, which lets you visualize how the interpolation engine blends two templates before applying it to sections.

Activating the preview

1. In the Station Definitions grid, select a row that has a Transform To template and a Transform Length greater than 0.
2. Click Test Transform in the toolbar.
3. The preview switches to transformation mode and a control panel appears below the preview area.

The button is disabled when the selected station definition has no transformation configured.

Preview controls

Control	Description
Slider	Drag from 0% (pure source template) to 100% (pure destination template) to see the interpolated profile at any point in the transition zone.
Chainage	Type a chainage value and press Enter to jump to that station within the transition zone. The slider updates to match, and vice versa.
Type dropdown	Switch between Linear and Cubic easing to compare the transition behavior.
Check	Opens a diagnostic report showing which lines will be interpolated and which are skipped, with the reason (point count mismatch, empty geometry, etc.).
Close	Exits the transformation preview and returns to normal template editing.

Visual display

In transformation preview mode, the preview area shows three layers:

- Source template – drawn as dim gray lines (ghost).
- Destination template – drawn as dim purple lines (ghost).
- Interpolated template – drawn in full color using the Template Line Definition colors, representing the blended profile at the current slider position.

As you drag the slider, the interpolated lines smoothly morph between the source and destination shapes.

Check report

The Check button opens a grid dialog showing the compatibility analysis for every template line:

Column	Description
Line Name	Name of the template line
Source Pts	Number of points in the source template
Dest Pts	Number of points in the destination template
Status	OK (will interpolate), or SKIP with the specific reason

Possible skip reasons:

- both empty – neither template has geometry for this line.
- source empty / destination empty – geometry exists in only one template.
- point count mismatch – the line has a different number of points in each template. Edit the templates to match the point counts.
- not found in source / not found in destination – the line definition exists in one template but not the other.

> **Tip**
>
> Always run the Check report before relying on a transformation. It quickly reveals which lines need editing to enable full interpolation.

4.7.2 Station Definitions

Station Definitions control which template is used at each chainage along the alignment. They appear in a grid at the bottom of the Template Editor dialog, below the preview area.

Purpose

When a new cross-section is added at a particular station, TunnelCAD looks up the station definitions to find the one whose chainage range contains that station. The matching definition determines which template is automatically assigned to the section. Without station definitions, sections would have no template reference for deviation analysis.

Station Definitions grid

The grid contains the following columns:

Column	Description
Station From	Start chainage of the range
Station To	End chainage of the range
Template	Name of the template to use (dropdown selection)
Transform To	Target template for transition (optional)
Transform Length	Length in meters over which the transition occurs
Transform Type	Type of interpolation: Linear or Cubic

Adding a station definition

Click Add below the station definitions grid. A new row is appended with default values. Edit the Station From and Station To values to define the chainage range, and select a template from the dropdown in the Template column.

Deleting a station definition

Select the row to remove and click Delete.

Chainage ranges

Station definitions divide the alignment into non-overlapping chainage ranges. Each range maps to one primary template. When a section's station falls within a range, that range's template is assigned.

> **Note**
>
> Ranges should be contiguous and non-overlapping. If a station falls outside all defined ranges, no template will be assigned to sections created at that chainage.

A typical setup for a tunnel from chainage 0+000 to 1+200 might look like:

Station From	Station To	Template
0.000	400.000	Standard Section
400.000	600.000	Wide Section
600.000	1200.000	Standard Section

Transform types

Station definitions support transitions between templates to handle gradual profile changes:

None (no transform)

When Transform To is empty and Transform Length is 0, the template is used as-is throughout the entire range. This is the most common configuration – the same profile applies uniformly from Station From to Station To.

Linear

When a Transform To template is specified with Transform Type set to Linear, the profile transitions linearly from the primary template to the target template. The Transform Length controls how many meters the transition spans. The interpolation factor increases uniformly from 0% (pure source) to 100% (pure destination).

Cubic

When Transform Type is set to Cubic, the transition uses a smoothstep easing curve (3t^2 - 2t^3) instead of a straight line. The profile starts and ends with zero velocity, producing a smoother transition that avoids abrupt changes at the zone boundaries. Cubic is recommended when templates have large shape differences.

How interpolation works

The transformation engine interpolates each template line independently. For each line present in both the source and destination templates:

- The vertex coordinates (offset and elevation) are blended point-by-point.
- Arc bulge values are blended between corresponding vertices.
- The line must have the same number of points in both templates.

Lines that exist in only one template, have no geometry, or have different point counts are skipped – they are not included in the interpolated result. Use the Check button in the transformation preview to identify which lines will be interpolated and which will be skipped (see *Template Editor*).

> **Tip**
>
> Use linear or cubic transforms at geological boundaries or design transitions to avoid sharp discontinuities in the as-designed profile. This produces more realistic volume calculations in the transition zone.

Important

For interpolation to work correctly, corresponding template lines in the source and destination templates must have the same number of points. If a line is skipped due to a point count mismatch, edit the templates so the point counts match.

Station definitions are sorted

Internally, station definitions are sorted by their starting chainage. The grid displays them in this order. When the Template Editor applies changes, the list is re-sorted to maintain consistency.

Interaction with cross-sections

Station definitions are consulted at the time a cross-section is created. If a station definition is changed after sections have been created, the existing sections retain their original template assignment. To update previously created sections, delete and re-add them, or manually reassign the template.

4.7.3 DXF Import

Templates can be created by importing geometry from DXF files. This is useful when the tunnel design profile is provided by an architect or structural engineer as a CAD drawing, and you want to use it directly as a template rather than entering points manually.

Opening the DXF import

1. In the Template Editor, select the template you want to import geometry into.
2. Click the Import DXF button in the toolbar.
3. A file dialog opens – select the DXF file containing the tunnel profile geometry.

Note

The selected template must have at least one template line (from Template Line Definitions) before importing. If the template has no lines, you will see a warning.

DXF Preview and Assignment dialog

After selecting a DXF file, TunnelCAD reads all polylines from the file and opens the DXF Preview & Assignment dialog. This dialog has two main areas:

Preview canvas (left)

The preview shows all polylines found in the DXF file, each drawn in a distinct color and labeled with a number. Existing template line geometry (if any) is shown as dashed lines in a muted color for reference.

Navigation in the preview:

- Left-click on a polyline to select/highlight it (drawn in white when selected).

- Right-click or middle-click drag to pan the view.
- Mouse wheel to zoom in/out.

A crosshair marks the origin (0,0), which corresponds to the section axis position.

Assignment grid (right)

The grid lists every polyline found in the DXF file with the following columns:

Column	Description
#	Polyline number
DXF Polyline	Description including layer name, point count, and open/closed status
Assign To	Which template line this polyline maps to, or "(Skip)"
Existing	Shows "Yes" if the target template line already has geometry

Assigning polylines to template lines

Each DXF polyline must be assigned to a template line or skipped:

- Double-click on the "Assign To" cell to cycle through the available template lines and the "(Skip)" option.
- Selecting a row in the grid highlights the corresponding polyline in the preview, making it easy to identify which polyline is which.
- Clicking a polyline in the preview selects the corresponding row in the grid.

> **Tip**
>
> If the number of DXF polylines exactly matches the number of template lines, TunnelCAD auto-assigns them in order. You can then adjust individual assignments as needed.

Confirming the import

Click OK to apply the assignments. For each polyline that is not skipped:

- The polyline geometry (points and bulge values for arcs) is copied into the assigned template line.
- If the target template line already contains geometry, you will be prompted to confirm overwriting.

Click Cancel to discard all assignments and return to the Template Editor without changes.

Supported DXF content

The import reads all polyline entities (LWPOLYLINE and POLYLINE) from the DXF file. Other entity types (lines, circles, text, etc.) are ignored. Polylines with fewer than 2 points are also skipped.

The DXF polyline's layer name is shown in the assignment grid to help identify the purpose of each polyline (e.g., a layer named "Excavation" likely corresponds to the theoretical excavation template line).

Important

Ensure that the DXF drawing uses the same coordinate convention as TunnelCAD templates: X = horizontal offset from the section axis, Y = elevation. If the DXF uses a different orientation, you may need to rotate or transform the drawing in a CAD application before importing.

Typical workflow

1. Receive a DXF file from the design engineer with the tunnel profile geometry.
2. Open the Template Editor and select (or create) the target template.
3. Click Import DXF and select the file.
4. In the preview dialog, verify that the polylines look correct and match the expected profile.
5. Assign each DXF polyline to the appropriate template line (e.g., the outer polyline to "Theoretical Excavation", the inner one to "Theoretical Lining").
6. Click OK to import.
7. Click Apply in the Template Editor to commit the changes.

4.7.4 Copy Templates Between Tunnels

When a project contains multiple tunnel alignments that share the same or similar design profiles, you can copy templates from one tunnel to another instead of recreating them manually.

Opening the Copy Templates dialog

From the ribbon, go to Template > Copy. This opens the Copy Templates dialog.

Dialog layout

The dialog contains:

- Source tunnel dropdown – select the tunnel alignment to copy from.
- Target tunnel dropdown – select the tunnel alignment to copy to.
- Templates checklist – lists all templates in the source tunnel with checkboxes. All templates are checked by default.
- Copy Line Definitions checkbox – when checked, Template Line Definitions are also copied.
- Copy Station Definitions checkbox – when checked, Station Definitions are also copied.
- Copy button – executes the copy operation.
- Close button – closes the dialog.

What gets copied

The copy operation transfers the following items from the source tunnel to the target tunnel:

Template Line Definitions

When “Copy Line Definitions” is checked, all Template Line Definitions from the source are copied to the target. Each definition’s name, layer, color, and draw flag are preserved.

Templates

Each checked template in the list is copied with its full geometry:

- Template name and description
- All template lines within the template
- Point coordinates for each template line
- Bulge values for arc segments
- Closed/open status of each polyline

Station Definitions

When “Copy Station Definitions” is checked, the chainage-range-to-template mappings are copied. This includes the station from/to values, the assigned template name, and any transform settings (transform-to template, length, and type).

Duplicate handling

The copy operation skips items that already exist in the target tunnel:

- Template Line Definitions are matched by name. If a definition with the same name already exists in the target, it is not overwritten.
- Templates are matched by name. If a template with the same name exists, its existing lines may be updated with geometry from the source, but the template itself is not duplicated.
- Station Definitions are matched by template name and chainage range. If an identical station definition already exists (same template name, same Station From, same Station To), it is skipped.

This makes the operation safe to run multiple times – it will not create duplicates or overwrite existing data.

> **Note**
>
> The source and target must be different tunnels. The dialog will show an error if you attempt to copy a tunnel to itself.

Completion summary

After the copy completes, a summary dialog shows how many items were copied:

- Number of templates copied
- Number of line definitions copied
- Number of station definitions copied

If all selected items already exist in the target, the dialog reports “Nothing Copied” with an explanation.

Typical use case

Consider a project with a left tube and a right tube that share the same design profile:

1. Define templates and station definitions in the first tunnel (e.g., “Left Tube”).
2. Open Template > Copy.
3. Set Source to “Left Tube” and Target to “Right Tube”.
4. Ensure all checkboxes are checked.
5. Click Copy.
6. Both tunnels now have identical template definitions. Adjust the station definitions in the target tunnel if the chainage ranges differ.

> **Tip**
>
> After copying, you can modify the copied templates in the target tunnel independently. Changes to one tunnel’s templates do not affect the other.

CHAPTER

FIVE

VOLUMES

TunnelCAD computes areas and volumes between measured and theoretical tunnel profiles. The volume system lets you define exactly what to measure – overbreak, underbreak, lining thickness, total excavation, or any custom combination – using a formula builder with terms and arithmetic operations.

5.1 How volume computation works

Volume computation proceeds in two stages:

1. Area per section – for each cross-section, TunnelCAD evaluates a formula against the section's line data and template lines. The result is an area value in square meters (m2) for that station.
2. Volume across sections – area values are accumulated along the alignment to produce volumes in cubic meters (m3), using one of two computation methods.

5.2 Computation methods

TunnelCAD supports two methods for converting per-section areas into volumes:

- Applicable Length – each section's area is multiplied by its applicable length, which is the chainage interval that the section represents. For the first and last sections, this is half the distance to the adjacent section; for middle sections, it is half the distance between the preceding and following sections.
- Average Areas – for each pair of adjacent sections, the volume is computed as the average of the two areas multiplied by the distance between them: `V = (A1 + A2) / 2 * d`. This method is generally more accurate when the profile varies significantly between stations.

5.3 Volume definitions

Volume definitions are stored per tunnel – each alignment maintains its own list. A volume definition consists of:

- A name and color (used for hatch preview on the section canvas)
- One or more terms, each referencing measured or template lines
- Operations (add or subtract) between terms
- Optional clipping levels to restrict the computation region

- An optional additive constant applied to every section's result

5.4 Results and export

Computed results are displayed in the Mass Table – a grid showing station, area, and volume for each section, with a cumulative total at the bottom. The mass table can be exported to CSV or Excel (XLSX) format.

5.5 Chapter contents

5.5.1 Volume Definition Editor

The Volume Definition Editor is the primary dialog for creating and editing volume definitions. It provides a dynamic term builder where you construct a formula from line references and arithmetic operations.

Opening the editor

To open the Volume Definition Editor:

1. Expand the Volumes node under a tunnel in the project tree.
2. Double-click an existing volume definition to edit it, or right-click the Volumes node and choose Add Volume to create a new one.

Basic properties

At the top of the dialog you configure:

- Name – a descriptive name for the volume definition (e.g., "Overbreak", "Lining Zone")
- Color – the hatch color used when previewing the volume region on the section canvas. Click the color button to open the color picker.
- Method – choose between Applicable Length and Average Areas for volume computation. See *Mass Table* for details on each method.
- Preset – a dropdown of common volume configurations. Selecting a preset populates the term builder automatically. See *Volume Presets* for descriptions of each preset.

Term builder

The core of the editor is the term builder – a scrollable list of term rows. Each row defines one component of the volume formula.

Adding and removing terms

- Click Add Term to append a new term row at the bottom of the list.
- Click the Remove button on a term row to delete it. You cannot remove the last remaining term.

Term types

Each term has a type that determines which area function is applied. The four available types are described below.

Area(LineA, LineB) – Intersection area

Returns the area where both LineA and LineB polygons overlap simultaneously. This is the standard area measurement for comparing two profiles.

Example: `Area(Excavation, Final Lining)` returns the area that is inside both the measured excavation and the design lining – effectively the "good" excavation that matches the design.

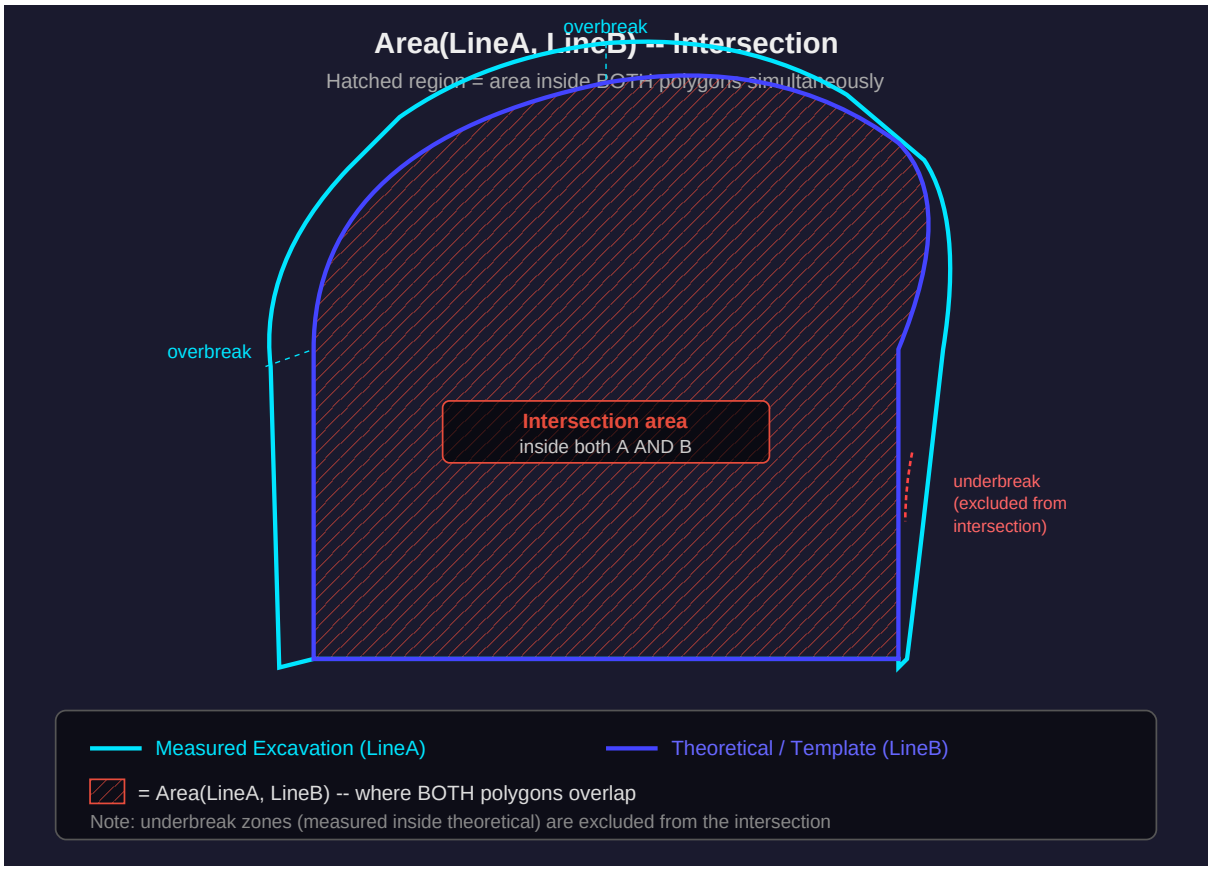


Fig. 1: Area(LineA, LineB) computes the intersection of two polygons. The hatched region shows where both profiles overlap. Areas of overbreak (measured outside theoretical) and underbreak (theoretical outside measured) are excluded.

Length(LineA) – Polyline perimeter

Returns the total length along a line in meters. This is not an area – it measures the perimeter of a polyline. Useful for computing shotcrete surface coverage or lining perimeter.

Example: `Length(Excavation)` returns the perimeter of the measured excavation profile at that section.

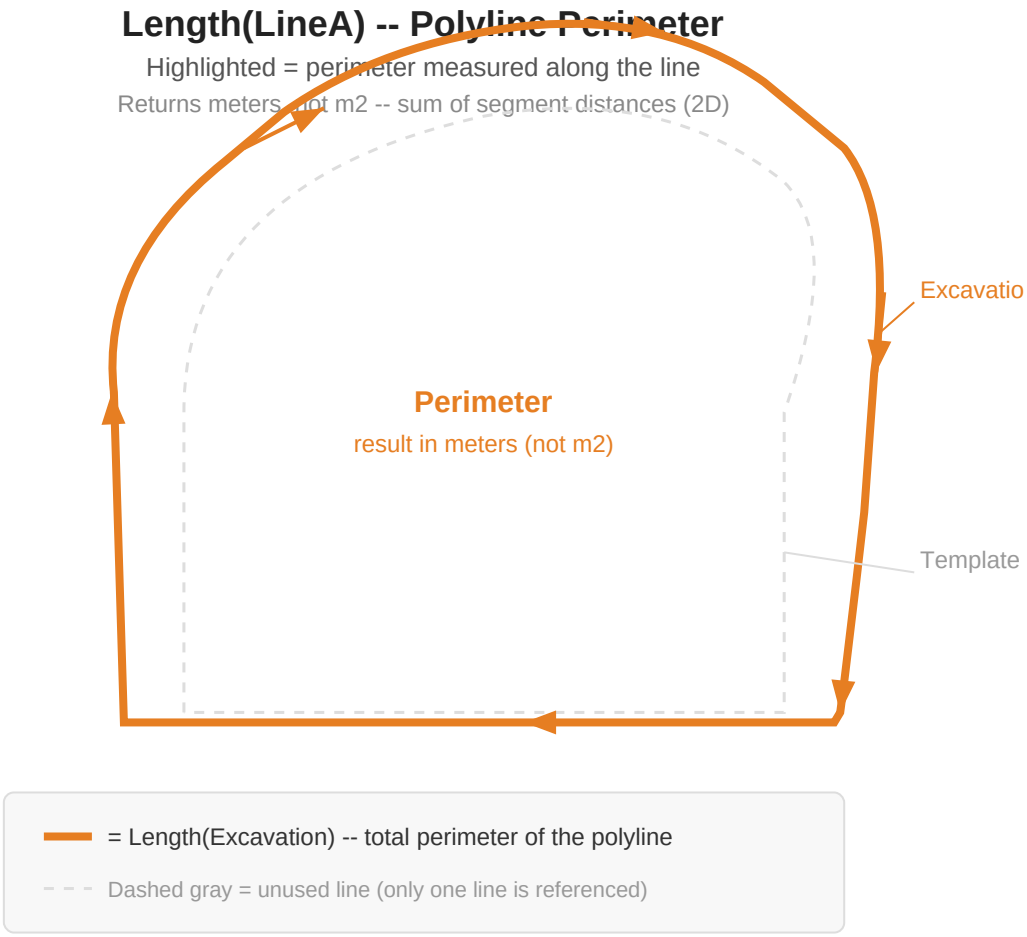


Fig. 2: Length(LineA) measures the total distance along the polyline. The result is in meters, not square meters.

EnclosedArea(LineA) – Single polygon area

Returns the total area enclosed by a single closed line, computed using the Shoelace formula. Only one line is needed.

Example: `EnclosedArea(Excavation)` returns the full cross-sectional area inside the measured excavation profile.

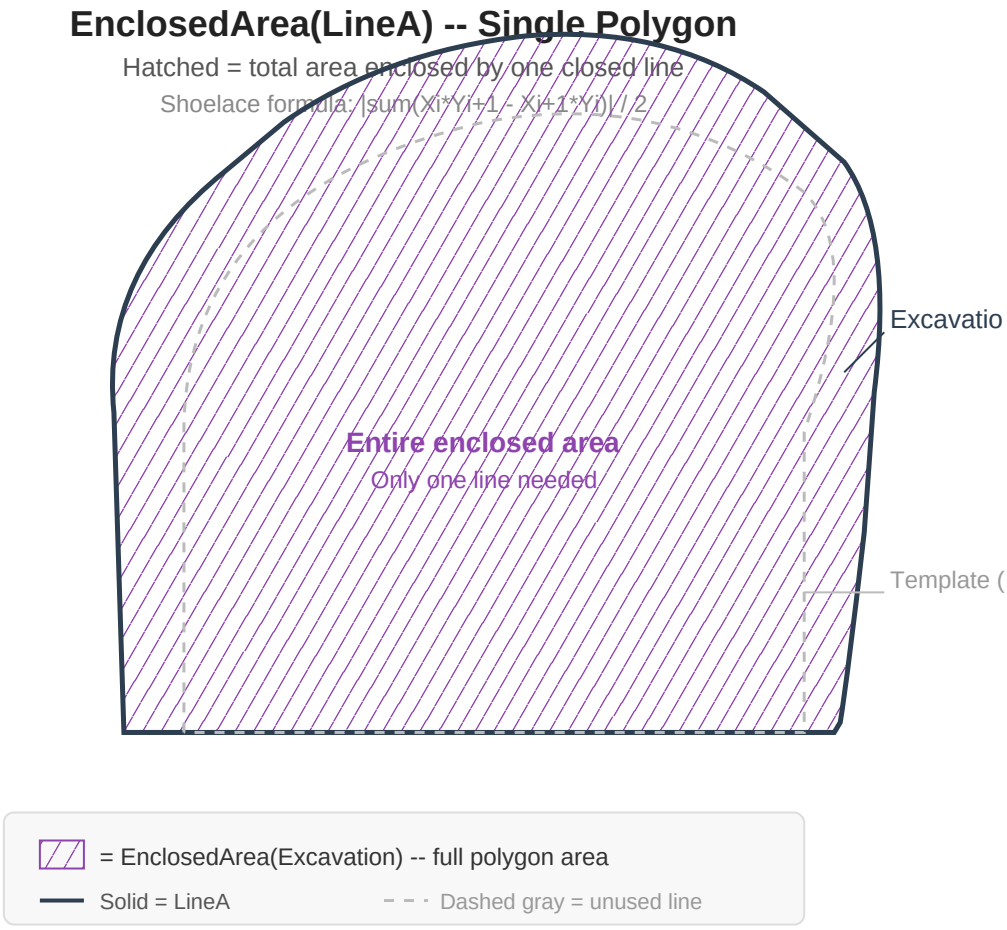


Fig. 3: EnclosedArea(LineA) computes the total area inside a single polygon using the Shoelace formula.

DiffArea(LineA, LineB) – Difference area

Returns the area inside LineA that is outside LineB. This produces a ring-shaped region between two polygons – the zone that belongs to one profile but not the other.

Example: `DiffArea(Excavation, Final Lining)` returns the lining zone – the area of the excavation that lies outside the final lining profile.

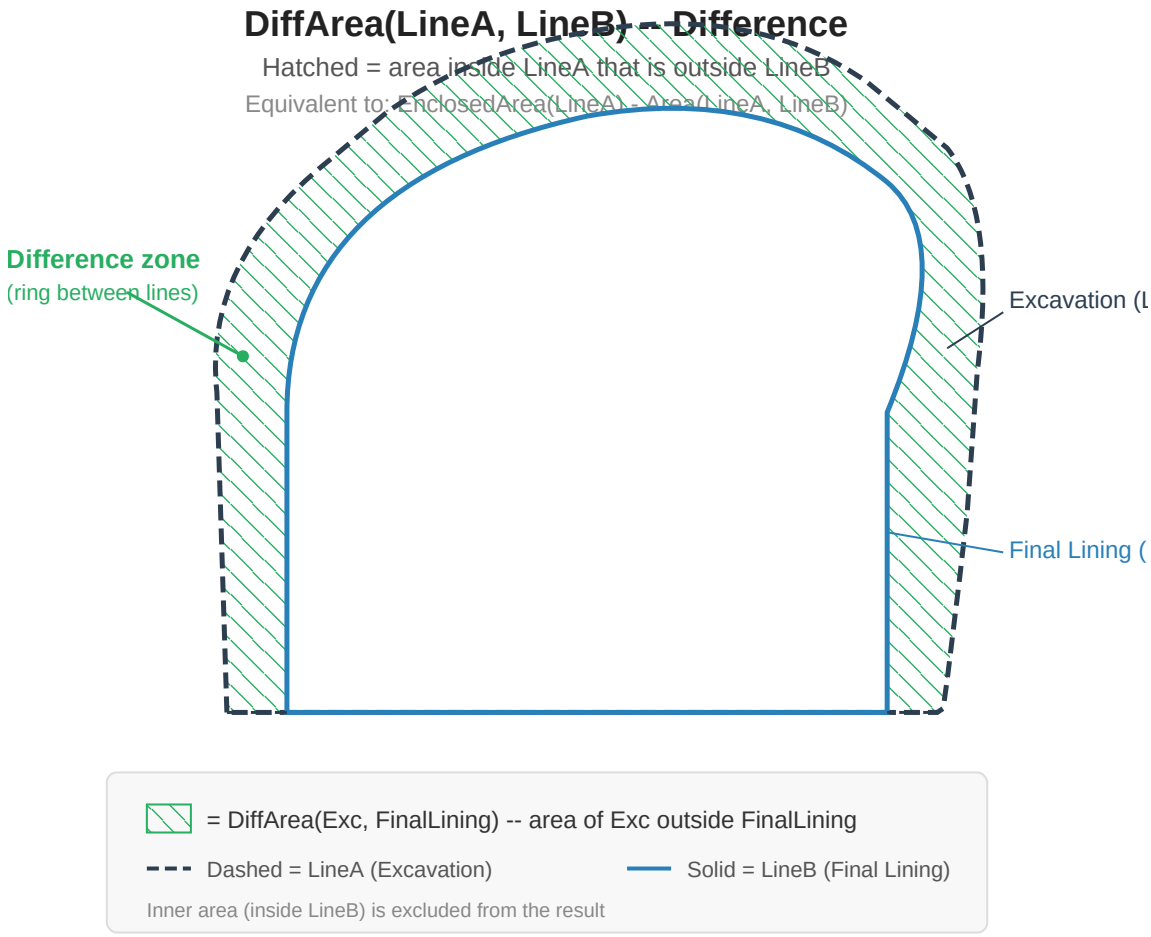


Fig. 4: DiffArea(LineA, LineB) computes the area inside LineA that is outside LineB, producing a ring between two concentric polygons.

Operations between terms

When a formula has more than one term, an operation dropdown appears before each subsequent term:

- Add (+) – the term's value is added to the running total
- Subtract (-) – the term's value is subtracted from the running total

The resulting formula is evaluated left to right. For example, a definition with three terms might produce:

```
Area(Excavation, Final Lining) + DiffArea(Excavation, Shotcrete) -
↪EnclosedArea(Invert)
```

Line selection

Each term row contains one or two line dropdowns (depending on the term type):

- Line A – always visible. Select a measured line definition or a template line definition.
- Line B – visible only for `Area` and `DiffArea` term types, which require two lines.

The dropdowns are populated from the tunnel's measured line definitions and template line definitions.

Preview

Click Preview to evaluate the current formula against the active cross-section. The result is displayed as:

- A numeric area value in the Result label (in m2)
- A hatch overlay on the section canvas: green hatching for positive area regions, red hatching for negative (subtracted) regions

The preview overlay remains visible until you close the dialog or modify the definition.

Calculate All

Click Calculate All to evaluate the formula across all cross-sections (or a station range) and display the results in the *Mass Table*.

Clipping levels

The bottom of the dialog contains clipping level controls. See *Clipping Levels* for full details.

Additive constant

The Constant field allows you to specify a fixed value that is added to every section's computed area. This can be used for systematic corrections or to account for known offsets.

Applying changes

- Apply – saves the current definition and marks the project as modified. The dialog remains open for further editing.
- Close – closes the dialog. If you have unapplied changes, they are discarded.

5.5.2 Volume Presets

The Volume Definition Editor includes a Preset dropdown that populates the term builder with common volume configurations. Presets provide a quick starting point – after applying a preset, you can modify the terms, change line selections, or add additional terms to customize the definition.

Available presets

Overbreak

Measures the excess excavation beyond the design template – the area of the measured profile that extends outside the theoretical line.

- Formula: `Area(Excavation, Template)`
- Term type: Area (intersection)
- Lines: first measured line definition + first template line definition
- Use case: quantifying over-excavation for cost analysis and shotcrete consumption

Note

The intersection-based `Area()` function captures only the overlapping region. To measure specifically the area outside the template, use `DiffArea(Excavation, Template)` instead.

Underbreak

Measures the area of the design template that was not excavated – the violation zone where the measured profile falls inside the theoretical line.

- Formula: `Area(Template, Excavation)`
- Term type: Area (intersection)
- Lines: first template line definition + first measured line definition
- Use case: identifying zones where the tunnel profile does not meet the design specification

Full Excavation

Measures the total area enclosed by the measured excavation profile.

- Formula: `EnclosedArea(Excavation)`
- Term type: EnclosedArea (single polygon)
- Lines: first measured line definition
- Use case: total cross-sectional area for material quantity estimation

Shotcrete Thickness

Measures the area between two measured lines – typically the excavation line and a shotcrete line. This represents the cross-sectional area of the applied shotcrete layer.

- Formula: `Area(Excavation, Shotcrete)`
- Term type: Area (intersection)
- Lines: first and second measured line definitions
- Use case: shotcrete volume computation for material tracking

Tip

For shotcrete thickness, the intersection of the two measured lines gives the area of the shotcrete layer. If you need the full ring between the two lines, use `DiffArea(Excavation, Shotcrete)` instead.

Invert Area

Measures the area at the bottom of the tunnel section, below a specified elevation level.

- Formula: `EnclosedArea(Excavation)` with Down clipping level enabled at 0.0
- Term type: EnclosedArea (single polygon) with clipping
- Lines: first measured line definition
- Use case: invert concrete volume, drainage channel area

After applying this preset, adjust the Down clipping level to the actual invert elevation for your tunnel.

Crown Area

Measures the area at the top of the tunnel section, above a specified elevation level.

- Formula: `Area(Excavation, Template)` with Up clipping level enabled at 0.0
- Term type: Area (intersection) with clipping
- Lines: first measured line definition + first template line definition
- Use case: crown shotcrete area, arch support zone analysis

After applying this preset, adjust the Up clipping level to the actual springline or crown elevation for your tunnel.

Modifying presets

When you select a preset from the dropdown, it replaces the current term configuration entirely. The preset dropdown then resets to “Custom” to indicate that any further changes create a custom definition.

You can freely modify a preset after applying it:

- Change the line selections to reference different measured or template lines
- Add additional terms with the Add Term button
- Adjust clipping levels or the additive constant
- Switch the computation method between Applicable Length and Average Areas

Creating custom definitions

If none of the presets match your needs, leave the preset dropdown on “Custom” and build the formula manually using the term builder. Common custom definitions include:

- Net lining area: `DiffArea(Final Lining, Excavation)` – the designed lining zone

- Combined area: `Area(Excavation, Template) + DiffArea(Excavation, Shotcrete)` – multiple terms combined
- Side-specific analysis: any term with Left/Right clipping to analyze one side of the tunnel independently

5.5.3 Mass Table

The Mass Table dialog displays the computed area and volume results for a volume definition across all cross-sections in a tunnel alignment. It is the primary output for quantity estimation and material tracking.

Opening the Mass Table

Open the Mass Table in one of two ways:

- From the Volume Definition Editor, click Calculate All or Mass Table.
- From the project tree, right-click a volume definition and choose Mass Table.

Grid layout

The grid columns depend on the computation method configured in the volume definition.

Applicable Length method

Column	Description
Section	Section name (with * suffix if warnings occurred during evaluation)
Station	Chainage along the alignment
Area (m2)	Computed area at this section
Appl. L. (m)	Applicable length – the chainage interval this section represents
Volume (m3)	Area multiplied by applicable length
Cumulative (m3)	Running total of volume from the first section

The applicable length for each section is computed as:

- First section: half the distance to the next section
- Last section: half the distance from the previous section
- Middle sections: half the distance between the previous and next sections

This ensures that each section's influence zone covers exactly the chainage interval it represents, with no gaps or overlaps.

Average Areas method

Column	Description
From	Name of the first section in the pair
To	Name of the second section in the pair
Sta From	Station of the first section
Sta To	Station of the second section
Avg Area (m2)	Average of the two sections' areas
Distance (m)	Chainage difference between sections
Volume (m3)	Average area multiplied by distance
Cumulative (m3)	Running total of volume

The Average Areas method computes volume for each pair of adjacent sections:

```
Volume = (Area_i + Area_{i+1}) / 2 * (Station_{i+1} - Station_i)
```

This method is generally more accurate when the tunnel profile varies significantly between stations, as it accounts for the change in area by averaging.

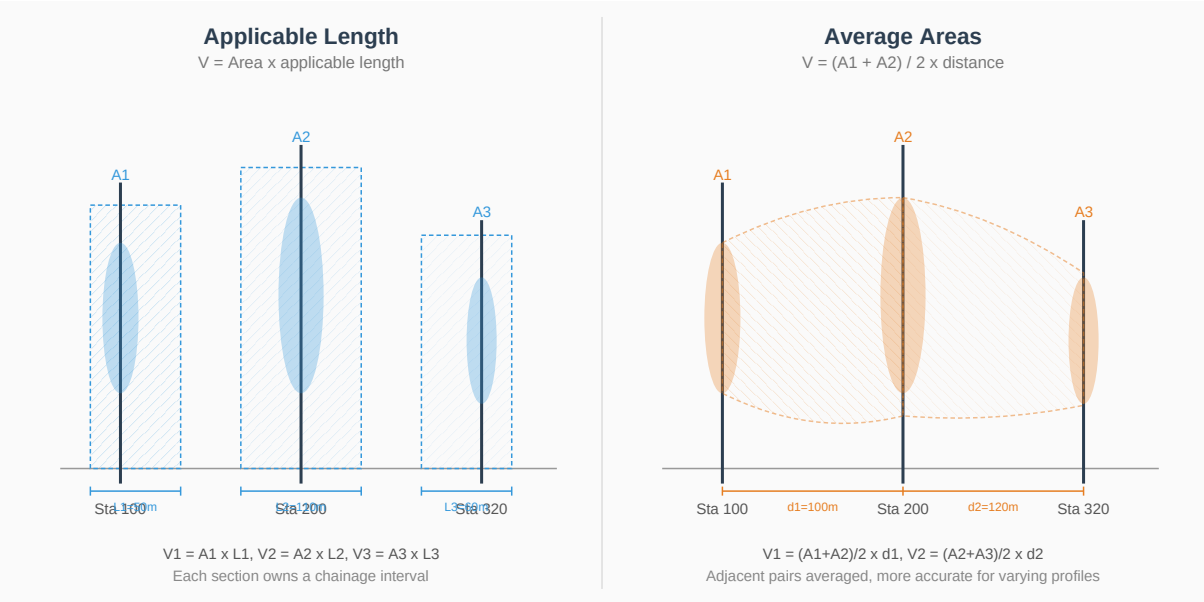


Fig. 5: Comparison of Applicable Length (left) and Average Areas (right) volume computation methods across three sections.

Choosing a method

> **Tip**
>
> Average Areas is recommended for most tunnel monitoring workflows, especially when sections are unevenly spaced or the profile changes rapidly. Applicable Length is simpler and sufficient when sections are closely and regularly spaced.

The computation method is set per volume definition in the *Volume Definition Editor*. You can change the method and recalculate without modifying the formula terms.

Station range

By default, the Mass Table computes volumes across all sections in the alignment. To restrict the range:

1. Select the Range radio button in the Station Range group.
2. Enter the From and To station values.
3. Click Recalculate to update the grid.

Only sections whose station falls within the specified range (inclusive) are included in the computation.

Total row

The last row in the grid shows the TOTAL cumulative volume across all computed sections. This is the primary quantity output for the volume definition.

Navigation

Double-click any row in the grid to navigate directly to that cross-section on the section canvas. This is useful for inspecting sections with unusually large or small area values, or sections flagged with warnings.

Warnings

Sections marked with an asterisk (*) after their name encountered evaluation warnings – typically a missing line definition at that station. The area value for such sections may be zero or incomplete. Review these sections to ensure all required line data is present.

Export

CSV export

Click Export CSV to save the mass table as a semicolon-delimited CSV file. The exported file contains the same columns and data as the grid, including the header row and total row.

Excel export

Click Export XLS to save the mass table as an XLSX file (Excel format). The export uses fpspreadsheet and produces a properly formatted workbook with:

- Bold header row
- Numeric cells for station, area, and volume values (enabling further calculations in Excel)
- Text cells for section names

> **Note**
>
> The Excel export produces `.xlsx` format (Office Open XML). Older `.xls` format is not supported.

Export to PDF

Export to PDF. Click Export PDF… on the Mass Table dialog (next to Export XLS) to save a printable mass-table report. The PDF starts with a title block (volume name, tunnel, method, station range, generated timestamp + colour swatch) followed by the same grid you see on screen, paginated as needed and topped with a TOTAL row. The final page draws two stacked panels sharing the station X axis: Area (m2) on top, Cumulative Volume (m3) below. The default filename is `<TunnelName>_MassTable_<volume-definition>.pdf`. Sections that flagged warnings during volume calculation appear with a * next to the section name and a footnote at the table tail explains the marker.

5.5.4 Clipping Levels

Clipping levels restrict the area computation to a specific region of the cross-section. By enabling one or more clipping boundaries, you can isolate portions of the tunnel profile for targeted analysis – for example, computing area only below the invert level or only on one side of the tunnel axis.

How clipping works

When a clipping level is enabled, the polygon used for area computation is clipped to a rectangular boundary before evaluation. The clipping rectangle is defined by up to four independent boundaries:

- Up – clips to a maximum Y (elevation) value. Area above this level is excluded.
- Down – clips to a minimum Y (elevation) value. Area below this level is excluded.
- Left – clips to a minimum X (offset) value. Area to the left of this offset is excluded.
- Right – clips to a maximum X (offset) value. Area to the right of this offset is excluded.

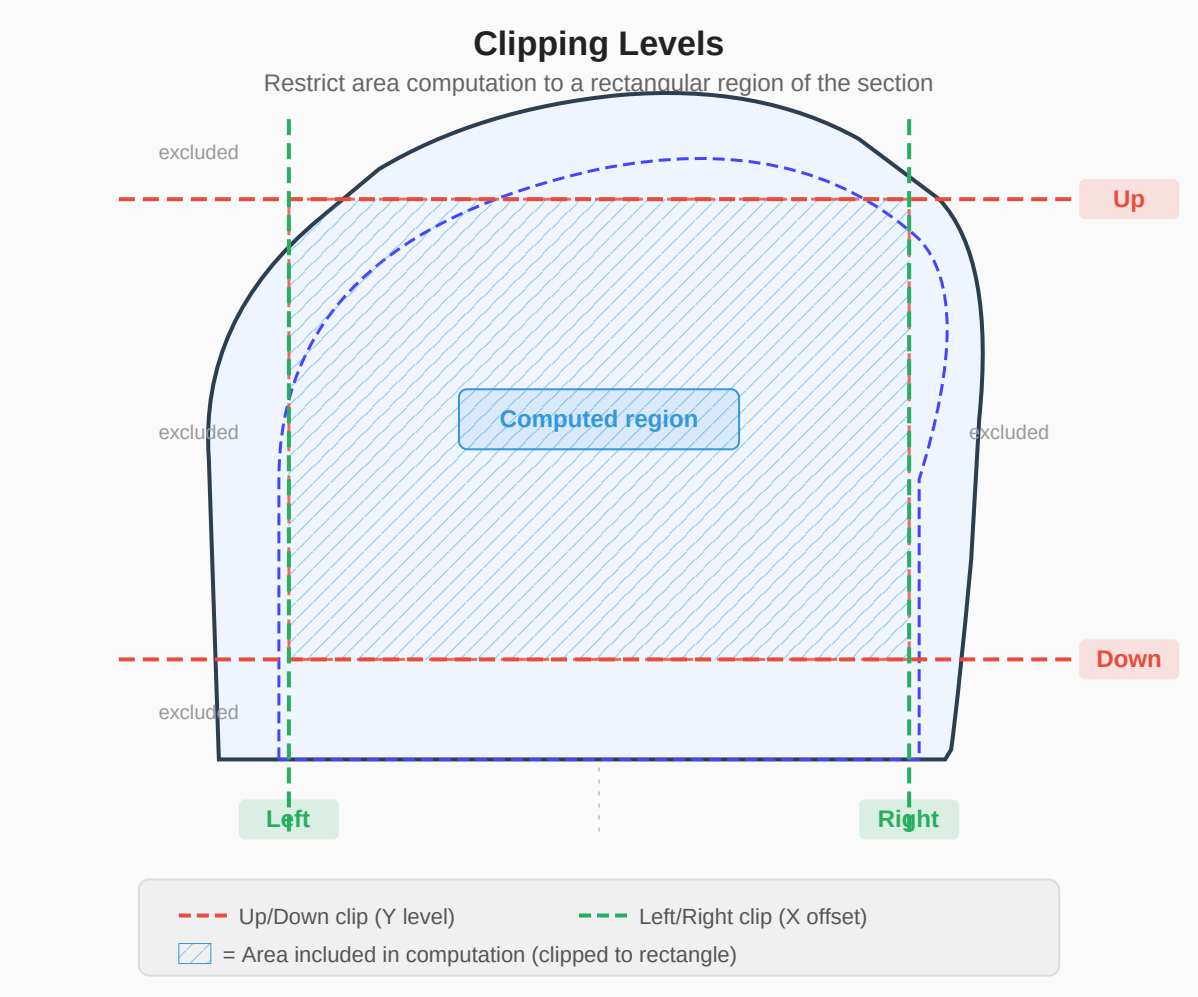


Fig. 6: Clipping levels illustrated on a tunnel cross-section. Dashed lines show the Up, Down, Left, and Right clip boundaries. Only the area within the clipped region (shaded) is included in the computation.

Enabling clipping

Each clipping level is controlled independently in the Volume Definition Editor:

1. Check the checkbox next to the level (Up, Down, Left, or Right) to enable it.
2. Enter the clipping value in the adjacent text field.
3. Levels that are unchecked are ignored – no clipping is applied on that boundary.

You can enable any combination of the four levels. For example, enabling both Down and Right restricts computation to the lower-right quadrant of the section.

Coordinate system

Clipping values are specified in the section's local coordinate system:

- X axis – horizontal offset from the alignment axis. Positive values are to the right, negative values are to the left.
- Y axis – elevation relative to the section's reference point. Positive values are upward.

Important

The clipping values are in the same coordinate system as the section line data – local offsets, not world coordinates. A Down level of `-2.0` means "exclude everything below Y = -2.0 in the section view."

Use cases

Crown analysis

Enable the Up clipping level to restrict computation to the upper portion of the tunnel. Set the Up level to the springline elevation to analyze only the crown area.

Example: compute overbreak in the crown only, excluding the sidewalls and invert.

Invert analysis

Enable the Down clipping level to restrict computation to the lower portion. Set the Down level to the invert elevation to analyze only the invert concrete zone.

Example: compute the invert area for concrete volume estimation.

Side-specific analysis

Enable Left or Right clipping to analyze one side of the tunnel independently. This is useful when:

- Different construction methods are used on each side
- One side has a known geological condition requiring separate reporting
- Comparing left vs. right excavation symmetry

Example: set Left to `0.0` to analyze only the right half of the tunnel (positive X offsets).

Combined clipping

Enable multiple levels simultaneously to define an arbitrary rectangular region. For example:

- Down = -1.0 and Up = 3.0 – analyze only the zone between Y = -1.0 and Y = 3.0
- Left = -5.0 and Right = 5.0 – limit analysis to a 10-meter-wide band centered on the axis

Additive constant

The Constant field in the Volume Definition Editor specifies a fixed value added to every section's computed area result. This is applied after clipping and formula evaluation.

Use cases for the additive constant:

- Systematic correction for known measurement bias
- Accounting for a fixed material allowance per section
- Adjusting for features not captured in the line data

Note

The additive constant is in the same units as the area result (m2 for area terms, meters for Length terms). It is added to the total formula result, not to individual terms.

CHAPTER

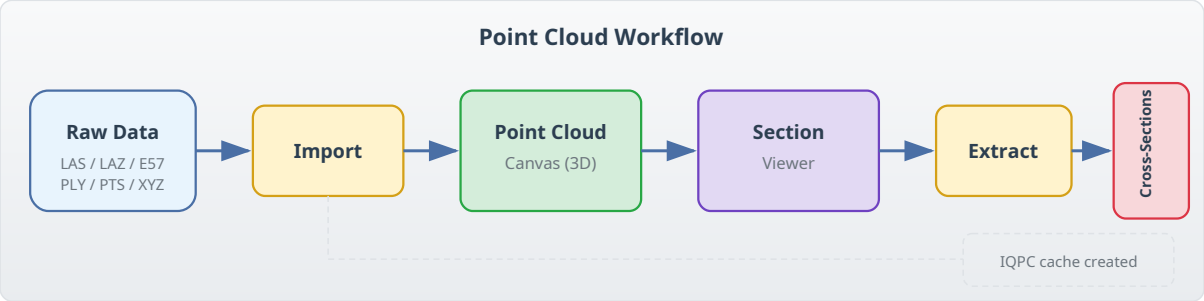
SIX

POINT CLOUD

TunnelCAD supports importing and processing 3D point cloud data for automated cross-section extraction. This eliminates the need for manual profile digitization by sampling measured tunnel geometry directly from laser scan data.

6.1 Workflow overview

The typical point cloud workflow in TunnelCAD follows these steps:



1. Import raw point cloud data (LAS, LAZ, E57, PLY, PTS, or XYZ format) into the project.
2. View the point cloud in the Point Cloud canvas tab, which renders the data using OpenGL.
3. Open the Section Viewer to interactively inspect point cloud slices at alignment stations.
4. Adjust filter parameters (angular binning, radius limits, elevation cutoffs) to isolate the tunnel surface.
5. Extract the filtered points into measured cross-section line data at one or more stations.
6. The extracted sections join the tunnel's cross-section list and can be used for volume calculations, clearance analysis, and reporting.

6.2 Supported formats

Format	Extension	Description
LAS	`.las`	ASPRS LIDAR data exchange standard
LAZ	`.laz`	Compressed LAS (requires liblaszip library)
E57	`.e57`	ASTM E2807 standard for 3D imaging data
PLY	`.ply`	Polygon File Format – simple vertex data
PTS	`.pts`	Leica point cloud format (text: X Y Z Intensity R G B)
XYZ	`.xyz`	Plain text format (X Y Z per line, optionally with RGB)

6.3 IQPC cached format

When you import a raw point cloud, TunnelCAD converts it to the IQPC (IQsoft Point Cloud) format – an optimized binary representation with a spatial octree index. The IQPC file is cached alongside the project and reloaded on subsequent sessions without re-parsing the original file. This makes repeated work on the same dataset substantially faster.

IQPC files can also be shared between projects via Point Cloud > Attach (.iqpc)….

6.4 Point Cloud canvas tab

The Point Cloud tab in the main canvas area renders all loaded point clouds in 3D using OpenGL. You can orbit, pan, and zoom to inspect the data before opening the Section Viewer for extraction.

> **Note**
>
> On Linux, point cloud import requires two shared libraries in the application directory:
>
> - `libE57CWrapper.so` – for E57 format support
> - `liblaszip.so` – for LAZ compressed format support
>
> These are not needed on Windows, where the equivalent DLLs are bundled with the application.

6.4.1 Importing Point Clouds

How to import

Open a point cloud file using one of these methods:

- Menu: Point Cloud > Import…
- Ribbon: Point Cloud tab > Import button

A standard file dialog appears. Select one or more files in any supported format. TunnelCAD reads the raw data, converts it to its internal IQPC format, and displays the result on the Point Cloud canvas tab.

Format details

LAS / LAZ

LAS is the industry-standard binary format for LIDAR point cloud data, defined by the ASPRS (American Society for Photogrammetry and Remote Sensing). It stores point coordinates, intensity, classification, RGB color, and return information.

LAZ is the compressed variant of LAS, typically 5–10x smaller on disk. TunnelCAD uses the liblaszip library to decompress LAZ files transparently during import.

E57

E57 is the ASTM E2807 standard for storing 3D imaging data from laser scanners, structured-light systems, and other 3D measurement devices. It supports multiple scans in a single file, point coordinates, color, intensity, and scanner metadata.

TunnelCAD uses the libE57CWrapper library to read E57 files.

PLY

PLY (Polygon File Format, also known as Stanford Triangle Format) is a simple format for storing 3D vertex data. TunnelCAD reads the vertex positions and optional RGB color attributes. Both ASCII and binary PLY variants are supported.

PTS

PTS is a text-based point cloud format commonly exported from Leica scanners. Each line contains space-separated values:

```
X Y Z Intensity R G B
```

Intensity is a reflectance value. R, G, B are 0–255 color components.

XYZ

XYZ is the simplest text-based format. Each line contains space-separated coordinates:

```
X Y Z
```

Some XYZ files include additional columns for RGB color (X Y Z R G B). TunnelCAD auto-detects the column count.

Import behavior

- The import process runs in a background thread with a progress indicator. Large files (tens of millions of points) may take several seconds to load.
- Once imported, the point cloud is cached as an IQPC file alongside the project. On the next session, TunnelCAD reloads the cached IQPC file instead of re-parsing the raw format.
- The point cloud appears immediately on the Point Cloud canvas tab after import.
- Multiple point clouds can be loaded simultaneously (e.g., separate scans of different tunnel sections).

Removing point clouds

To remove a loaded point cloud from the project:

- Menu: Point Cloud > Clear

This unloads all point cloud data from memory. The cached IQPC files remain on disk and can be reattached later.

Working with large datasets

TunnelCAD supports point clouds with millions of points. The Point Cloud canvas uses Level of Detail (LOD) rendering – when zoomed out, a subset of points is displayed for smooth navigation; as you zoom in, progressively more detail is shown. The full dataset is always available for section extraction regardless of the current LOD level.

> **Tip**
>
> For very large scan datasets (100M+ points), consider splitting the data into per-station or per-zone files in your scanning software before importing. This lets you load only the relevant portion when working on a specific section of the tunnel.

6.4.2 Section Viewer

The Section Viewer is the primary tool for extracting measured cross-sections from point cloud data. It displays a 2D slice through the point cloud at each alignment station, applies configurable filters to isolate the tunnel surface, and samples the result into cross-section line data.

Open it via Point Cloud > Section Viewer.

Dialog layout

The Section Viewer window has four areas:

Toolbar (top)
: Toggle side panel | Prev/Next station buttons | Station number edit | Track bar slider | Plane mode | Slab thickness

Side panel (left, collapsible)
: Cloud list, station list, filter settings, extraction controls

Section canvas (center)
: 2D rendering of the point cloud slice at the current station

3D preview (right)
: Downsampled view of the checked point clouds, the alignment, and the section positions. Drag the splitter to give either pane more room.

Click the toggle button in the toolbar to collapse or expand the side panel, giving more room to the section canvas when needed.

3D preview

The right-hand pane shows the clouds that are checked in the side panel, thinned to a fixed preview budget so orbiting stays quick while you cut sections. Colours follow each cloud's style (elevation, RGB, intensity, classification, or a single colour).

- Cyan crosses — saved cross-section stations
- Yellow plane — the station currently shown in the 2D canvas. The filled square is the cutting plane; the two faint rings sit half a slab thickness either side of it
- White line — alignment centreline

Left-drag orbits, right-drag or middle-drag pans, the mouse wheel zooms, and a double-click fits the view. Checking or unchecking a cloud rebuilds the preview. Scrubbing the station moves the yellow plane without resampling the cloud.

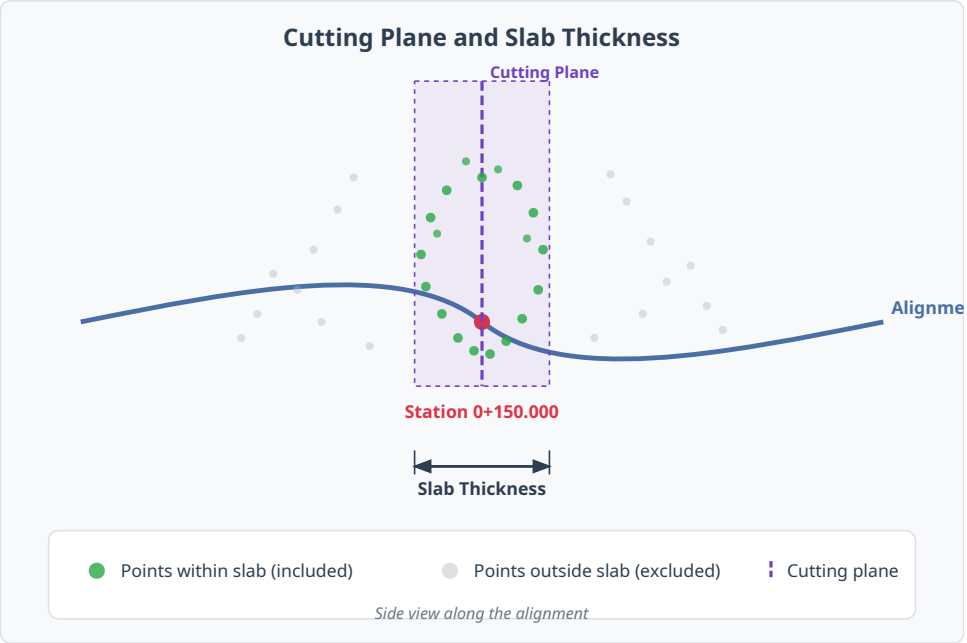
Navigating stations

The station list on the side panel shows all existing cross-section stations for the active tunnel alignment. Select a station to jump to it.

You can also navigate using:

- Prev / Next buttons in the toolbar (or Left/Right arrow keys)
- Station edit field – type a chainage value directly (format: `0+000.000`)
- Track bar – drag to scrub through the full chainage range
- Home / End keys – jump to the first or last station

Cutting plane



At each station, TunnelCAD constructs a cutting plane perpendicular to the alignment. All point cloud points within a certain distance of this plane are projected onto the 2D section view.

Plane mode

Two plane orientations are available:

Vertical
: The cutting plane is vertical – its normal lies in the horizontal plane along the alignment direction. The up direction is always world-Z. This is the standard mode for most tunnels.

Perpendicular
: The cutting plane is truly perpendicular to the alignment in 3D, accounting for the longitudinal gradient. The “up” direction tilts with the tunnel slope. Use this for steeply graded sections where a vertical cut would produce a skewed profile.

Slab thickness

The Slab Thickness parameter (in the toolbar) controls how thick the slice is around the cutting plane. Points within half the slab thickness on either side of the plane are included. A thicker slab captures more points but may introduce noise from adjacent geometry; a thinner slab gives a cleaner profile but may have gaps.

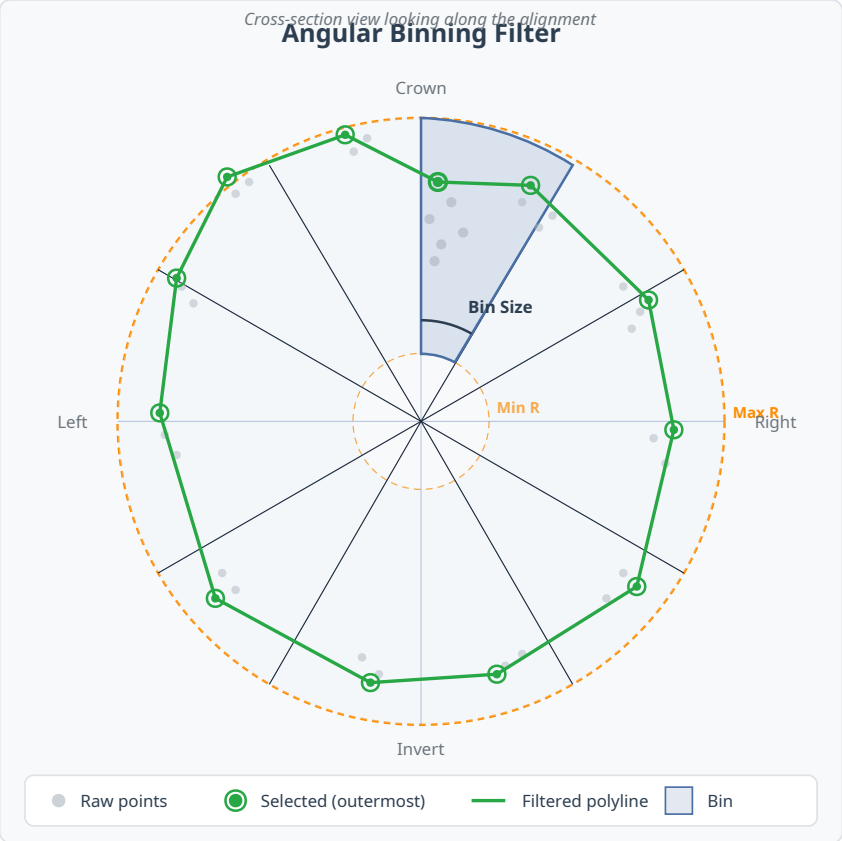
> **Tip**
>
> Start with a slab thickness of 0.5 m. Increase it if the section appears sparse (too few points), or decrease it if you see double-wall artifacts from adjacent rings or segments.

Cloud selection

The Cloud list (checkboxes at the top of the side panel) lets you choose which loaded point clouds contribute to the section slice. Uncheck a cloud to exclude it – useful when multiple scans overlap and you want to isolate one.

Filter settings

The filter transforms the raw point cloud slice into a clean polyline representing the tunnel surface. The algorithm divides the 2D section into angular bins radiating from the section center and selects one representative point per bin.



Filter mode

Four modes control which point is selected within each angular bin:

Mode	Description
Outer-most	Maximum radius – selects the point farthest from center. Best for detecting the excavation surface.
Inner-most	Minimum radius – selects the point closest to center. Useful for finding the lining or shotcrete surface.
Median	Median radius – robust estimate that ignores outliers in both directions.
Per-centile	User-defined percentile (0–100%). The Percentile spinner is enabled only when this mode is selected.

Bin size

The angular width of each bin in degrees. Smaller bins produce a higher-resolution polyline but require denser point cloud data to fill each bin.

- Default: 5 degrees (72 bins around the full circle)
- Typical range: 1–15 degrees

Min / Max Radius

Distance range from the section center (in meters). Points outside this range are excluded before binning.

- Min Radius: filters out points too close to the axis (e.g., survey targets, equipment near the center). Default: 0 m.
- Max Radius: filters out distant outliers or points from adjacent structures. Default: 100 m.

Min Points Per Bin

The minimum number of raw points required in a bin to produce an output point. Bins with fewer points are skipped, leaving a gap in the polyline. This prevents isolated noise points from being treated as surface data.

- Default: 3

Percentile

Active only in Percentile mode. Specifies which percentile of points (by radius) to select within each bin. For example, 90% selects the point at the 90th percentile of radius values – close to the outermost but ignoring the top 10% of outliers.

Proximity

A fraction (0–100%) controlling how many of the points closest to the cutting plane are kept before radius selection. At 100%, all points in the slab are used. At 50%, only the half closest to the cutting plane are kept per bin, reducing noise from the slab edges.

Gap threshold

When greater than zero (meters), the filter detects radial gaps within each bin. If the largest gap between consecutive points exceeds the threshold, only the outer cluster is kept. This removes ventilation ducts, cables, and other equipment that appear as inner rings in the section.

Template constraint

When a foreign object hangs inside the cross-section (a vent duct, hose, cable bundle, or similar), the angular-binning filter sometimes picks the object's points instead of the wall behind it. The Template Constraint dropdown removes such points before they enter the per-bin selection.

The constraint compares each candidate point's distance from the section centre against the *template's* distance at the same angle. The template must be selected via the Template Line dropdown – pick a specific named line, not "All", or the constraint silently disables and the hint label "select a single template line" appears below the controls.

Four modes:

Mode	Behaviour
None	Constraint disabled (default – current behaviour).
A. Reject inside	Drops any candidate whose radius is more than `Inside Tol` smaller than the template radius at that angle. The wall and excavation overbreak are kept; objects hanging well inside the design profile are removed. Use for excavation surfaces.
B. Band (per-point)	Keeps only candidates within `[template - Inside Tol, template + Outside Tol]`. Each candidate is checked against the template radius at *its own* angle. Use for shotcrete/lining surfaces or any "the wall sits close to design" scenario.
C. Band (per-bin)	Same band as B, but the template radius is sampled once at each angular bin's centre angle and reused for every point in that bin. Slightly faster and easier to reason about when bin sizes are large.

Inside Tol (m): how far inside the template a candidate may sit and still be kept. Default 0.10. Mode A uses only this value.

Outside Tol (m): how far outside the template a candidate may sit. Used only by modes B and C. Default 0.50, allowing typical excavation overbreak.

Where the template doesn't define a wall along a given ray (e.g. an open template that doesn't cover the invert), candidates along that ray pass through unconstrained – downstream rules (radius cap, gap, etc.) still apply.

Raw points removed by the constraint render as dim grey on the canvas, so you can see exactly which points were filtered and tune the tolerances accordingly. Points removed by other rules (elevation, MinR/MaxR, gap) keep their elevation-rainbow colour as before.

> **Tip**

Start with mode A and Inside Tol = 0.10 m to sweep out objects in the tunnel interior without affecting the wall. If wall noise gets aggressive in mode A, try mode B with Outside Tol = 0.30–0.50 m to also cap stray outside-the-wall hits.

Elevation filters

Min Elevation

Excludes points below this elevation (relative to the section center, in meters). Set to a negative value to cut debris or water at the tunnel invert. Default: -999 (no cutoff).

Max Elevation

Excludes points above this elevation (relative to the section center, in meters). Useful for excluding overhead services or open-cut sections. Default: 999 (no cutoff).

Invert Skip Distance

Skips angular bins near the tunnel invert (bottom). The value is in degrees: it defines a symmetric zone around the bottom of the section (180 degrees from the top). Bins within this zone are excluded.

This is useful when the tunnel floor contains rail tracks, muck, or other material that does not represent the excavated surface.

- 0: no skip (default)
- 60: skips bins within +/- 30 degrees of the bottom

Canvas interaction

The section canvas shows the filtered polyline overlaid on the raw point cloud slice.

Action	Effect
Right-click drag	Pan the view
Middle-click drag	Pan the view
Scroll wheel	Zoom in/out
Home key	Jump to first station
End key	Jump to last station
Left/Right arrow	Previous/next station
Esc	Cancel an in-progress drag and reset to the Move tool

A coordinate grid is drawn in the background. The status bar at the bottom shows the total raw point count, the number of filtered (selected) points, the current chainage, and the empty/total bin ratio.

The hint label on the edit toolbar (see below) shows a live `(Offset, Elev, dZ)` cursor readout while the cursor is over the canvas.

Manual editing

The edit toolbar above the section canvas lets you correct the auto-sampled polyline by hand before committing it to the cross-section. Edits target the in-viewer working copy (the filtered preview); they do not touch the persisted cross-section until you click Sample Current.

> **Important**
>
> After editing, you must click Sample Current (or Sample Range) for the changes to take effect. Re-extracting (changing slab thickness, plane mode, slab, station, or any filter setting) discards uncommitted edits and rebuilds the preview from the cloud.

Edit tools

The toolbar groups three tool-radio buttons followed by two command buttons:

Tool / Command	Effect
Move (default)	Click and drag a vertex (green dot) onto a different raw cloud point.
Add	Click on a raw cloud point to insert a new vertex. The new vertex is spliced into the polyline at the segment whose perpendicular distance to the click is smallest, so the line connects through it cleanly.
Delete	Click a vertex to remove it. A confirmation dialog appears the first time; Shift+click suppresses confirmations for the rest of the session.
Reverse	Reverses the polyline direction. Useful when the radial order needs to be flipped before sampling.
Closed	Toggle that controls whether the line is treated as closed. Drawn closed when on (with at least 3 vertices and no force-open filter active); written as `coForceClosed` / `coForceOpen` to the persisted line on Sample Current.

Add and Move are snap-to-cloud: a small cyan square marker appears on the nearest raw point within ~12 px of the cursor. Clicking with no marker visible is a no-op. Move drags rubber-band visually but only commit to raw points; if no raw point is nearby on release, the vertex stays at its last snapped position.

Keyboard shortcuts

Key	Effect
Esc	Cancel an in-progress drag (revert the vertex to its pre-drag position) and reset the active tool to Move.
Del	Delete the vertex currently under the cursor (subject to the same confirmation as the Delete tool).

Edit lifecycle

1. Extract + filter at the target station (any combination of slab/plane/filter changes).
2. Pick a tool (Move/Add/Delete) and edit the preview. Toggle Reverse / Closed as needed.
3. Click Sample Current to commit the edited preview to the cross-section's persisted line data.
4. Save the project to persist on disk.

The radial sort that Sample Current normally applies (clockwise from the invert) is suppressed when manual edits are present, so reversed direction and topologically-inserted points survive sampling. The user-driven Closed toggle takes precedence over the line definition's default `Closed` flag at sampling time.

> **Tip**
>
> Re-extract is the explicit "discard edits" gesture. Any change to the slab, plane, filter, cloud check, or station triggers a fresh extract and filter, which clears the working preview and resets the toolbar to the Move tool.

Extracting sections

Line definition

Before extracting, select the target Line Definition from the dropdown. The extracted polyline is stored as line data under this definition in the cross-section. For example, select "Excavation" to store the scanned tunnel profile as the excavation line.

Template line

The Template Line dropdown controls which template overlay is displayed on the canvas for visual reference. Select "All" to see all template lines, or a specific one to focus on a single design profile.

Append mode

When Append is checked, the extracted points are merged with any existing line data at that station rather than replacing it. This is useful for combining data from multiple scans or from manual measurements.

Extract current station

Click Sample Current to extract the filtered polyline at the currently displayed station. The points are radially sorted (clockwise from the invert) and saved as line data in the cross-section.

> **Note**
>
> If the station does not yet have a cross-section, one is created automatically. The alignment geometry (insertion point, elevation, bearing, template) is computed from the alignment engine.

Extract a range of stations

Click Sample Range… to batch-extract sections within a chainage interval. A modal dialog opens with From station and To station edits, pre-filled with the tunnel start and end. A live label shows how many existing cross-sections fall in the chosen range (`Sections in range: N / M`).

Click Sample to confirm and run the loop. A confirmation dialog summarises the count and chainage range; on Yes, TunnelCAD iterates the in-range cross-sections, extracts and filters the point cloud slice at each one, and saves the result. A progress indicator is shown in the status bar.

Stations where the filter produces fewer than 2 points are skipped.

> **Tip**
>
> To re-sample every section (the previous “Sample All” workflow), open the dialog and click Sample without editing the chainage fields – the defaults already span the full tunnel.

Direction display

Check Show Direction to display the alignment direction arrow on the section canvas. This helps verify that the section orientation matches expectations (left/right sides of the tunnel).

6.4.3 Attaching IQPC Files

What is IQPC?

IQPC (IQsoft Point Cloud) is TunnelCAD’s native cached point cloud format. It stores point coordinates, colors, and a spatial octree index in a compact binary layout optimized for fast loading and spatial queries.

When you import a raw point cloud (LAS, E57, etc.), TunnelCAD automatically creates an IQPC cache file alongside the project. On subsequent sessions, the IQPC file is loaded directly instead of re-parsing the original format – typically an order of magnitude faster.

Attaching an existing IQPC file

To re-link a previously created IQPC file without re-importing raw data:

- Menu: Point Cloud > Attach (.iqpc)…

A file dialog opens. Select the `.iqpc` file and it is loaded into the project immediately.

When to use Attach

- Reopening a project – if the IQPC cache was moved or the automatic cache path no longer resolves, use Attach to point TunnelCAD at the correct file.
- Sharing between projects – multiple tunnel projects can reference the same IQPC file. For example, if two tunnel alignments pass through the same scan area, both projects can attach the same cached cloud.
- Working on a different machine – copy the IQPC file to the new machine and attach it rather than re-importing the original raw data (which may be very large or unavailable).

File management

> **Note**
>
> IQPC files can be large (comparable in size to the original point cloud). Keep them on a local or fast-access drive for best performance. Loading IQPC files over a network share may be noticeably slower.

- IQPC files are independent of the raw source data. Once created, the original LAS/E57/PLY file is not needed for viewing or section extraction.
- Deleting an IQPC file does not affect the project – you can always recreate it by re-importing the raw data.
- The IQPC format includes the octree spatial index, so no additional indexing step is required after attaching.

CHAPTER

SEVEN

ANALYTICS

The Analytics module provides quantitative analysis of tunnel excavation quality by comparing measured cross-section profiles against theoretical design templates. It transforms raw survey data into actionable engineering metrics – quality grades, compliance reports, trend analysis, and statistical distributions – enabling project teams to identify problems early and document construction quality.

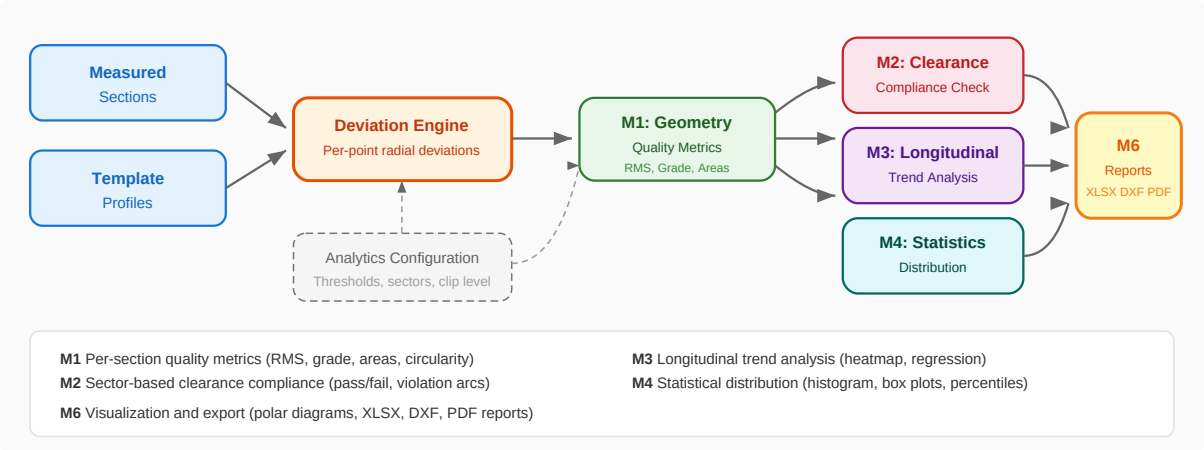


Fig. 1: Data flow through the Analytics module: measured sections and templates feed the Deviation Engine, which produces metrics consumed by all sub-modules.

7.1 Module overview

The Analytics module is organized into five sub-modules, each addressing a different aspect of excavation quality:

Module	Name	Purpose
–	*Analysis Modes*	Analysis modes: Measured vs Template or Measured vs Measured
M1	*Geometry Quality (M1)*	Per-section geometric quality metrics (RMS, areas, grading)
M2	*Clearance & Compliance (M2)*	Clearance and compliance checking (pass/fail per sector)
–	*Tolerance Band & Cpk Analysis*	Tolerance band analysis: Cpk, % within tolerance, max exceedance
M3	*Longitudinal Analysis (M3)*	Multi-section longitudinal trend analysis and heatmaps
M4	*Statistics (M4)*	Statistical distribution of deviations across sections
M6	*Reporting (M6)*	Visualization, polar diagrams, and export (XLSX, DXF, PDF)

All analytics sub-modules consume data from `TTunnelDeviationEngine`, which computes per-point radial deviations between the measured profile and the template at each cross-section. The deviation engine produces a signed distance for every measured point: positive values indicate overbreak (excavation beyond the template) and negative values indicate underbreak (template not fully excavated).

7.2 Accessing Analytics

The Analytics dashboard is located on the Analytics tab in the main application window. To run an analysis:

1. Select an Analysis Mode: `Measured vs Template` (compare against design) or `Measured vs Measured` (compare two survey lines). See *Analysis Modes* for details.
2. Select a Measured line (the line definition containing survey data, e.g., “Excavation”)
3. Select a Reference line (template line or another measured line, depending on the selected mode)
4. Optionally set a chainage range using the From and To fields
5. Click Analyze

The dashboard grid populates with per-section results, and clicking any row displays the polar deviation diagram in the panel below.

7.2.1 Active-tunnel synchronisation

The Measured / Reference / From / To controls on the Analytics ribbon are tied to the active tunnel of the current project tab. They are refreshed automatically whenever:

- the user switches project tabs (the ribbon re-reads the tab’s active alignment);
- the user changes the active tunnel within a project (tree node, load-alignment dialog, etc.) — the frame fires an `OnAlignmentChanged` notification and the ribbon re-binds its combos and chainage range to the new tunnel.

The defaults on re-bind are: *Measured / Reference* → first line definition of the new tunnel, *From* → `StartChainage`, *To* → `EndChainage`. If the user had typed custom values into From/To while working on a previous tunnel they are replaced — the ribbon always shows values that are valid for the currently active alignment.

7.3 Configuration

Analytics thresholds and parameters are configured through the Analytics Configuration dialog, accessible via the Settings button on the Analytics dashboard. All settings are stored per project and saved in the `.tun` file.

7.3.1 Grade thresholds

These define the boundaries between quality grades A through D:

Parameter	Default	Description
Grade A – RMS limit	30 mm	Maximum RMS deviation for Grade A
Grade B – RMS limit	60 mm	Maximum RMS deviation for Grade B
Grade C – RMS limit	100 mm	Maximum RMS deviation for Grade C
Grade A – Ratio limit	108%	Maximum excavation ratio for Grade A
Grade B – Ratio limit	115%	Maximum excavation ratio for Grade B
Grade C – Ratio limit	125%	Maximum excavation ratio for Grade C

7.3.2 Compliance parameters

Parameter	Default	Description
Underbreak area maximum	0.1 m^2^	Maximum underbreak area for Grade C (Grade A/B require zero)
Sector count	24	Number of angular sectors for compliance check (24 = 15 degrees per sector)
Warning threshold	10 mm	Distance below which a sector is flagged as warning rather than compliant
Fail on warnings	Off	When enabled, warning sectors also cause an overall FAIL result
Clearance threshold	0 mm	Sections with minimum clearance below this value are marked as critical

7.3.3 Area and cost parameters

Parameter	Default	Description
Clip level enabled	Off	When enabled, points below the clip level are excluded from analysis
Clip level	-2.0 m	Y-offset below section center for level clipping (used for open-invert sections)
Concrete unit price	150 EUR/m^3^	Unit price for overbreak volume cost estimation in XLSX export

7.3.4 Tolerance parameters

Parameter	Default	Description
Enable Tolerance Band	Off	Master switch for tolerance analysis (Cpk, % within tolerance)
Upper Limit (USL)	20 mm	Upper Specification Limit – maximum allowed positive deviation
Lower Limit (LSL)	-20 mm	Lower Specification Limit – maximum allowed negative deviation

When tolerance is enabled, three additional columns appear in the dashboard grid (% in Tol, Cpk, Exceed), a fourth row appears in the status strip, and the polar diagram shows dashed tolerance band lines. See *Tolerance Band & Cpk Analysis* for a complete explanation of Cpk and tolerance metrics.

> **Tip**
>
> Click Defaults in the configuration dialog to reset all parameters to factory values. This is useful when starting a new project or when experimenting with different threshold schemes.

> **Warning**
>
> Changing grade thresholds or tolerance limits after analysis invalidates previously computed results. Re-run the analysis after modifying configuration to ensure all sections reflect the updated criteria.

Analysis Modes

The Analytics module supports two comparison modes, selectable from the Mode dropdown in the ribbon toolbar or the dashboard frame.

Measured vs Template

The standard analysis mode. A measured survey line is compared against the theoretical design line (template) at each cross-section.

The template is automatically interpolated at each section's chainage using `GetTemplateAtStation`. If the template changes along the alignment (e.g., wider at portals, narrower in the bore), the correct template geometry is used for each section.

Use cases for Measured vs Template

- Excavation quality assessment: Compare "Excavation" line against "Design Excavation" template to evaluate how accurately the tunnel was excavated
- Shotcrete compliance: Compare "Shotcrete" line against "Design Shotcrete" template to verify that the shotcrete layer conforms to the design

- Lining thickness: Compare “Inner Lining” line against “Lining Design” template

Reference combo in Template mode

When this mode is selected, the Reference combo lists all template line definitions from the active alignment (`TemplateLineDefinitions`).

Measured vs Measured

Compares two measured lines from the same cross-section. Instead of using a template as the reference, a second measured line definition serves as the baseline.

Both lines must exist in the same cross-section. The deviation engine computes deviations identically – the first line (Measured) is compared against the second line (Reference), with positive deviations indicating the measured line is outside the reference and negative deviations indicating it is inside.

Use cases for Measured vs Measured

- Before/after shotcrete: Compare “Excavation” (before) vs “Shotcrete” (after) to evaluate shotcrete layer thickness and uniformity
- Deformation monitoring: Compare “Epoch 1” vs “Epoch 2” measurements at the same stations to detect ground convergence or tunnel deformation over time
- Method comparison: Compare “Laser Scan” vs “Total Station” to validate measurement consistency between survey methods
- Construction stages: Compare “First Pass” vs “Second Pass” in a multi-stage excavation

Reference combo in Measured mode

When this mode is selected, the Reference combo lists all measured line definitions from the active alignment (`LineDefinitions`) – the same list as the Measured combo. You can select any two different lines.

> **Warning**
>
> When comparing two measured lines, ensure both lines have data at the same cross-sections. Sections where either line is missing will be skipped. The chainage range filter helps focus on sections where both lines are available.

Engine behavior

The deviation engine (`TTunnelDeviationEngine`) is polyline-agnostic – it does not distinguish between “measured” and “template” geometries. It simply compares two point arrays:

- First array (measured): The profile being evaluated
- Second array (reference): The baseline for comparison

All computations – RMS, overbreak/underbreak areas, compliance sectors, tolerance metrics – work identically in both modes. The only difference is the source of the reference polyline:

Mode	Reference source	Display name
Measured vs Template	`TTemplateLine.Entity.GetWorldPoly`	Template section name
Measured vs Measured	`TSectionLineData.Points`	Measured line definition name

Switching modes

Changing the mode immediately repopulates the Reference combo with the appropriate line definitions (template or measured). The previously selected reference is cleared, and the first available line is auto-selected.

> **Tip**
>
> When using Measured vs Measured mode for deformation analysis, set up a tolerance band (e.g., +/-5mm) to quantify the agreement between epochs. The Cpk index will indicate whether deformations are within acceptable limits.

Geometry Quality (M1)

The Geometry Quality module computes per-section quality metrics by analyzing the radial deviation between measured and template profiles. It wraps `TTunnelDeviationEngine` to produce higher-level indices that characterize the excavation precision at each cross-section.

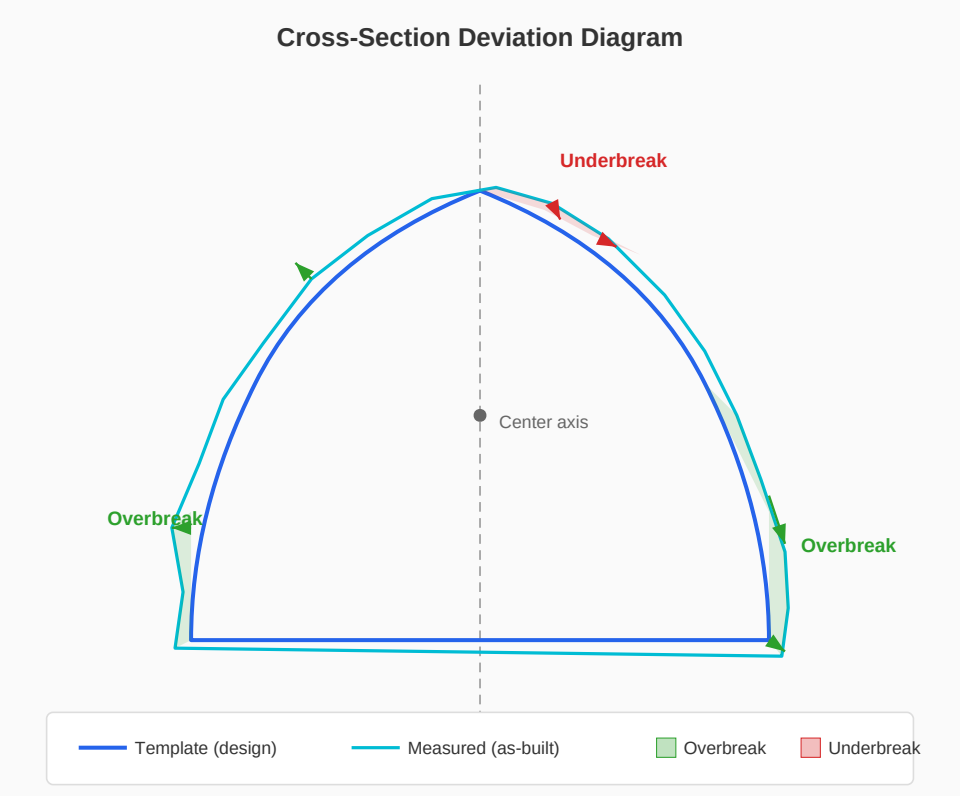


Fig. 2: Measured profile (cyan) compared against template profile (blue). Green arrows indicate overbreak (outward deviation); red arrows indicate underbreak (inward deviation).

Computed metrics

For each cross-section, M1 computes the following metrics:

Metric	Formula	Unit	Notes
Overbreak Area	`AreaOuter()`	m^2^	Area of measured profile outside template boundary
Underbreak Area	`AreaInner()`	m^2^	Area of template not excavated – should be zero
Excavation Ratio	(A~measured~ / A~template~) x 100	%	Ideal = 100%; values above 100% indicate overbreak
RMS Deviation	sqrt(1/n x sum(d~i~^2^))	mm	Root mean square of radial deviations
Mean Deviation	(1/n) x sum(d~i~)	mm	Positive = systematic overbreak bias
Max Overbreak	max(d~i~ > 0)	mm + position	Largest outward deviation with world coordinates
Max Underbreak	min(d~i~ < 0)	mm + position	Critical violation point with world coordinates
Circularity Index	4 x pi x A / P^2^	0–1	1.0 = perfect circle (meaningful for circular designs)
Irregularity Index	Variance of d^2^r/d-theta^2^	–	Detects jagged, uncontrolled excavation profiles
Quality Grade	Weighted composite	A/B/C/D	See grading system below
Quality Score	Continuous	0–100	Numeric score within the grade band

Area metrics

Overbreak and underbreak areas are computed by the deviation engine using polygon clipping between the measured and template profiles. When clip level is enabled, points below the Y-level threshold (relative to the section center) are excluded – this is useful for open-invert sections where the floor is not part of the design profile.

Deviation statistics

Deviations are extracted from the engine's `ComputePointInfos` result. Each measured point receives a signed radial distance in millimeters: positive for overbreak (outside template) and negative for underbreak (inside template). The RMS deviation is the primary quality indicator, while the mean deviation reveals systematic bias.

Shape metrics

The Circularity Index measures how close the measured profile is to a perfect circle. For circular tunnel designs, a value near 1.0 indicates uniform excavation. For non-circular designs (horseshoe, D-shape), this metric is less meaningful but still indicates profile regularity.

The Irregularity Index captures the roughness of the excavation surface by computing the variance of the second derivative of the deviation with respect to angle. High values indicate jagged profiles with abrupt local variations, even if the overall RMS is acceptable.

Quality grading system

Each section receives a quality grade from A (excellent) to D (non-compliant) based on the combination of RMS deviation, underbreak area, and excavation ratio.

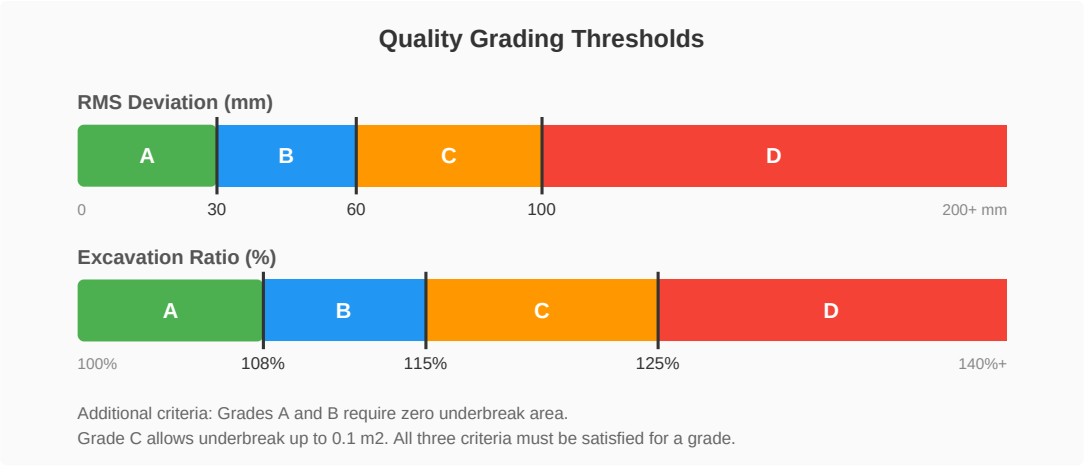


Fig. 3: Quality grade thresholds showing the A/B/C/D classification with default RMS and ratio limits.

Grade	Criteria	Interpretation
A	RMS <= 30 mm, Underbreak = 0, Ratio <= 108%	Excellent – controlled, precise excavation
B	RMS <= 60 mm, Underbreak = 0, Ratio <= 115%	Good – mild overbreak within tolerance
C	RMS <= 100 mm, Underbreak <= 0.1 m^2^, Ratio <= 125%	Acceptable – review recommended
D	Any criterion exceeds Grade C limits	Non-compliant – corrective action required

Grades are assigned using a waterfall evaluation: the section must satisfy all three criteria for a given grade. If any single criterion fails, the section falls to the next lower grade. Grade D is the catch-all for sections that exceed Grade C limits on any axis.

Quality score

Within each grade band, a continuous numeric score (0–100) provides finer granularity:

- Grade A: 90–100 (scaled by how far RMS is below the A threshold)
- Grade B: 70–90 (scaled by how far RMS is below the B threshold)
- Grade C: 40–70 (scaled by how far RMS is below the C threshold)
- Grade D: 0–40 (scaled inversely by how far RMS exceeds 200 mm)

Note

All grade thresholds are configurable per project through the Analytics Configuration dialog. The values shown here are factory defaults. Adjust thresholds to match project specifications or contractual requirements.

Clip level

For tunnels with open inverts (where the floor is not excavated to a designed profile), enabling the clip level excludes measured points below a Y-level threshold from analysis. The clip level is specified as a vertical offset below the section center point.

When clip level is active:

- Points below (center Y + clip offset) are excluded from deviation statistics
- Area calculations use the engine's level clipping system
- The excluded zone is typically the tunnel floor where no template exists

Tip

Set the clip level to approximately the invert depth (e.g., -2.0 m) to analyze only the arch and walls of an open-invert section. This prevents floor irregularities from skewing the quality metrics.

Clearance & Compliance (M2)

The Clearance module checks whether the measured tunnel profile fully contains the design template – that is, whether the excavated section provides sufficient clearance for the intended use. Any point where the measured profile falls inside the template boundary represents an underbreak violation that may require remedial action.

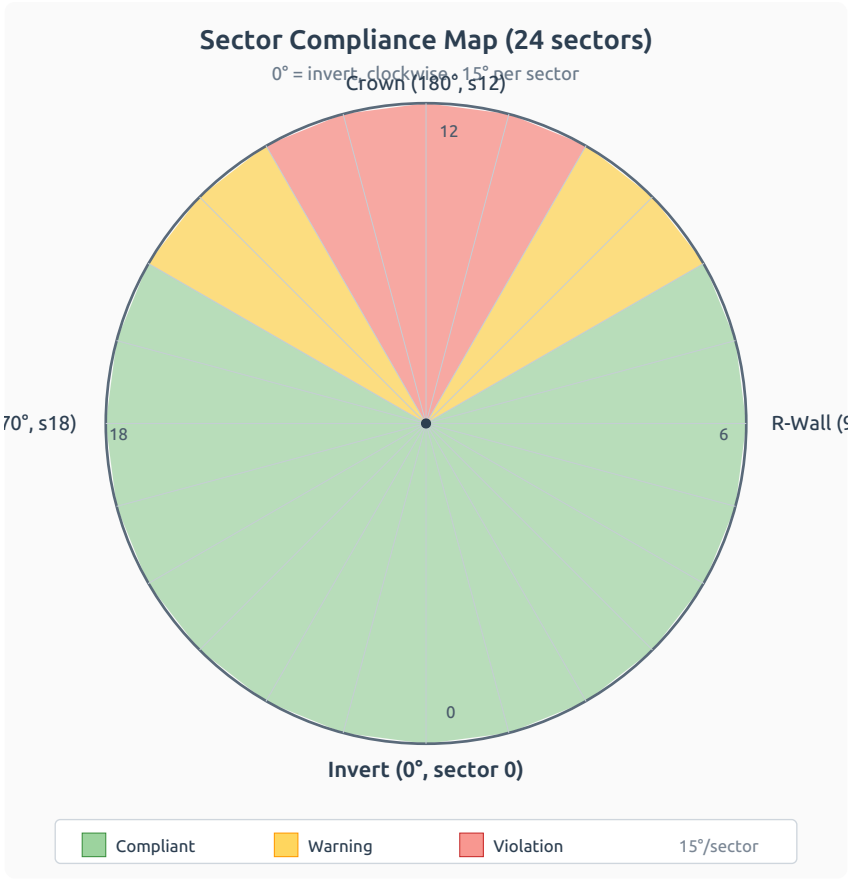


Fig. 4: Cross-section divided into 24 angular sectors (15 degrees each). Green = compliant, yellow = warning, red = violation. Angle convention: 0° = invert (bottom), 90° = right wall, 180° = crown, 270° = left wall — measured clockwise.

How compliance checking works

The compliance check operates on the per-point deviation data produced by `TTunnelDeviationEngine`. Each measured point has a signed radial deviation: positive means the measured profile is outside the template (overbreak, compliant), and negative means it is inside the template (underbreak, violation).

The section perimeter is divided into angular sectors centered on the section axis. Each sector collects the deviation values of all measured points whose angle falls within the sector span. The sector's status is determined by its minimum deviation value.

Sector assignment

Points are assigned to sectors based on their angular position, measured clockwise from the invert (bottom). With the default 24 sectors, each sector spans 15 degrees:

- Sector 0: 0–15 degrees — invert (bottom)
- Sector 6: 90–105 degrees — right wall
- Sector 12: 180–195 degrees — crown (top)
- Sector 18: 270–285 degrees — left wall

This matches the angle convention of `TTunnelDeviationEngine.RadialAngle`, which is the single source of truth for the whole Analytics suite.

Sector status classification

Each sector receives one of four status values:

Status	Condition	Meaning
Compliant	All points have deviation >= 0	Sufficient clearance in this sector
Warning	Minimum deviation between 0 and -threshold	Marginal clearance – approaching violation
Violation	Any point has deviation < -threshold	Underbreak detected – template not fully excavated
No Data	No measured points fall in this sector	Insufficient survey coverage

The warning threshold is configurable (default: 10 mm). Points with deviation between 0 and the negative threshold are in the warning band – technically compliant but close to the design boundary.

> **Note**
>
> Sectors with No Data status are treated as transparent for the purpose of violation arc detection. They do not break the contiguity of adjacent violation sectors, ensuring that a gap in survey coverage does not artificially split a single underbreak zone into two separate arcs.

Compliance results

The compliance check produces the following outputs:

Minimum clearance

The overall minimum clearance is the smallest radial deviation (in mm) across all measured points. A negative value means the closest point is inside the template – an underbreak violation. This single number summarizes the worst-case clearance condition for the section.

Sector map

A per-sector array of pass/warning/fail/no-data status values. This map can be visualized as a color ring around the section (green/yellow/red) to quickly identify problem areas. See *Reporting (M6)* for the polar diagram visualization.

Violation arcs

Contiguous groups of violation sectors are merged into violation arcs, each described by:

- Start angle (degrees) – where the underbreak zone begins

- End angle (degrees) – where the underbreak zone ends
- Maximum depth (mm) – the worst underbreak within the arc

Violation arcs provide a concise description of where remedial excavation is needed.

Total violation arc

The sum of all violation arc spans, in degrees. This indicates how much of the section perimeter is affected by underbreak. A section with 360 degrees of violation arc has underbreak around the entire perimeter.

Overall pass/fail

The section receives an overall PASS if all sectors are compliant or warning, and FAIL if any sector has violation status.

When the Fail on warnings option is enabled in the configuration, warning sectors also cause an overall FAIL result. This stricter mode is useful for critical zones where any approach to the design boundary must be flagged.

Clearance threshold

The clearance threshold (configurable, default 0 mm) marks sections as critical in the clearance report when their minimum clearance falls below this value. This is separate from the per-sector warning threshold and operates on the overall section minimum.

> **Tip**
>
> Use the clearance threshold to flag sections that are technically compliant (no underbreak) but have very tight clearance. For example, setting the threshold to 20 mm will highlight any section where the measured profile comes within 20 mm of the template, even if it never crosses it.

Clearance heatmap — dashboard + PDF

A dashboard heatmap toggle exposes a Clearance mode alongside the Grade and Tolerance modes. The Clearance heatmap uses only two colours:

- Red — the sector has `ssViolation` (any measured point violates the template);
- Green — the sector is compliant;
- Grey — no data in that bin.

Each heatmap bin's midpoint angle is mapped into the corresponding compliance sector index (`Trunc(MidAng / SectorAng)`), so the 36-bin heatmap is a finer-resolution rendering of the same sector map described above.

The Clearance PDF report (see *Reporting (M6)*) includes the identical heatmap as a full page inserted between the chainage chart and the Clearance Details table. A reviewer can therefore use the heatmap to spot problem zones across the tunnel, then scroll to the per-section sketches where each red sector is drawn as a dashed red wedge on the polar plot. When the alignment looks toward decreasing chainage, both the heatmap and those sketches are mirrored, so a red band stays on the same side of the page as the wedge.

Violation sector wedges on section sketches

The per-section sketches in the Clearance PDF (and in the Grade and Tolerance PDFs — see *Reporting (M6)*) draw a dashed red wedge for every sector with `ssViolation`. Wedges are bounded by two radial dashed lines from the section centre to the outer radius and closed by a short red arc, forming a pie-slice that highlights the exact angular span of the underbreak. Adjacent violation sectors are merged: the shared radial boundary is skipped so that a continuous underbreak arc renders as a single wedge rather than a fence of radials.

Practical interpretation

- All green sectors: The excavation fully contains the design profile with comfortable margin.
- Yellow sectors at the crown: Common in drill-and-blast tunnels where the crown is difficult to control. Monitor on subsequent sections.
- Red sectors at the walls: May indicate insufficient drilling depth or ground convergence. Check re-measurement data if available.
- Large violation arcs: Suggest systematic under-excavation. Review drilling patterns and face advance procedures.

Warning

Underbreak is a safety-critical finding. Sections with Grade D (underbreak exceeding the configured maximum area) should be reviewed by the project engineer and may require re-excavation before lining installation.

Tolerance Band & Cpk Analysis

The Tolerance module evaluates measured profiles against externally defined project specifications. Given a tolerance band (upper and lower limits), it computes process capability metrics that answer: "Does the profile reliably meet the specification?"

Unlike the *Geometry Quality (M1)* grading system (which uses internal thresholds) and *Clearance & Compliance (M2)* checking (which tests for spatial intrusion), tolerance analysis compares deviations against contractual or project specification limits.

Configuration

Enable tolerance analysis in the Analytics Configuration dialog:

Parameter	Default	Description
Enable Tolerance Band	Off	Master switch for tolerance analysis
Upper Limit (USL)	20 mm	Upper Specification Limit – maximum allowed positive deviation
Lower Limit (LSL)	-20 mm	Lower Specification Limit – maximum allowed negative deviation

USL and LSL can be asymmetric. For example, a specification might allow +50mm overbreak but only -20mm underbreak:

- USL = +50 mm (generous overbreak allowance)
- LSL = -20 mm (strict underbreak limit)

When tolerance is disabled, the three tolerance columns in the dashboard grid show - and the tolerance row in the status strip is hidden.

Computed metrics

Tolerance metrics are computed from the existing per-point deviation array (`TQualityMetrics.DeviationPoints`) – no additional engine calls are needed. Each deviation value is in millimeters, signed (positive = overbreak, negative = underbreak).

Percentage within tolerance (% in Tol)

The most intuitive metric: what fraction of measured points fall within the specification band.

```
% in Tol = (count of points where LSL <= deviation <= USL) / N x 100
```

Dashboard color coding:

Value	Color	Meaning
>= 95%	Green	Excellent specification compliance
80–95%	Orange	Marginal – some points outside tolerance
< 80%	Red	Poor – significant specification violations

> **Tip**
>
> A section with 100% within tolerance but tight margins (e.g., many points near USL) will show high % in Tol but may have a low Cpk – the Cpk captures the risk that future sections could exceed the limits. Both metrics together give a complete picture.

Process Capability (Cp)

Cp compares the width of the tolerance band to the spread of the process:

```
Cp = (USL - LSL) / (6 x sigma)
```

Where sigma is the sample standard deviation of all deviations. The 6-sigma denominator covers approximately 99.7% of a normal distribution.

Interpretation:

Cp value	Meaning
> 1.0	The process spread (6-sigma) fits within the tolerance band
= 1.0	The spread exactly equals the tolerance – no margin for centering error
< 1.0	The spread is wider than the tolerance – cannot meet spec even if perfectly centered

Cp measures potential capability only. It ignores whether the process is centered within the tolerance band. A high Cp with a shifted mean will still produce violations on one side.

Process Capability Index (Cpk)

Cpk accounts for both spread AND centering:

```
CPU = (USL - mean) / (3 x sigma)     <- room on the upper side
CPL = (mean - LSL) / (3 x sigma)     <- room on the lower side
Cpk = min(CPU, CPL)                   <- weakest side governs
```

The minimum is taken because violations will occur first on whichever side has less room. Cpk is always less than or equal to Cp, with equality only when the mean is exactly at the midpoint of the tolerance band.

Visual explanation:

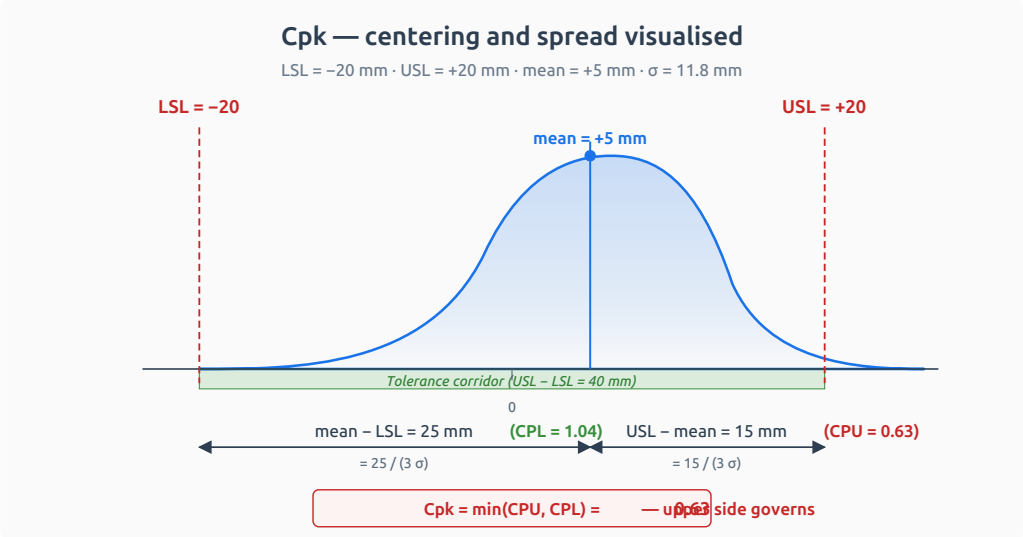


Fig. 5: A distribution with mean = +5 mm and σ = 11.8 mm between LSL = −20 mm and USL = +20 mm. The upper side (CPU = 0.63) is tighter than the lower (CPL = 1.04), so `Cpk = min(CPU, CPL) = 0.63` — the upper side governs.

In this example the mean is shifted +5 mm toward USL. The upper side (CPU = 0.63) is the weak side and governs the Cpk.

Dashboard color coding:

Cpk value	Rating	Color	Meaning
>= 1.33	Excellent	Green	Comfortably within spec, well centered
1.00–1.33	Capable	Orange	Within spec but limited margin
0.67–1.00	Marginal	Dark orange	Some exceedances expected
< 0.67	Not Capable	Red	Significant specification violations

Diagnostic use of Cp vs Cpk:

Cp	Cpk	Diagnosis	Action
High	High	Narrow spread, well centered	No action needed
High	Low	Spread is fine but mean is shifted	Correct the systematic bias
Low	Low	Too much scatter	Improve excavation consistency
Low	High	Impossible – Cpk <= Cp always	–

Maximum exceedance

The largest distance any point falls beyond its nearest tolerance limit:

```
For each point:
  if deviation > USL:  exceedance = deviation - USL
  if deviation < LSL:  exceedance = LSL - deviation
  otherwise:           exceedance = 0

Max Exceedance = maximum of all exceedances
```

A value of 0 means all points are within tolerance. A value of 12mm means the worst point exceeds the spec by 12mm. The world position of the worst exceedance point is tracked for localization.

Relationship to defect rate

For a normally distributed process, Cpk predicts the expected fraction of points outside tolerance:

Cpk	Expected % outside tolerance	Points per 1000
0.50	13.4%	~134
0.67	4.6%	~46
1.00	0.27%	~3
1.33	0.006%	~0.06
1.67	0.00006%	~0.001

Note

These defect rates assume a normal (Gaussian) distribution. Tunnel deviations are often skewed (more overbreak than underbreak), so the actual exceedance rate may differ from the theoretical prediction. The % in Tol metric gives the actual observed rate, while Cpk gives a normalized capability index.

Special cases

Cpk = 99.99

All deviation values are identical (zero standard deviation). This typically means the measured and reference lines are the same polyline, or the section has insufficient data. The sentinel value 99.99 indicates "perfect" capability but should be treated as a data quality flag.

Cpk is negative

The mean deviation is outside the specification limits entirely. For example, if mean = +25mm and USL = +20mm:

```
CPU = (20 - 25) / (3 x sigma) = negative
```

This indicates a severe systematic deviation where the profile center is already beyond the spec limit. The section requires corrective action regardless of the spread.

Asymmetric tolerances

When USL and LSL have different magnitudes (e.g., USL = +50, LSL = -20), the Cpk naturally handles the asymmetry because CPU and CPL are computed independently. The tighter limit (in this case LSL at -20) will typically be the governing side.

Fewer than 2 points

Standard deviation requires at least 2 points. Sections with 0 or 1 measured points after clipping produce `Valid = False` and tolerance columns show `-`.

Visualization

Polar diagram tolerance band

When tolerance is enabled, the polar diagram draws two dashed lines around the reference profile:

- Outer dashed line: Reference + USL offset (radially outward)
- Inner dashed line: Reference + LSL offset (radially inward)

These form a visible corridor around the design profile. Points of the measured line that fall outside this corridor are exceeding the specification.

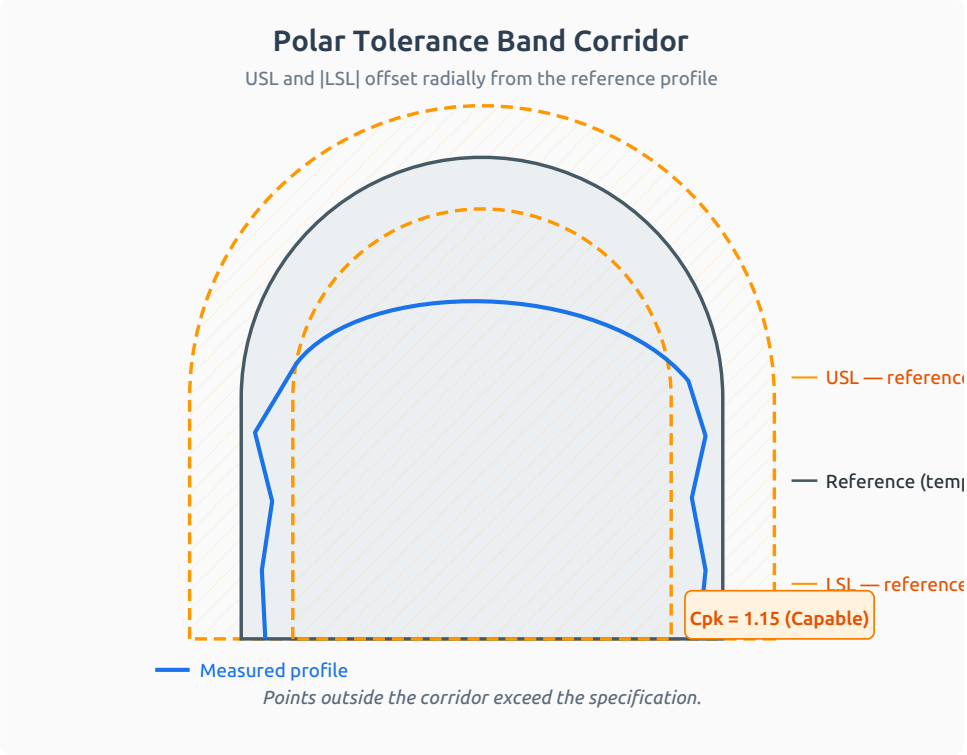


Fig. 6: Tolerance corridor on a horseshoe tunnel: the outer dashed orange polyline is the reference offset by USL outward, the inner dashed polyline is the reference offset by |LSL| inward, and the blue measured polyline runs inside the corridor. The Cpk badge in the corner mirrors what the polar diagram shows on screen.

The Cpk value with its rating (e.g., “Cpk: 1.15 (Capable)”) and % within tolerance are displayed at the bottom-right of the diagram.

Status strip tolerance row

The 4th row of the status strip shows tolerance compliance for each section as a colored bar segment:

Color	Condition
Green	>= 95% of points within tolerance
Orange	80–95% within tolerance
Red	< 80% within tolerance
Silver	Tolerance disabled or insufficient data

Dashboard heatmap — Tolerance mode

The section heatmap panel on the Analytics dashboard has a toggle that cycles Grade → Tolerance → Clearance. In Tolerance mode the cell colour is driven by the corridor compliance of the worst point in that (section × bin):

Colour	Condition
Blue	deviation > USL (overbreak beyond upper limit)
Red	deviation < LSL (underbreak beyond lower limit)
Green	`LSL <= deviation <= USL` (within the tolerance corridor)
Grey	no measured point in that bin

This colour mapping is the inverse of an intuitive "red = bad / green = good" because the colour now carries directional information — reds and blues tell the reviewer which side of the corridor is being violated. The same mapping is used on the Tolerance PDF report's heatmap page (see *Reporting (M6)*).

Tolerance PDF report

The standalone Tolerance Report export produces a PDF dedicated to tolerance analysis:

- Cover page with the current USL/LSL settings.
- Methodology pages (two): a sketch of the corridor width (`USL − LSL`) relative to 6σ, and a sketch of `CPU / CPL / Cpk = min(...)`.
- Tolerance heatmap page with the colour mapping above (blue / red / green / grey).
- Per-section sketch pages with dashed orange USL/LSL offset bands and dashed red violation-sector wedges. Sectors where the worst point exceeds tolerance are drawn with a larger wedge so critical ones are visually prominent.
- Summary table with per-section % in Tol, Cpk and max exceedance.

See *Reporting (M6)* for a full description of the PDF page flow and common section-sketch conventions.

Grid columns

Three columns are added to the dashboard grid when tolerance is enabled:

Column	Width	Content	Color coding
% in Tol	50px	Percentage of points within [LSL, USL]	Green >= 95%, Orange >= 80%, Red < 80%
Cpk	42px	Process capability index	Green >= 1.33, Orange >= 1.00, Dk.Orange >= 0.67, Red < 0.67
Exceed	48px	Maximum exceedance in mm, or `-` if all within	Plain text

Exports

XLSX

Three additional columns are appended to the Section Analysis sheet:

- Column 14: `% in Tol` (number)

- Column 15: Cpk (number)
- Column 16: `Max Exceed (mm)` (number)

PDF

The batch table in PDF All reports includes two additional columns:

- `% Tol`: Percentage within tolerance
- Cpk: Process capability index

The single-section PDF includes tolerance information in the polar diagram (tolerance band lines + Cpk text).

Worked example

Specification: +/-20mm tolerance on shotcrete profile

Section at chainage 2+100.000 (150 measured points):

Step	Computation	Result
Count within [-20, +20]	138 of 150 points	92.0%
Mean deviation (mu)	Sum(d_i) / N	+5.2 mm
Sample std dev (sigma)	sqrt(Sum(d_i - mu)^2 / (N-1))	11.8 mm
Cp	(20 - (-20)) / (6 x 11.8)	0.56
CPU	(20 - 5.2) / (3 x 11.8)	0.42
CPL	(5.2 - (-20)) / (3 x 11.8)	0.71
Cpk	min(0.42, 0.71)	0.42 (Not Capable)
Max exceedance	Worst point at +31mm -> 31-20	11 mm

Interpretation: Both Cp (0.56) and Cpk (0.42) are below 0.67 – the process has too much scatter AND is off-center. The +5.2mm mean bias makes the upper side worse (CPU = 0.42 vs CPL = 0.71). To improve:

1. Reduce scatter (sigma): Improve excavation/shotcrete consistency to narrow the distribution
2. Correct bias (mean): Shift the process center toward zero to balance both sides
3. If only the bias is corrected (mean -> 0), Cpk would improve to Cp = 0.56 – still not capable, so reducing scatter is also necessary

See also

For a detailed mathematical explanation of Cp and Cpk including derivations and defect rate tables, see the specification documents `specs/Cpk_Process_Capability_EN.md` and `specs/Cpk_Process_Capability_GR.md`.

Longitudinal Analysis (M3)

The Longitudinal Analysis module processes all cross-sections along the alignment to identify spatial trends in excavation quality. While M1 and M2 evaluate individual sections in isolation, M3 reveals patterns across the tunnel length – quality degradation, systematic biases, and problem zones.

Analysis scope

Longitudinal analysis operates on all sections within the selected chainage range that have both measured data (for the chosen line definition) and a valid template. Sections without data or without a template assignment are skipped silently.

The analysis produces:

- Per-section quality metrics and compliance results (M1 + M2 for every section)
- Linear trend regression of RMS deviation vs chainage
- Deviation heatmap grid

Longitudinal deviation profile

The RMS deviation for each section is plotted against chainage to produce a longitudinal deviation profile. This chart shows how excavation quality varies along the tunnel:

- Flat profile with low RMS: consistent, controlled excavation
- Rising profile: quality degrading with advancing chainage (possible equipment wear, ground change)
- Spikes: isolated problem sections (geological anomalies, blasting incidents)

Section ranking

Sections are ranked by quality grade and RMS deviation. The worst sections appear at the top, making it easy to identify the most critical locations that require attention. The ranking includes:

- Station (chainage)
- Section name
- Quality grade (A/B/C/D)
- RMS deviation (mm)
- Excavation ratio (%)
- Compliance status (PASS/FAIL)
- Overbreak area (m^2^)

Deviation heatmap

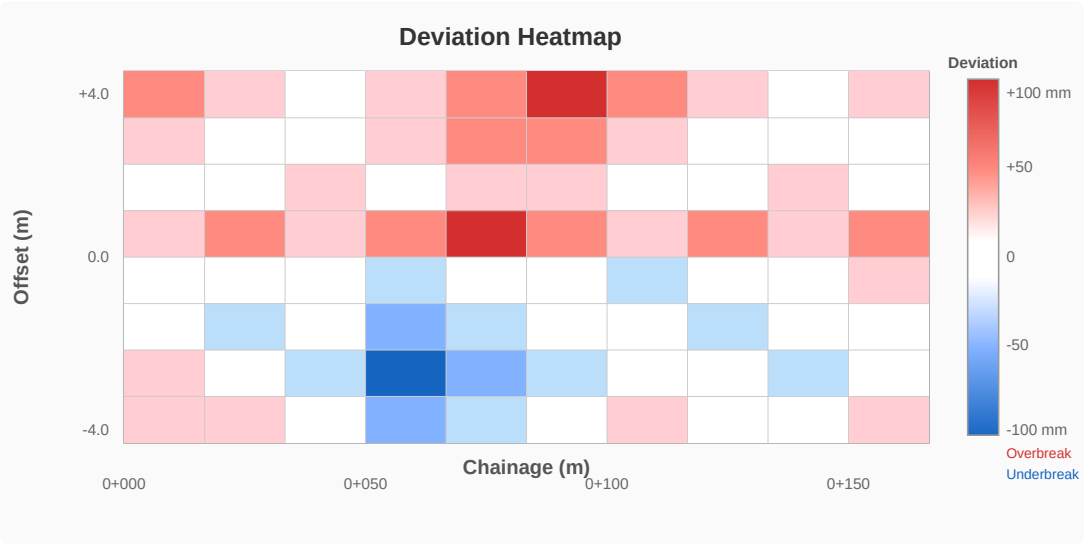


Fig. 7: Deviation heatmap: X-axis shows chainage, Y-axis shows horizontal offset from the tunnel axis, color intensity represents deviation magnitude.

The deviation heatmap provides a 2D visualization of deviations across the entire tunnel:

- X-axis: Chainage (station along the alignment)
- Y-axis: Horizontal offset from the tunnel axis (meters)
- Color: Deviation magnitude (mm)

The color scale uses a diverging scheme:

Color	Range	Meaning
Blue	< -50 mm	Severe underbreak
Light blue	-50 to -20 mm	Moderate underbreak
White	-20 to +20 mm	Within tolerance
Light red	+20 to +100 mm	Moderate overbreak
Red	> +100 mm	Severe overbreak

The Y-axis uses horizontal offset position (distance from the tunnel axis), not polar angle. This provides a natural spatial representation where left-wall deviations appear on the left side and right-wall deviations on the right.

Dashboard heatmap panel

The same underlying grid drives the section heatmap panel on the Analytics dashboard. The panel's toggle button cycles through three colour modes:

Mode	Purpose	Scale
Grade	Worst absolute deviation in the bin.	Green → yellow → orange → red (Grade A → D thresholds).
Tolerance	Bin's relation to the USL/LSL corridor.	Blue (above USL), red (below LSL), green (in corridor).
Clearance	Sector pass/fail reused from *Clearance & Compliance (M2)*.	Green (pass), red (fail), grey (no data).

All three modes use the same axis convention: Invert / R-Wall / Crown / L-Wall / Invert on the Y-axis, bottom to top, matching the walking direction when stepping into the tunnel along increasing chainage. The X-axis is chainage. Hovering a cell shows the section name, chainage, bin centre angle and the mode-specific value.

When the alignment's View Along Decreasing Chainage setting is on, the heatmap mirrors with the section sketch. Bottom to top then reads Invert / L-Wall / Crown / R-Wall / Invert, and the panel shows "View: decreasing chainage". The same mirror is applied to the grade, tolerance, and clearance heatmap pages in the PDF reports.

Heatmap construction

The offset range is divided into bins (default 36). For each section-bin pair, the deviation with the largest absolute magnitude is retained. Empty bins (no measured points at that offset for that section) are marked as no-data and rendered transparent.

> **Tip**
>
> The heatmap is particularly effective for identifying directional biases. A persistent red band on one side of the tunnel may indicate a systematic drilling offset that should be corrected in the excavation procedure.

Deviation trend

A linear regression of RMS deviation against chainage produces three values:

Parameter	Interpretation
Slope	Rate of quality change per meter of chainage (mm/m). Positive = quality degrading.
Intercept	Baseline RMS at chainage zero (extrapolated)
R^2^	Goodness of fit. High R^2^ with positive slope = systematic quality degradation. Low R^2^ = random variation, no clear trend.

Note

The trend regression is most meaningful when the tunnel is excavated sequentially from low to high chainage. If sections were excavated in non-sequential order (e.g., from both portals), the chainage trend may not reflect temporal quality changes.

Convergence monitoring

When re-measurements are available at the same chainage (multiple survey campaigns), the longitudinal module can track ground movement over time. By comparing deviations at the same station across different measurement dates, convergence patterns become visible:

- Inward movement: Increasing underbreak over time indicates ground convergence
- Stable profile: No change between campaigns confirms ground stability
- Differential movement: Asymmetric changes suggest non-uniform ground loading

Warning

Convergence analysis requires that re-measurement sections are recorded at identical stations. Small chainage offsets between campaigns will produce misleading results because the comparison is station-based, not interpolated.

Statistics (M4)

The Statistics module performs distribution analysis on the radial deviations collected across sections. While M1 summarizes each section with a single RMS value, M4 examines the full population of per-point deviations to reveal distributional characteristics, outliers, and directional biases.

Distribution analysis

The module takes the per-point deviation data from `TTunnelDeviationEngine` (converted to millimeters) and computes:

Central tendency and spread

Statistic	Description
Mean	Average deviation across all points (mm). Positive = net overbreak.
Standard Deviation	Spread of deviations around the mean
Skewness	Asymmetry of the distribution. Positive skew = long tail toward overbreak.
Excess Kurtosis	Tail heaviness relative to normal distribution. Positive = more outliers than expected.

Percentiles

The full percentile table (P0 through P100) is computed from the sorted deviation values. Key percentiles for engineering interpretation:

Percentile	Typical use
P5	Lower bound of the practical range – deviations below this are outliers
P25 (Q1)	First quartile – 25% of points are below this deviation
P50 (Median)	Central value – more robust than mean when outliers are present
P75 (Q3)	Third quartile – 75% of points are below this deviation
P95	Upper bound of the practical range – deviations above this are outliers

Tip

If the mean and median differ significantly, the distribution is skewed. A mean much larger than the median indicates a few large overbreak values pulling the average up. In this case, the median is a better indicator of typical excavation quality.

Histogram

The deviation values are binned into a frequency histogram (default 20 bins). Each bin records:

- Low and high boundary values (mm)
- Count of points in the bin
- Relative frequency (0.0–1.0)

The histogram reveals the shape of the deviation distribution:

- Symmetric, narrow peak: Well-controlled excavation with uniform overbreak
- Right-skewed: Most sections are close to the template, with occasional large overbreak
- Bimodal: Two distinct excavation regimes (possibly different ground conditions or equipment)
- Heavy left tail: Significant underbreak population requiring attention

Normal distribution fit

If deviations follow a Gaussian (normal) distribution, the mean and standard deviation fully characterize the population. The skewness and kurtosis values indicate departures from normality:

- Skewness near 0 and kurtosis near 0: approximately normal
- Significant positive skewness: log-normal or Weibull distribution may be more appropriate
- High positive kurtosis: heavy tails with more extreme values than a normal distribution predicts

Box plot by zone

The module computes box plot statistics (minimum, Q1, median, Q3, maximum, mean, count) separately for six angular zones around the tunnel perimeter:

Zone	Angle range	Location
Invert	330–30 degrees	Bottom
Left Wall	30–90 degrees	Lower left
Left Shoulder	90–150 degrees	Upper left
Crown	150–210 degrees	Top
Right Shoulder	210–270 degrees	Upper right
Right Wall	270–330 degrees	Lower right

Note

Angles are measured clockwise from the invert (bottom = 0 degrees), following the internal convention of the deviation engine. The crown is at 180 degrees.

Per-zone statistics enable directional bias detection:

- Crown median significantly higher than walls: Normal in drill-and-blast – crown overbreak is expected due to gravity and blast gas effects
- Asymmetric left/right: Systematic drilling offset or geological structure
- High wall variance: Inconsistent excavation at the walls, possibly due to support installation interference
- Invert outliers: Floor irregularities (if clip level is not enabled)

Tip

Compare zone medians across multiple sections to determine whether a directional bias is systematic (present in all sections) or localized (only at specific chainages). Combine with the M3 longitudinal heatmap for spatial context.

Practical workflow

1. Run the full analysis from the Analytics dashboard
2. Export to XLSX for the tabular per-section metrics
3. Review the histogram shape in the statistics output:
    - If approximately normal, the mean and standard deviation provide a complete summary
    - If skewed, focus on percentiles and median instead
4. Check per-zone box plots for directional biases
5. Cross-reference zones with high variance against the M3 heatmap to locate problem chainages

Reporting (M6)

The Reporting module provides visualization and export capabilities for all analytics results. It includes the polar deviation diagram renderer, the dashboard summary panel, and export functions for DXF, XLSX, and PDF formats.

Polar deviation diagram

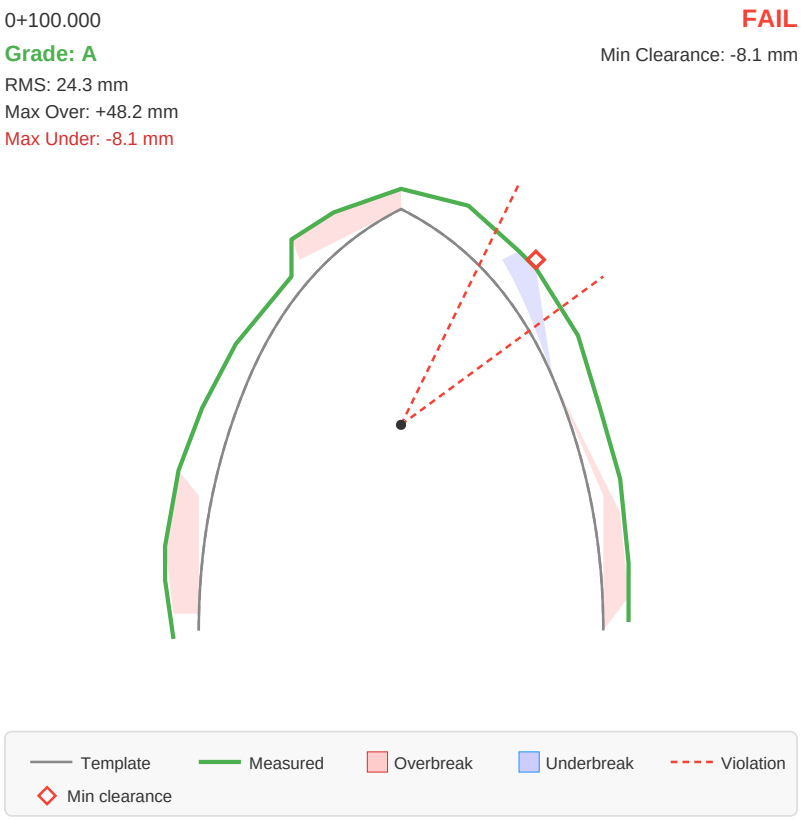


Fig. 8: Polar deviation diagram showing the template (gray) and measured (colored) profiles with overbreak (light red) and underbreak (light blue) hatched regions. Violation sector boundaries are drawn as red dashed radial lines.

The polar deviation diagram is the primary per-section visualization. It renders the following elements:

- Template profile (gray line): the design boundary
- Measured profile (grade-colored line): green for Grade A, orange for B, dark orange for C, red for D
- Overbreak regions (light red fill): areas where the measured profile is outside the template
- Underbreak regions (light blue fill): areas where the measured profile is inside the template
- Violation sector boundaries (red dashed radial lines): drawn at transitions between compliant and violation sectors
- Min clearance marker (red diamond): located at the angle of minimum clearance

- Tolerance band (dashed lines): USL and LSL offset bands when tolerance is enabled (see *Tolerance Band & Cpk Analysis*)

Text annotations

The diagram includes text overlays:

- Chainage (top-left): formatted as km+meters (e.g., “0+100.000”)
- Grade (top-left, colored): quality grade with grade-appropriate color
- RMS deviation (top-left): root mean square in mm
- Max overbreak (top-left): largest outward deviation in mm
- Max underbreak (top-left, if present): largest inward deviation in mm
- PASS/FAIL (top-right, bold): overall compliance result (green/red)
- Min clearance (top-right): closest approach to the template in mm
- Cpk (bottom-right): process capability index with rating, when tolerance is enabled
- % in Tol (bottom-right): percentage within tolerance, when tolerance is enabled

Sector visualization

Violation sector boundaries are drawn as red dashed radial lines from the section center to the diagram edge. Lines are drawn only at transitions between violation and non-violation sectors. No-data sectors are treated as transparent – they do not generate boundary lines, preserving the visual contiguity of violation zones.

Dashboard summary panel

The Analytics dashboard grid displays one row per analyzed section with the following columns:

Column	Content
Chainage	Chainage formatted as km+m
Section	Section name
Reference	Reference line/template name
Grade	Quality grade (A/B/C/D) with color background
RMS (mm)	RMS deviation
Max Over	Maximum overbreak (mm)
Max Under	Maximum underbreak (mm), or - if none
Ratio %	Excavation ratio
Over (m^2^)	Overbreak area
Clearance	Minimum clearance (mm), color-coded
Angle	Angular position of minimum clearance
Compliant	PASS (green) or FAIL (red)
Violations	Violation sectors (e.g., 2/24)
% in Tol	Percentage within tolerance (color-coded, see *Tolerance Band & Cpk Analysis*)
Cpk	Process capability index (color-coded)
Exceed	Maximum exceedance (mm), or -

Clicking a row updates the polar diagram panel to show that section.

Section heatmap panel

Below the grid, the dashboard carries a section heatmap panel with a (`sections × 36 angular bins`) grid. The top-right of the panel has a toggle button that cycles through three modes; the currently selected mode is shown next to the button and in the panel title:

Mode	Cell colour	Scale
Grade	Worst absolute deviation of the points falling inside the bin.	Green → yellow → orange → red, with the same thresholds as the Grade A→D classification.
Tolerance	Deviation vs the configured USL/LSL corridor.	Blue for overbreak beyond USL, red for underbreak beyond LSL, green when inside the tolerance band.
Clearance	Per-sector compliance result reused from *Clearance & Compliance (M2)*.	Two-colour map — green = sector compliant, red = sector has an ssViolation. Grey = no data.

The Y-axis is labelled Invert / R-Wall / Crown / L-Wall / Invert from bottom to top, matching the walking direction when you step into the tunnel. The X-axis is chainage. Hovering a cell shows a tooltip with the section name, chainage, bin centre angle and the mode-specific value (deviation in mm, % in tolerance, or Pass/Fail/no-data).

The Clearance mode reuses the same sector-violation mapping as the polar diagram and the clearance PDF report, so reds on the heatmap line up one-to-one with red sector wedges on the section sketch. The sector count is driven by the Analytics configuration's `Sector count` field (default 24); each heatmap bin's midpoint angle is mapped into the corresponding sector index.

Polar panel — pan and zoom

The polar deviation panel above the heatmap is interactive:

- Mouse wheel — zoom in / out centred on the cursor.
- Click-drag — pan.
- Double-click — reset to 100% / origin.

The polar rendering is split into two layers: the geometry layer (template, measured, fills, tolerance corridor, violation wedges, clip-level guide) scales with zoom, while the chrome layer (title, chainage, grade, RMS, PASS/FAIL, Cpk badge, legend text) stays anchored to the panel corners. This prevents labels from stretching when the user zooms in on a specific part of the section.

The panel footer shows `Zoom N% (wheel zoom · drag pan · dbl-click reset)` whenever zoom ≠ 100%.

Status strip

The status strip below the grid provides a tunnel overview with four horizontal bar rows, one colored segment per section:

Row	Green	Orange	Red	Silver
Grade	A	B	C, D	–
Compliance	PASS	–	FAIL	–
Clearance	>= warning threshold	0 to threshold	< 0 (intrusion)	–
Tolerance	>= 95% in tol	80–95%	< 80%	Disabled/no data

The currently selected section is highlighted with a white border. Clicking a segment selects that section in the grid.

Export formats

XLSX export

Exports a two-sheet Excel workbook via the Export XLSX button:

Sheet 1 – Section Analysis: One row per section with all metrics (station, name, reference, grade, RMS, ratio, areas, max deviations, compliance, violation count, % in tolerance, Cpk, max exceedance). Below the data rows, batch statistics are appended:

- Mean and standard deviation of RMS values
- Grade distribution counts (how many A/B/C/D sections)
- Total overbreak volume (sum of overbreak area x section spacing)
- Estimated concrete cost (overbreak volume x unit price)

Sheet 2 – Grading Criteria: The active threshold table showing the configured Grade A/B/C/D limits for RMS, ratio, and underbreak area.

> **Tip**
>
> The XLSX export is well-suited for further analysis in spreadsheet software. Use pivot tables to group sections by grade and summarize metrics by chainage ranges.

DXF export

Exports annotated section drawings via the Export DXF button. One DXF file is created per section with the following layers:

Layer	Content	Color
TEMPLATE	Design polyline	Gray
MEASURED	Measured polyline	Grade-colored
OVERBREAK	Hatched overbreak regions (ANSI31 pattern)	Red
UNDERBREAK	Hatched underbreak regions (ANSI31 rotated)	Blue
ANNOTATION	Chainage, section/template names, grade, RMS, ratio	White
SECTORS	Violation boundary radial lines	Red

The DXF files can be opened in any CAD application for further annotation or inclusion in construction drawings.

PDF export

PDF reports are generated via the Export PDF and Export PDF All buttons:

- Export PDF: Generates a report for the currently selected section
- Export PDF All: Generates a multi-section report with an option to include all sections or only failed (non-compliant) sections

Each section page includes the polar deviation diagram, metrics summary, and compliance status.

Grade report (PDF)

The Grade Report button produces a multi-page PDF focused on geometric quality. It includes:

- Cover page with project/tunnel identification and the active grade thresholds.
- Summary statistics: grade distribution, mean and standard deviation of RMS, total overbreak volume, estimated concrete cost.
- Grade heatmap (sections × bins) using the same colour scale as the dashboard heatmap's Grade mode. The Y-axis is labelled Invert → R-Wall → Crown → L-Wall → Invert from bottom to top. With View Along Decreasing Chainage on, left and right swap to match the section sketches, and the page is marked "View: decreasing chainage". The tolerance and clearance heatmap pages use the same rule.
- One page per section with the section sketch (template, measured, overbreak/underbreak fills), violation-sector wedges drawn as dashed red radial lines from the section centre, a metrics panel (grade, RMS, max over/under, ratio, area), and, when Y-level clipping is active, a dashed orange horizontal guide line at `Y = ClipLevelDown` labelled `Y = x.xx m (clip)`. When the alignment looks toward

decreasing chainage, the sketch is mirrored and labelled "View: decreasing chainage" in the top-left of the sketch. The tolerance and clearance section pages use the same label.

- A PDF-level option to include all sections or only non-compliant ones (grade D, or grade C with issues).

Tolerance report (PDF)

The Tolerance Report button produces a PDF focused exclusively on the tolerance-band analysis (see *Tolerance Band & Cpk Analysis*). The report drops the Grade/Deviation/Area blocks of the generic report and shows tolerance-only metrics: % in tolerance, Cp, Cpk, max exceedance and per-sector exceedance.

It contains:

- Cover page with project/tunnel identification and the current USL/LSL settings.
- Methodology pages (two pages) explaining USL/LSL graphically and the Cp/Cpk calculation. Includes a sketch of `(USL − LSL) / 6σ` and a worked example of the `CPU / CPL / min(...)` waterfall.
- Tolerance heatmap page (sections × 36 angular bins). Cells are coloured:
  - Blue — deviation beyond USL (overbreak outside the corridor);
  - Red — deviation beyond LSL (underbreak outside the corridor);
  - Green — deviation within the tolerance band;
  - Grey — no data in that bin.

  The Y-axis labels match the dashboard panel (Invert → R-Wall → Crown → L-Wall → Invert, bottom to top), and the X-axis is chainage.
- Per-section pages with the section sketch:
  - the template (grey) and measured (blue) polylines;
  - dashed orange USL/LSL offset bands drawn radially outside and inside the template, matching the dashboard corridor;
  - dashed red violation-sector wedges on sectors whose worst point exceeds the tolerance. Wedges that violate are drawn larger so critical sections stand out;
  - the clip-level horizontal guide when Y-level clipping is active.
- Summary / batch table with one row per section: chainage, % in Tol, Cpk rating, max exceedance.

Clearance report (PDF)

The Clearance Report button generates a dedicated PDF focused on clearance compliance. The report is laid out as:

- Summary page with overall statistics (critical section count, minimum clearance, threshold, date, active clip-level setting).

- Longitudinal clearance chart — minimum clearance vs chainage with a coloured strip under the plot: red for negative clearance, orange for below threshold, green for compliant.
- Clearance heatmap page (new). A (`sections × 36 angular bins`) grid coloured:
  - Red — sector fails clearance (ssViolation);
  - Green — sector passes;
  - Grey — no data.

  This is the same mapping the dashboard uses in Clearance mode, so reds on the heatmap correspond one-to-one with red sector wedges on the per-section sketches later in the report.
- Clearance Details table — one row per section with chainage, section name, reference name, minimum clearance, angle of minimum clearance, and PASS/CRITICAL status. When the user selects *Critical only* at export time, compliant sections are skipped in the table too — not just on the per-section pages.
- Per-section pages for the selected sections (all or critical-only). Each page contains:
  - the section sketch with overbreak (light red) and underbreak (light blue) fills;
  - dashed red violation-sector wedges for every sector with `ssViolation`, drawn the same way as in the grade and tolerance reports, so reviewers can trace heatmap reds directly to the sketch;
  - the minimum-clearance marker (red diamond) at the angle of worst clearance;
  - the Y-level clip guide — dashed orange horizontal line at `Y = ClipLevelDown` with the label `Y = x.xx m (clip)`, when Y-level clipping was active for the analysis;
  - a right-hand panel with `Min Clearance`, `At Angle: x.x°`, `Threshold`, `STATUS: OK / CRITICAL`, and `Violation Sectors: k / N`.

The angle value in the panel is rendered natively with the ° symbol (DejaVu Sans embedded), so Greek/Unicode section names and degree signs render correctly in both Linux and Windows PDF viewers.

> **Note**
>
> The clearance threshold from the Analytics Configuration determines which sections count as critical. Sections with minimum clearance below the threshold are highlighted in the report and appear in the *Critical Only* export. The same threshold drives the colour strip of the longitudinal chart.

Common section-sketch features

Grade, Tolerance and Clearance PDF reports share the same per-section sketch conventions:

- Template — grey polyline.
- Measured — coloured polyline (grade colour for the grade/tolerance reports, blue for clearance).
- Overbreak fill — light red polygon.

- Underbreak fill — light blue polygon.
- Violation-sector wedges — dashed red radial lines from the section centre, closed by a red arc at the outer radius. A wedge is drawn for every sector with `ssViolation`. Adjacent violation sectors are merged into a single wedge by skipping the shared radial boundary, so a continuous underbreak arc reads as one zone.
- Y-level clip guide — dashed orange horizontal line with a `Y = x.xx m (clip)` label, drawn only when Y-level clipping was active at analysis time.
- Tolerance corridor (tolerance report and, when tolerance is on, the grade report) — two dashed orange polylines offset radially outward by USL and inward by `abs(LSL)`.

Workflow summary

A typical reporting workflow:

1. Run analysis from the Analytics dashboard
2. Review the grid and polar diagrams interactively
3. Export XLSX for the engineering team's quantitative records
4. Export PDF All (failed only) for the project compliance file
5. Export DXF for sections requiring detailed CAD review
6. Generate a Clearance Report for the structural engineering team

CHAPTER

EIGHT

REPORTS

The Reports section of TunnelCAD produces line-centric documents: coordinate listings, deviation summaries and trend analyses built directly from the measured line definitions of the active tunnel. Unlike the *Analytics* suite — which operates on whole cross-sections and compares a measured profile against a template — the Reports suite operates line by line: every measured line definition in the active alignment (for example *Excavation*, *Shotcrete*, *Inner Lining*) can be reported independently.

All reports are launched from the Reports main menu:

Menu entry	Purpose
Line Data…	Coordinate listing per line with point counts and optional per-point X/Y/Z.
Line vs Theoretical…	DR (signed deviation) of each measured line against its configured theoretical polyline.
DR Trend / Stats…	Regression of DR vs chainage, per-zone statistics and histograms.

Each menu entry opens a configuration dialog where the user picks the line definitions, the chainage range, a detail mode (summary vs full) and an output format (PDF or XLSX). Output is written through a standard file-save dialog — no intermediate preview.

8.1 Common dialog controls

All three dialogs share the same layout:

Control	Meaning
Header	Active tunnel name and the full chainage range available for the tunnel.
From / To	Chainage filter. Pre-filled with the alignment's start and end chainage when the dialog opens, so the default run covers the whole tunnel; edit either field to narrow the band.
Line Definitions (check list)	Every measured line definition in the active tunnel, with a tick box. Only ticked lines are included. Defaults to all ticked.
Mode — Summary / Full	*Summary* collapses detail into per-section or per-line aggregates; *Full* emits every data row.
Format — PDF / XLSX	Output type. PDF uses A4 portrait pages with embedded fonts (Greek and symbols render natively); XLSX produces one sheet per logical table.
Save	Commits the dialog, prompts for a destination file and runs the exporter with a progress dialog.
Cancel	Closes without running anything.

Line-specific extra controls (overlay plot, chainage chart, zone matrix, histograms) are documented inside each report page.

8.2 Tunnel-data scope

Reports always run against the active tunnel of the current project tab. The chainage filter and line list are populated from the tunnel's current state, so they follow the dashboard: switching the active tunnel or opening a different project immediately refreshes the ribbon's Analytics range and Line combos (see *Active-tunnel synchronisation*).

8.3 PDF rendering

All PDF reports share a single engine (`UPDFWriter`) with DejaVu Sans / DejaVu Sans Bold embedded. The glyph coverage includes the Basic Latin, Latin-1 Supplement, Latin Extended-A/B, Greek and commonly used symbols (°, ±, ²), so section names and headers in Greek render as-is. Page numbers are emitted in the footer of every page, and the header repeats the tunnel/project identification block.

8.4 XLSX rendering

XLSX exports use `fpspreadsheet`. Sheet names are derived from logical table names and truncated to the 31-character Excel limit. Column widths and numeric formats are set per column so that stations display as `0.000`, DR values in millimetres with one decimal place, and angles in degrees with one decimal place.

8.4.1 Line Data Report

The Line Data report is a coordinate listing for every measured line definition in the active tunnel. It does not compute deviations — use *Line vs Theoretical Report* or *DR Trend / Stats Report* for DR analysis. The report answers three practical questions:

- Which sections contain data for each measured line?

- How many measured points are in each (section × line)?
- What are the exact section-local coordinates — and, when horizontal geometry is available, the world X/Y/Z — of every measured point?

Dialog

Open Reports → Line Data… from the main menu.

Control	Effect
From / To	Restrict the report to sections inside the chainage band. Pre-filled with the alignment's start and end chainage when the dialog opens; edit to narrow the band.
Line Definitions	Tick the measured line definitions to include. All measured lines of the tunnel are listed; template lines are never offered here.
Mode — Summary	Produces only the Point-Counts table (one row per section × line).
Mode — Full Detail	Produces the Point-Counts table followed by Per-Point Detail pages.
Format — PDF / XLSX	Output type.

Default selection: all line definitions ticked, Mode = *Full Detail*, Format = *PDF*.

Point-Counts table

Always emitted, regardless of Mode. One row per (section × line) combination:

Column	Content
Chainage	Station formatted km+m (e.g. `0+125.500`).
Section	Section name as stored on the cross-section.
Line	Measured line definition name.
Points	Number of measured points the line currently has in that section.

The table is sorted by chainage ascending and, within the same chainage, by line name. Sections where a line has no points are still listed with Points = 0 so gaps in survey coverage are visible at a glance.

PDF output

Rendered as a continuous table on A4 portrait pages. Column headers repeat at the top of every page. Zero-point rows are shown in light grey so the eye skims past them.

XLSX output

One sheet named Counts with a header row and one data row per entry. All point counts are written as integers.

Per-Point Detail

Emitted only in *Full Detail* mode. One row per measured point, grouped by section then by line.

Every row reports the section-local coordinates — the (X, Y) of the point expressed in the section's own frame, where X is horizontal offset from the axis and Y is elevation relative to the axis. When the alignment has horizontal geometry configured (non-empty `Engine.HGeometry`), the world X/Y/Z columns are also filled. When no horizontal geometry is available the world columns render `-` and the report still produces a complete section-local listing.

Columns

Column	Content	Notes
Chainag	Station of the section.	
Section	Section name.	
Line	Line definition name.	
Layer	Line's layer name (from the line definition).	
Colour	Colour swatch of the line.	Rendered as a filled rectangle in PDF, as a hex value in XLSX.
#	Zero-based point index within the line.	
Sect X	Horizontal offset in metres.	Negative = left of axis.
Sect Y	Elevation relative to the section's axis point, in metres.	Negative = below axis.
World X	Easting in metres.	`-` when horizontal geometry is missing.
World Y	Northing in metres.	`-` when horizontal geometry is missing.
World Z	Elevation (height) in metres.	Computed from `SetoutOffset`'s `PointHeight`.

The world transform calls `Alignment.Engine.SetoutOffset(Station, SectX, SectY)` for each measured point. This routine places the point on the alignment's 3-D geometry, so bearings and super-elevation are honoured: the world X/Y is where the point actually sits on the ground, and World Z is that point's terrain-referenced height.

Colour column

The colour column shows the colour as configured on the line definition. In the PDF report it is rendered as a filled rectangle so that a reviewer can match ink on paper with what they see on screen (see *Line definitions*). In XLSX the same column holds the 6-digit hex code (e.g. #2F7FBF) so that conditional-formatting rules can still pick it up.

> **Tip**
>
> The Line Data report is the fastest way to hand raw survey data to an outside party. Export the Full Detail PDF for a signed-off paper copy, and export the XLSX for onward processing in spreadsheet software.

PDF layout

A4 portrait, 15 mm margin on all sides.

- Page 1 — Counts: tunnel and project header, then the Point-Counts table.
- Pages 2+ — Detail: one continuous table, paginated. Each page repeats the header row.

A footer line is drawn across the bottom of every page with the page number and the project/tunnel name.

XLSX layout

Two sheets:

- Counts — the Point-Counts table.
- Detail — the per-point rows, written only when *Full Detail* is selected.

8.4.2 Line vs Theoretical Report

The Line vs Theoretical report computes the signed deviation (DR) of every measured point from its configured theoretical polyline, for every selected line definition and every section in the chainage range.

Unlike the *Analytics* pipeline — which compares a whole cross-section against a chosen reference — the Line vs Theoretical report runs once per measured line definition and uses the line's own theoretical reference (the polyline name stored on the line definition as `DeviationLine`). This is the same reference the Section View uses when it draws DR labels, so the DR numbers in the report match what the user sees interactively.

Dialog

Open Reports → Line vs Theoretical… from the main menu.

Control	Effect
From / To	Chainage filter. Pre-filled with the alignment's start and end chainage when the dialog opens; edit to narrow the band.
Line Definitions	Tick the measured lines to include. Lines without a configured `DeviationLine` still appear in the summary but with `HasTheoretical = False` and DR columns left blank.
Mode — Summary	Produces only the per-(section × line) aggregate table.
Mode — Full Detail	Adds per-point rows with measured / nearest-on-theoretical / DR.
Include overlay plot	PDF only. When ticked, each section with Full Detail gets an extra mini-plot with the measured line in blue and the theoretical line in grey, to visualise the DR geometrically. Default on.
Format — PDF / XLSX	

Default selection: all lines ticked, Mode = *Full Detail*, Format = *PDF*, Overlay = on.

DR sign convention

For every measured point the closest point on the configured theoretical polyline is located. The signed DR is then:

```
DR > 0  — measured point is **farther** from the tunnel axis origin (0,
↪0) than the nearest theoretical point → over-excavation.
DR < 0  — measured point is **closer** to the axis origin than the
↪nearest theoretical point → under-excavation.
```

This matches the Section View's DR labels exactly, so the report and the on-screen annotations are always in agreement.

Theoretical-polyline resolution

For each section and each measured line, the report looks up the theoretical polyline by name:

1. Read `LineDefinition.DeviationLine` (set in Section Details / Line Definitions).
2. If the section has a line with that name, use its points directly.
3. Otherwise, if the tunnel has a template at that station, fetch the template and retrieve the line whose name matches `DeviationLine` (falling back to the template-line library).
4. If neither step resolves a polyline, the section is listed in the summary as `HasTheoretical = False` and DR is not computed for it.

This two-step resolution means an alignment without a full template library can still produce a DR report as long as each section carries the theoretical polyline inline.

Summary table

Always emitted. One row per (section × line) combination:

Column	Content
Chainage	Station, km+m.
Line	Measured line definition name.
Theoretical	Name of the theoretical polyline (same as `DeviationLine`). Blank when not configured.
Points	Number of measured points on that line in that section.
Max Over (mm)	Largest positive DR.
Max Under (mm)	Largest absolute-value negative DR. Stored as a negative number in the XLSX.
Mean DR (mm)	Arithmetic mean of DRs.
RMS (mm)	Root-mean-square of DRs.

When Mode = *Summary*, this is the only table produced.

Per-point detail (Full mode)

One row per measured point, grouped by section then by line:

Column	Content
Chainage	
Line	
#	Zero-based point index.
Meas X, Y	Measured point, section-local coordinates.
Theo X, Y	Nearest point on the theoretical polyline, section-local.
DR (mm)	Signed deviation.
Over / Under	Short text — `Over` if positive, `Under` if negative, `-` if zero.

Rows with `DR > 0` are tinted green in the PDF; `DR < 0` rows tinted red. In XLSX a conditional-format icon set highlights the same split.

Overlay plot (PDF only)

When Include overlay plot is ticked, each section with detail data gets a single-page overlay: the theoretical polyline is drawn in grey, the measured polyline in blue, and every measured-to-theoretical match is connected with a thin red/green tick in the DR direction. The plot is framed in a square picture box and scaled to the common bounding rectangle of both polylines.

The overlay is useful as a quick visual check that the theoretical polyline resolution picked the intended reference.

PDF layout

A4 portrait, 180 mm usable width after margins.

- Page 1+ — Summary table. Paginates with a repeated header.
- Subsequent pages — Full-detail rows, with optional overlay plots interleaved per section when enabled.
- Footer on every page with page number and project/tunnel.

XLSX layout

Two sheets:

- Summary — one row per (section × line).
- Detail — one row per measured point (only when Full Detail is selected).

> **Note**
>
> If a line definition has no `DeviationLine` configured, the Summary row still appears but with DR columns blank and Theoretical empty. This makes the gap visible to reviewers — they see the line exists but was never matched to a reference.

> **Tip**
>
> If you want the full analytics pipeline (grade, compliance, Cpk, sector map) on a specific line pair, use the *Analysis Modes* *Measured vs Measured* mode instead. Line vs Theoretical is the quick per-line listing; Analytics is the full quality assessment.

8.4.3 DR Trend / Stats Report

The DR Trend / Stats report turns the per-point DR values of the selected measured lines into three longitudinal and distributional views:

- a chainage chart per line, with a scatter of DR vs station plus a rolling-mean trend;
- a zone statistics matrix that tabulates DR statistics per line and per polar zone (invert, walls, shoulders, crown);
- per-zone histograms that show how DR is distributed inside each zone.

Each of the three sections can be switched on and off independently. The report is intended as the single document the project engineer prints when the question is *"how is my DR behaving along this tunnel and where am I taking the hits?"*.

Dialog

Open Reports → DR Trend / Stats… from the main menu.

Control	Effect
From / To	Chainage filter. Pre-filled with the alignment's start and end chainage when the dialog opens; edit to narrow the band.
Line Definitions	Tick the measured lines.
Chainage chart	Emit the per-line scatter chart page(s). Default on.
Zone stats matrix	Emit the (lines × zones) statistics table. Default on.
Per-zone histograms	Emit one page per zone with mini-histograms. Default off.
Mode — Summary / Full	*Full* writes the raw-points XLSX sheet too (PDF is unaffected).
Format — PDF / XLSX	

Zone assignment

The report classifies every measured point into one of six zones based on its polar angle inside the section. The angle convention is 0° = invert, 90° = right wall, 180° = crown, 270° = left wall, measured clockwise:

Zone	Angle range (deg)
Invert	345–360 and 0–15
Right Shoulder	15–75
Right Wall	75–105
Crown	105–255 (the top half from shoulder to shoulder)
Left Wall	255–285
Left Shoulder	285–345

This convention matches the per-sector compliance map in *Clearance & Compliance (M2)* and the heatmap axis labels in *Longitudinal Analysis (M3)*, so the DR Trend report is directly comparable with the Analytics heatmaps.

Chainage chart

Produced when Chainage chart is ticked. One A4 page per measured line:

- X-axis — chainage along the alignment, ticks drawn at sensible multiples of 10 m depending on the visible range.
- Y-axis — signed DR in millimetres, centred on zero. Positive (over) is drawn green, negative (under) is drawn red.
- Rolling mean — a blue line tracing the windowed mean of DR over a sliding window of adjacent points. Smooths short-scale noise so the systematic trend is visible even on a busy scatter.
- Regression caption — a single line under the chart with the linear-regression slope, intercept, R^2, RMS and n for that line across the visible chainage band.

The caption values let the reviewer read off systematic bias at a glance: a non-zero slope means DR is drifting as the tunnel advances; a high R^2 says the drift is not just noise.

Zone statistics matrix

Produced when Zone stats matrix is ticked. One page with a matrix where:

- rows are the selected measured line definitions;
- columns are the six zones (Invert, L-Wall, R-Wall, L-Shoulder, R-Shoulder, Crown).

Every cell holds six numbers stacked vertically:

Stat	Meaning
n	Point count inside the zone.
mean	Arithmetic mean of DR.
σ	Sample standard deviation of DR.
min	Smallest (most negative) DR.
max	Largest (most positive) DR.
p95	95th percentile of abs(DR).

Zero-count cells are greyed out so the reader can see where survey coverage is thin.

> **Tip**
>
> The zone matrix is the fastest way to find systematic biases: a non-zero mean at the Crown with a comfortable σ means the crown is consistently over-excavated (or under-excavated) and is a candidate for a drilling-pattern correction.

Per-zone histograms

Produced when Per-zone histograms is ticked. One page per zone (up to six pages). Each page shows a 3×2 grid of mini-histograms — one tile per selected line, arranged three rows × two columns to fit an A4 portrait. Each histogram shares the same bin edges across tiles so that a reviewer can compare lines side-by-side.

The x-axis of a histogram is DR in millimetres, the y-axis is bin count. A zero-DR tick is drawn as a dashed vertical line for reference.

PDF layout

A4 portrait, 15 mm margin. The three logical sections (chart / matrix / histograms) are gated by their corresponding dialog checkbox and appear in that order.

XLSX layout

- Summary — the zone statistics matrix as a flat (line × zone × stat) table.
- Regression — one row per line definition with slope, intercept, R^2, RMS, n.
- Points (Full mode only) — one row per measured point with its chainage, line, DR, zone and angle. Handy for downstream pivot tables.

Note

Both the chainage chart and the zone matrix use the same DR numbers as the *Line vs Theoretical Report* report, so the two documents always agree. If a section shows up as red in the chart, you can cross-reference its DR value in the Line vs Theoretical detail table for the same (section × line).

CHAPTER

NINE

IMPORT / EXPORT

TunnelCAD supports multiple file formats for exchanging project data with other software and for archiving tunnel monitoring records.

9.1 Supported formats

Native format – `.tun`
: TunnelCAD's own XML-based project format (IQML). Stores the complete project state including alignments, sections, templates, volumes, styles, and settings. See *TUN File Format Reference* for the schema reference.

LandXML 1.2 / 2.0
: Industry-standard XML format for civil engineering and survey data. TunnelCAD can both import and export LandXML files, with optional TunnelCAD-specific extensions encoded as `<Feature>` elements. See *LandXML Import and Export*.

ASCII measurements
: Per-section line points exchanged as comma- or whitespace-delimited text files (XYZ, station/offset/Z, or station/offset/dZ). Both directions are supported through the same column-mapping engine. See *Measurement Import and Export*.

Legacy TCM
: The file format used by earlier versions of TunnelCAD. A one-way conversion tool reads `.tcm` files and produces `.tun` projects. See *Legacy TCM Conversion*.

DXF templates
: Cross-section design profiles can be imported from DXF files. This workflow is covered in the *Templates* chapter.

9.2 Export-only formats

Mass tables
: Volume and area computation results can be exported to CSV or XLSX spreadsheet files from the mass table dialog.

Analytics reports
: The analytics module exports clearance reports and deviation data to DXF drawings and XLSX spreadsheets.

9.2.1 LandXML Import and Export

TunnelCAD reads and writes LandXML files following the LandXML 1.2 specification, with optional TunnelCAD-specific extensions stored in <Feature> elements. Version 2.0 files are also supported on import and are auto-detected.

Exporting LandXML

Open the export dialog from File > Export LandXML….

Export dialog options

Version
: Select the LandXML version for the output file. Currently LandXML 1.2 variants are available.

Content selection
: Checkboxes control which data categories are written to the file. These are divided into two groups:

Standard LandXML content (readable by any compliant application):

- Alignments – horizontal alignment geometry (lines, curves, spirals)
- Profiles – vertical alignment as a sequence of PVI (Point of Vertical Intersection) elements
- Superelevation – cross-slope and cant data along the alignment
- Cross-section Model – design template cross-section lines
- Cross-section Sections – measured cross-section data at each station
- Survey data (CgPoints) – coordinate geometry points from the project

TunnelCAD extensions (encoded as <Feature code="TunnelCAD:..."> elements):

- Line Definitions – section line style assignments and properties
- Template Line Definitions – template line properties
- Templates – full template geometry with bulge arcs
- Station Definitions – template-to-station assignment rules
- Styles – section line styles and alignment styles
- Volume Definitions – per-tunnel volume definitions (color, calculate flag, method, additive constant, four level values + enabled flags, and the term list)

> **Note**
>
> TunnelCAD extensions are stored inside standard <Feature> elements, so the file remains valid LandXML. Applications that do not recognize the extensions will simply ignore them.

Alignment selector
: When the project contains multiple tunnel alignments, choose which ones to include in the export.

File path
: Browse to select the output file location and name.

Coordinate conventions

LandXML uses a "Northing Easting" ordering convention. In TunnelCAD's world coordinate system this maps to Y X – that is, LandXML Northing = World Y and LandXML Easting = World X. The export handles this mapping automatically.

Cross-section points are stored as offset and elevation values measured from the alignment axis, not as world coordinates.

Importing LandXML

Open the import dialog from File > Import LandXML….

Two-step process

The import follows a scan-then-select workflow:

1. Select file and scan – Browse to a LandXML file and click Scan. TunnelCAD reads the file and builds a list of all available data items.
2. Choose items and import – A hierarchical checklist shows the scanned contents organized by category (alignments, profiles, cross-sections, survey points, etc.). Check or uncheck items to control exactly what gets imported, then click Import.

Version detection

TunnelCAD auto-detects the LandXML version (1.2 or 2.0) from the file header. No manual version selection is needed on import.

Importable data

Standard LandXML elements:

- Alignment geometry (lines, curves, spirals)
- Profile PVIs (vertical alignment)
- Superelevation records
- Cross-section data (template and measured lines)
- Survey points (CgPoints)

TunnelCAD extensions (if present in the file):

- Line definitions and template line definitions
- Template geometry with arc bulge values
- Station definitions
- Section line and alignment styles
- Volume definitions (color, calculate flag, method, additive constant, level values + enabled flags, term list)

- Design review (DR) annotation data

> **Tip**
>
> If you are importing a LandXML file that was exported from TunnelCAD, the extension data will be recognized and the round-trip will preserve line definitions, templates, and styles. Files from other applications will import only the standard LandXML elements.

After import

Imported alignments appear in the project tree. Cross-section data is attached to the corresponding alignment stations. You can immediately view imported sections in the Sections canvas tab and alignment geometry in the Alignment canvas tab.

> **Warning**
>
> Importing into a project that already contains data will add to the existing content. If you want a clean import, create a new project first via File > New.

9.2.2 Measurement Import and Export

TunnelCAD reads and writes per-section measurement data (line points) as ASCII text files, in addition to the LandXML round-trip described in *LandXML Import and Export*. These ASCII workflows are intended for exchanging survey data with total stations, scanners, and external analysis tools that produce simple delimited text.

Concepts

A *measurement* in this context is a 3D point that belongs to a specific cross-section's line data. The import and export tools share the same column-mapping engine (the format profile system), which lets the same file shapes be read and written.

Three coordinate flavours are supported:

XYZ
: World-coordinate points. The alignment engine reduces each point to its nearest section via offset-aware projection. This is the format produced by most field instruments.

Station / Offset / Z
: Pre-projected points already expressed along the alignment. The station selects the section; the offset is signed (right-positive) and Z is the absolute elevation.

Station / Offset / dZ
: Same as above, but Z is the difference from the alignment axis at that station rather than an absolute elevation. This matches TunnelCAD's internal section-local convention.

> **Note**
>
> Section local coordinates inside TunnelCAD use dZ from the offset-axis point, not absolute Z. The Sta-Off-dZ flavour matches this internal representation; the other two are converted on the fly.

Format profiles

A format profile names a column layout (delimiter + column roles such as `Name`, `X`, `Y`, `Z`, `Sta`, `Offset`, `DZ`, `Code`, `Ignore`). 13 profiles ship out of the box:

- CSV variants (5) – comma-delimited XYZ and station-based layouts. The default is `Name,X,Y,Z`.
- Whitespace variants (7) – space- or tab-delimited equivalents.
- LandXML – reads `<CgPoints>` from a LandXML file using the same column mapping abstraction.

Profiles can be renamed (with the active delimiter visible in the list) and reordered. Custom profiles are saved with the application settings.

Importing measurements

Open the workbench from File > Import Measurements….

Two-tab workflow

The dialog has two tabs that share the same target alignment and line-definition selection:

1. ASCII – pick one or more text files, choose a profile, parse, then commit.
2. LandXML – pick a LandXML file and commit its CgPoints.

Workflow

1. Choose the line definition(s) the imported points should populate. Multi-select is supported – when multiple files are selected, each file binds to one line definition.
2. Pick the format profile. The Auto-resolve toggle lets TunnelCAD guess from the file extension and column count; switch it off to lock a profile manually.
3. Click Parse. The preview grid fills, the progress bar advances, and any rows that fail to bind to a section are flagged.
4. Pick the commit policy:

   Replace
   : Existing line data on the bound section is cleared once per (section, line-def) group, then replaced with the parsed points.

   Append
   : Parsed points are appended to whatever the section already holds.

   Skip
   : Sections that already have data for the chosen line def are left alone.

5. Click Commit. The activity log records the import as a single project event. See *Calendar / Activity Log*.

Snap-to-nearest binding

For XYZ inputs the engine projects each point onto the alignment via `MeasureOffset`. Points are snapped to the nearest configured section, not interpolated – if your sections are sparse you will see clusters at each chosen station rather than a smooth curve.

Exporting measurements

Open the workbench from File > Export Measurements….

Dialog options

File / folder
: Choose an output file. When multiple line definitions are selected the field is treated as a folder and each line is written to its own file (`<basename>_<linename>.<ext>`).

Profile
: Pick from the ASCII profiles. The LandXML profile is hidden here – use File > Export LandXML… instead.

Line definitions
: Checklist of line defs on the active alignment. Each selected entry produces one file.

Station range
: Optional from / to limits.

Header
: Optional first line containing the column names plus the line definition name.

Preview
: Live preview memo showing what the first rows will look like with the chosen profile.

Notes

- Bulges (arc tangent values) are not part of the cross-section .tun storage and are therefore not written.
- The progress bar advances per section; the dialog auto-closes on success.
- The activity log records the export as a single project event.

Round-trip

The export side writes files that the import side can read. A common workflow is to export current measurements, edit in a spreadsheet, then re-import with the Replace policy to overwrite the original data.

9.2.3 Legacy TCM Conversion

TunnelCAD can convert project files created with earlier versions of the application. The old format uses the `.tcm` extension; the conversion produces a native `.tun` project.

Converting a TCM file

1. Open File > Convert TCM….
2. Browse to the `.tcm` file and confirm.
3. TunnelCAD reads the legacy data, converts it, and opens the result as a new project.

> **Note**
>
> This is a one-way conversion. TunnelCAD does not export back to the TCM format. Once converted, save the project as a `.tun` file to preserve it in the current format.

What gets converted

The converter reads all major data from the TCM file:

- Alignment geometry – the alignment section of a TCM file uses the same format as ALM (alignment) files. TunnelCAD reuses its ALM parser to read this data, so all element types (lines, arcs, spirals) are fully supported.
- Templates – design profile geometry including arc segments. Template arcs are stored in TCM files as bulge values rather than tessellated polylines, which preserves curve accuracy during conversion.
- Cross-sections – measured section data at each station.
- Line definitions and styles – section line properties and display settings.

Character encoding

Older TCM files may contain text encoded in Windows-1253 (Greek character set) rather than UTF-8. The converter automatically detects and cleans up non-UTF8 characters so that station names, descriptions, and other text display correctly after conversion.

Recommended workflow

1. Convert the TCM file using File > Convert TCM….
2. Review the imported data – check alignment geometry in the Alignment tab, inspect sections in the Sections tab, and verify templates in the project tree.
3. Save As a `.tun` file to preserve the converted project in the current format.

> **Tip**
>
> Keep the original `.tcm` file as a backup. The conversion does not modify the source file.

9.2.4 TUN File Format Reference

TunnelCAD's native file format is an XML-based format referred to as IQML. Files use the `.tun` extension and are human-readable plain text.

Document structure

The root element is <TunnelProject> with version and name attributes:

```
<TunnelProject version="2.0" name="My Project">
  <Units ... />
  <SectionLineStyles>...</SectionLineStyles>
  <AlignmentStyles>...</AlignmentStyles>
  <Tunnels active="...">
    <Tunnel ...>...</Tunnel>
  </Tunnels>
</TunnelProject>
```

Top-level elements

<Units>
: Project-wide unit settings including angular unit mode, coordinate decimal places, and display preferences.

```
<Units angularUnit="2" coordDecimals="3" ... />
```

<SectionLineStyles>
: Shared library of section line display styles. Each style is a <TSLStyle> element defining color, line weight, and other visual properties. These styles are shared across all tunnels in the project.

```
<SectionLineStyles>
  <TSLStyle name="Standard" color="..." lineWidth="..." ... />
</SectionLineStyles>
```

<AlignmentStyles>
: Shared library of alignment display styles.

```
<AlignmentStyles>
  <AlStyle name="Standard" color="..." ... />
</AlignmentStyles>
```

<Tunnels>
: Container for all tunnel alignments. The active attribute names the currently selected tunnel.

Tunnel element

Each <Tunnel> element is a self-contained tunnel alignment with all its associated data:

```
<Tunnel name="Main Tunnel" startChainage="0.000" endChainage="1250.000"
        description="Left bore" styleName="Standard">
  <AlignmentEngine version="1.0">...</AlignmentEngine>
  <LineDefinitions>...</LineDefinitions>
  <TemplateLineDefinitions>...</TemplateLineDefinitions>
  <TunnelTemplates>...</TunnelTemplates>
  <TemplateStationDefs>...</TemplateStationDefs>
```

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```
  <TunnelSections>...</TunnelSections>
  <VolumeDefinitions/>
  <Umbrellas>...</Umbrellas>
</Tunnel>
```

Tunnel sub-elements

`<AlignmentEngine>`
: Horizontal and vertical alignment geometry (lines, arcs, spirals, PVIs).

`<LineDefinitions>`
: Definitions of section line types used in this tunnel. Each `<LineDef>` specifies a name, style reference, and behavior.

`<TemplateLineDefinitions>`
: Definitions of template line types. Each `<TmplLineDef>` maps a template line to its display properties.

`<TunnelTemplates>`
: Design profile templates. Each `<Template>` contains point arrays defining the cross-section shape, with optional bulge values for arc segments.

`<TemplateStationDefs>`
: Rules that assign templates to chainage ranges. Each `<StationDef>` specifies which template applies at a given station or range of stations.

`<TunnelSections>`
: Measured cross-section data. Each `<Section>` contains point arrays and bulge arrays for each line in the section.

`<VolumeDefinitions>`
: Volume computation definitions including formula assignments and zone boundaries.

`<Umbrellas>`
: Forepoling umbrellas on this tunnel. Each `<Umbrella>` stores the design inputs only: name, collar chainage, template line, crown window (`fromCrownDeg`, `toCrownDeg`), spacing, radial standoff, pipe length, lookout, diameter, and `decreasingStation` (`1` or `0`). Angles in the file are degrees. Collar and tip coordinates are calculated from the alignment and are not stored. The tunnel attribute `drawForepolingPiles` (`1` or `0`) chooses whether those pipes are drawn on the section and in a per-section or atlas DXF. A file that omits the attribute draws them. See *Forepoling Umbrellas*.

Color serialization

Colors are stored as hexadecimal RGB strings (e.g., `"FF0000"` for red). The special value `clByLayer` (used when a color should inherit from the layer or parent style) is serialized as the string `"ByLayer"` rather than a numeric code.

> **Warning**
>
> When editing `.tun` files by hand, always use the string `"ByLayer"` for layer-inherited colors. Writing the numeric sentinel value (`$01000000`) as a hex string will produce `"000000"`

(black), making lines invisible on dark backgrounds.

Section data

Each <Section> stores its measured and computed lines as arrays of points. Points are recorded as offset and elevation pairs relative to the alignment axis at that station. Arc segments between consecutive points are represented by bulge values in a parallel array.

Style library behavior

Style libraries (<SectionLineStyles> and <AlignmentStyles>) live at the project level and are shared by all tunnels. Each tunnel references styles by name. The built-in "Standard" style cannot be deleted.

Tip

The .tun format is plain XML text. You can inspect or diff project files with any text editor or XML tool, which can be useful for troubleshooting or version control.

9.2.5 PDF Export

TunnelCAD exports cross-sections and reports to PDF through a layout-driven engine. A layout is an ICAD Paper Space drawing — authored in ICAD itself — that carries tagged viewports, text, and rectangles. At plot time, TunnelCAD walks each tagged entity, invokes a matching data provider, and produces a PDF page through ICAD's plot pipeline.

Note

Single-section + batch (multi-page) PDF export are both shipping. Multi-section sheet booklets aren't part of the PDF engine — when you need a multi-section sheet layout, use Export Sections (right-click a tunnel → *Export Sections…* → atlas mode) instead. The analytics, template, and volume PDF exports are planned to migrate to the layout engine in a future release.

Quick start

1. Open a project and select a section.
2. Choose File → Export Section to PDF… or click the Export PDF button on the Sections toolbar.
3. Pick a layout (every new project starts with a seeded section-A4 default).
4. Pick an output filename.
5. Click OK.

Architecture

Four components separate cleanly:

Component	Unit	Responsibility
Storage	`Project/UTunnelProjectIO.pas`, `Print/UProjectLayouts.pas`	Layouts + assets live as XML subtrees inside the `.tun` project file
Layout executor	`Print/ULayoutExecutor.pas`	Loads a layout, walks tagged entities, calls providers, plots via ICAD
Provider registry	`Print/UProviderRegistry.pas`	`IProvider` interface + global `RegisterProvider` / `LookupProvider`
ICAD plot bridge	`cad/PrintEngine/UCADPlotAPI.pas`	Thin `RenderCanvasToPDF` API that drives ICAD's existing plotter

Layouts

A layout is a regular ICAD drawing authored in Paper Space. Entities can be tagged with two reserved attributes on any `TDrawObject`:

- `provider` — the provider kind (e.g. `SECTION_VIEW`, `TEXT`, `DR_TABLE`)
- `providerArgs` — `key=val;key=val` argument string parsed by `TArgMap`

Untagged entities pass through as static layout content (title block lines, borders, company text).

Layouts live inside the `.tun` project as `<Layout>…</Layout>` nodes under a `<Layouts>` subtree. Binary assets (logos, photos) live as base64-encoded `<Asset>` nodes under `<Assets>`. New projects are seeded with a default `section-A4` layout on creation.

Built-in providers

Provider	Role	Target	Purpose
`TEXT`	paper	text entity	Substitute `%FIELD%` tokens (or replace entire text via `field=X`) from the plot context
`SECTION_VIEW`	model	viewport	Draw all section line data into model space on layers named `LINE_<DEF>` and frame the viewport
`DR_TABLE`	paper	rectangle	Draw DR min/max/avg/std table (placeholder until analytics integration in Plan 3)
`POLAR_CHART`	paper	rectangle	Concentric deviation polar grid + data polyline (placeholder as above)
`IMAGE`	paper	rectangle	Insert a project asset (PNG / JPEG / BMP) at the slot rectangle as an embedded `TCADImage`
`STATUS_STRIP`	paper	rectangle	Chainage bar with one grey tick per section in the alignment plus a red tick at the current section

Layout TEXT placeholder fields

Layout text entities tagged with the TEXT provider can substitute project values either inline as %FIELD% tokens or whole-text via the field= argument. All numeric fields default to the project's unit settings (Tunnel Settings → Units); override decimals or format with fmt= on the slot's args.

No-argument fields

Field	Source	Default format
PROJECT_NAME	Project name	string
TUNNEL	Active alignment name	string
STATION / CHAINAGE	Section station	0.000
SECTION_NAME	Section name	string
TEMPLATE	Section template name	string
PAGE_INDEX / PAGE_COUNT	Layout pagination	integer
EASTING / NORTHING	Alignment world coordinates at the station	project CoordinateDecimals
ELEVATION	Alignment elevation	project ElevationDecimals
BEARING	Alignment bearing at the station	project AngularUnit + AngleDecimals (e.g. 100.0000g)
GRADIENT	Vertical gradient at the station, percent	project OffsetDecimals, % suffix
RADIUS	Horizontal radius at the station	project CoordinateDecimals; inf on straight runs
START_CHAINAGE / END_CHAINAGE	Alignment chainage range	project StationDecimals
ALIGNMENT_LENGTH	End – start chainage	project CoordinateDecimals
SECTION_INDEX / SECTION_COUNT	1-based index in the alignment / total sections	integer
POINT_COUNT	Total measured points on the section (sum across all line definitions)	integer
DATE_NOW / TIME_NOW	Now, override format via fmt=	yyyy-mm-dd / hh:nn
PROJECT_FILE	Project file path; literal (unsaved) when the project has not been saved	string

Parameterised fields (field= mode only)

These cannot be used inline as %FIELD%; set them via field= with the companion arg.

Field	Required arg	Description
AREA	vol=<volume-defini	Cross-section area (m²) for the named volume definition at the current section.
POINT_(	line=<line-definit (optional)	Without line=, sums all lines (same as inline %POINT_COUNT%). With line=, returns only that one line's point count.

For cumulative or total volume across the whole alignment, use the Mass Table dialog (right-click a volume definition → *Mass Table…*). The dialog computes both values and exports them to CSV / XLSX / PDF.

Tagging a text entity — step by step

Two modes, picked per text entity:

Mode	When to use
Inline %FIELD% substitution (default)	The entity's existing text body holds a sentence with one or more %TOKEN% placeholders. The provider replaces only the tokens; everything else stays.
Whole-text field= mode	The entity should be replaced *entirely* by one resolved value (with optional prefix= / suffix=). Required for parameterised tokens like AREA and POINT_COUNT line=.

1. Drop the text in the layout

1. Open the layout in the layout editor (paper-space tab on the Sections workspace).
2. Use the standard CAD Text tool to place a text entity where you want the label. Type the default body — this is what shows in the layout when no project is loaded, and (in inline mode) it's also the template the provider rewrites.

2. Tag it as TEXT

1. Select the text entity on the paper canvas.
2. In the right-side Provider Palette panel, click TEXT. The palette's args form below the provider list switches to the TEXT schema (six widgets: field, fmt, prefix, suffix, vol, line).
3. Configure the args (next section).
4. Click Tag Selected. The entity now carries Provider=TEXT and the serialized args string. The Outline panel shows it; the Property Inspector has both rows.

To re-edit a tag later, select the entity again — the palette auto-loads its current Provider + args. Change values, click Tag Selected to save.

3. Configure the args form

The args form widgets:

Widget	Type	Effect
`field`	dropdown of every supported field	Empty → inline `%FIELD%` substitution mode. Set to a name → whole-text replacement mode.
`fmt`	text box	Optional override for numeric formatting. Examples: `0.000`, `0`, `0.00 m`. For `DATE_NOW` / `TIME_NOW` it's any FPC `FormatDateTime` pattern (`yyyy-mm-dd hh:nn`). Leave empty to use the project's unit defaults.
`prefix`	text box	Prepended to the resolved value. Only honoured in `field=` mode — ignored when `field` is empty.
`suffix`	text box	Appended to the resolved value. Only honoured in `field=` mode.
`vol`	text box	The volume-definition name. Required when `field=AREA`; ignored otherwise. Case-insensitive.
`line`	text box	The line-definition name. Optional when `field=POINT_COUNT` (without it, all lines are summed). Ignored when `field` is anything else.

4. Worked examples

These are the most common patterns. The "ProviderArgs" column shows the serialized form the editor stores under the hood (`key=val;key=val`); in normal use you fill in widgets, you don't type the string.

Inline mode — leave `field` empty

Type the tokens directly into the entity's text body. Tokens are uppercase and surrounded by `%`.

Entity text body	ProviderArgs	Resolved output (sample)
`Sta %STATION%`	*(empty)*	`Sta 125.500`
`Sta %STATION%, %SECTION_NAME%`	*(empty)*	`Sta 125.500, S-15`
`Tunnel: %TUNNEL%, axis %EASTING%E %NORTHING%N`	*(empty)*	`Tunnel: Bypass, axis 472301.250E 4218905.732N`
`Bearing %BEARING%, gradient %GRADIENT%`	*(empty)*	`Bearing 195.4220g, gradient 1.500%`
`Section %SECTION_INDEX% of %SECTION_COUNT%`	*(empty)*	`Section 12 of 47`
`Plotted %DATE_NOW% by %PROJECT_NAME%`	*(empty)*	`Plotted 2027-05-07 by Bypass-East-Phase2`

The entity's body is the template. Any text outside `%…%` is preserved literally.

Whole-text mode — set `field` to a token name

The entity's existing text body is discarded and replaced by `prefix + resolved + suffix`.

field	Other args	Resolved output	Use for
STATION	*(none)*	125.500	A station label that is *just* the station, no surrounding sentence.
STATION	prefix=Sta , suffix= m	Sta 125.500 m	Same, with caption + unit.
BEARING	*(none)*	100.0000g	Default project units (gradians here).
BEARING	fmt=0.00	100.00g	Override decimals; the angular unit and g suffix come from the project.
RADIUS	prefix=R = , suffix= m	R = 250.000 m *or* R = inf m on a straight run	Horizontal radius label.
DATE_N	fmt=dd/mm/yyyy	07/05/2027	Custom date format.
AREA	vol=Excavation	87.530	Per-section excavation area.
AREA	vol=Excavation, prefix=Area = , suffix= m²	Area = 87.530 m²	Same with full caption.
POINT_	*(none)*	42	Total points on the section.
POINT_	line=Crown	12	Just the Crown line's points.
POINT_	line=Crown, prefix=Crown: , suffix= pts	Crown: 12 pts	Caption + unit.

When you need multiple parameterised values on one label

You can't write %AREA[Excavation]% inline (parameterised tokens are field-mode only). To show, e.g., excavation and lining areas on the same drawing, drop two text entities side by side:

- Entity A: field=AREA, vol=Excavation, prefix=Excavation: , suffix= m²
- Entity B: field=AREA, vol=Lining, prefix=Lining: , suffix= m²

5. Troubleshooting

Symptom	Cause	Fix
The token shows up literally as `%STATION%` in the PDF	Inline mode but the token is misspelled, lower-case, or uses an unsupported name	Tokens are uppercase and must match the supported list. The PDF export emits a warning diagnostic listing the offending field.
Field-mode entity shows the original text instead of the resolved value	`field=` is empty (still in inline mode)	Set the `field` dropdown to the desired token.
`%AREA%` shows up literally	`AREA` is a parameterised token; inline `%AREA%` is intentionally not supported	Switch to `field=AREA` mode and fill `vol=` with the volume-definition name.
Empty text where you expected an area / radius / bearing	The alignment has no engine geometry yet, or `vol=` references a name that doesn't exist	Import the alignment geometry; verify the volume-definition name in *Tunnel Settings → Volumes*.
`fmt=0.000` ignored on `BEARING`	`fmt=` only overrides decimals; the angular unit stays from project units	Change *Tunnel Settings → Units → Angular Unit* if you want degrees / DMS / radians instead of gradians.

Tagging an IMAGE entity — step by step

The `IMAGE` provider drops a project-embedded raster (logo, photo, scan) into the slot rectangle.

1. Register the image as a project asset

Images live in the project's Assets collection — named binary blobs serialized inside the `.tun` file, so the layout travels with the project.

1. Open the asset manager from one of:
   - Ribbon File → Manage Project Assets…
   - Right-click the project root in the Project Tree → *Manage Project Assets…*
2. Click Add… → pick a PNG / JPEG / BMP file.
   - The MIME type is auto-detected from the file extension.
   - The asset name defaults to the filename stem (e.g. `company_logo.png` → asset name `company_logo`).
   - On a name collision the dialog prompts Replace / Rename / Cancel.
3. The list view shows every registered asset with name, MIME type, and size in KB. Rename and Remove operate on the selected row.
4. Close the dialog. Save the project (the assets are embedded as base64 in the `.tun`).

2. Drop a placeholder rectangle in the layout

In the layout editor, draw a regular CAD rectangle where the image should appear. The `IMAGE` provider sizes the bitmap to the rectangle's bounds (no scaling preserves aspect — make the rectangle the intended display size).

3. Tag the rectangle as `IMAGE`

1. Select the rectangle.
2. In the Provider Palette, click `IMAGE`. The args form has one widget: `asset`.
3. Type the asset name you registered in step 1 (e.g. `company_logo`) — case-insensitive.
4. Click Tag Selected.

The rectangle now resolves to your bitmap on the next plot. The bottom-left of the rectangle becomes the bottom-left of the image; the rectangle's width and height become the image's world width and height.

4. Worked examples

ProviderArgs	Effect
`asset=company_logo`	Inserts the asset named `company_logo` into the slot rectangle.
`asset=` (empty)	Warning — `IMAGE` requires `asset=`; nothing is drawn.
`asset=missing` (name not in the asset list)	Warning — `missing asset: missing`; the placeholder X-rectangle is drawn so you can still see the slot.

If the asset's MIME isn't one of `image/png` / `image/jpeg` / `image/bmp`, the provider draws the placeholder rectangle and emits a `unsupported MIME type` diagnostic.

Editing layouts on the Sections tab

Layouts are paper-space tabs on the existing Sections tab workspace. Model space holds the current section's geometry (auto-updated as you navigate); paper tabs compose the PDF output.

1. Open a project. The Sections tab shows the current section in model space. A Layouts side panel docks on the right.
2. Layouts → New Layout… creates an empty paper tab; Layouts → Load Layout… loads a dormant layout already in the project.
3. Flip to the paper tab on the workspace tab strip. The side panel's palette + args form become active.
4. Draw entities on the paper tab with standard CAD tools, or click Insert on the palette to drop a default-sized placeholder. Tag existing entities via Tag Selected.
5. Fill in provider arguments in the schema-driven form. Insert and Tag Selected both read the current args.
6. The side panel's Outline lists every tagged entity. The loaded-layouts list lets you unload without going through the menu.

7. Navigate to another section — tagged entities on every loaded paper tab re-resolve automatically (live WYSIWYG). The viewport auto-frames the new model geometry.
8. Layouts → Export Section to PDF… (or TUNPDF) plots the active paper tab. Layouts → Batch Export PDF… (or TUNPDFBATCH) plots a station range as a single multi-page PDF.
9. The Property Inspector shows `Provider` and `ProviderArgs` rows for any selected entity — edit tags there too.
10. Save the project — loaded layouts capture their live state into their `IQMLBlobs`; dormant layouts pass through unchanged.

Known limitations

- DR data (for DR_TABLE and POLAR_CHART) is not wired. Radial deviations come from the analytics engine; Plan 3 will integrate them. For now both providers emit a warning and draw a placeholder frame.
- No ICAD command-registry integration yet. TUNPDF / TUNPDFBATCH / TUNLAYOUT* are plain procedures invoked from menu items; typing them at the command line isn't wired until TunnelCAD adopts ICAD's command registry.
- Sheet sets / per-section booklet output are out of scope. Use Export Sections (right-click a tunnel → *Export Sections…* → atlas mode) when you need a multi-section sheet layout.

Verifying the editor (manual smoke test)

After building TunnelCAD locally:

1. Open TunnelCAD, create a new project → Sections tab active, Layouts side panel visible, no layouts loaded.
2. Layouts → New Layout… → type a name → empty paper tab appears on the workspace tab strip.
3. Flip to the paper tab. Click DR_TABLE in the palette → click Insert → a rectangle appears tagged with DR_TABLE. The outline lists it. The inspector shows `Provider=DR_TABLE`.
4. Navigate to a section that has data → the DR_TABLE rectangle refreshes (placeholder content until Plan 3 wires analytics).
5. Layouts → Export Section to PDF… → pick an output path → a valid single-page PDF is produced.
6. Layouts → Batch Export PDF… → pick the loaded layout + a station range → a multi-page PDF is produced.
7. Save project, close, reopen → the layout is present in the loader picker (dormant). Layouts → Load Layout… restores it with the same content.

Commands

- `TUNPDF` — plot the active paper tab on the Sections workspace to PDF. Wired as `ExecuteTunPDFCommand(Owner, Project, Section, Session)` in `Print/UCmdTunPDF.pas`.
- `TUNPDFBATCH` — plot a station range as a single multi-page PDF. Wired as `ExecuteTunPDFBatch(Owner, Project, Session, Navigate)` in `Print/UCmdLayouts.pas`.

- TUNLAYOUTLOAD / TUNLAYOUTUNLOAD / TUNLAYOUTNEW / TUNLAYOUTDELETE / TUNLAYOUTIMPORT / TUNLAYOUTEXPORT — the load/unload lifecycle.

Extending the engine

To add a new provider — for example, a custom chart type:

1. Create a new `Print/UProviderX.pas` unit implementing `IProvider` (name, role, `Resolve(Ctx, Slot, Canvas, Args, Result, LayoutName)`).
2. Call `RegisterProvider(TProviderX.Create)` — usually from a `RegisterProviderX` procedure invoked at app startup.
3. Author a layout in ICAD with a tagged entity using your new provider name and args.
4. That's it — the engine picks it up automatically.

See `Print/UProviderText.pas` and `Print/UProviderSectionView.pas` for worked examples of paper-role and model-role providers respectively.

Design documents

- Spec: `docs/superpowers/specs/2026-04-18-tunnel-pdf-export-design.md`
- Plan 1: `docs/superpowers/plans/2026-04-18-tunnel-pdf-export-plan-1-engine-skeleton.md`
- Layout Editor: `docs/superpowers/plans/2026-04-18-tunnel-layout-editor-plan.md`

CHAPTER

TEN

REFERENCE

This chapter provides quick-reference material for experienced TunnelCAD users. It covers keyboard shortcuts, CAD commands, coordinate and measurement conventions used throughout the application, and solutions to common issues.

10.1 Keyboard Shortcuts and CAD Commands

10.1.1 CAD Command Line

The command line panel at the bottom of the application window accepts typed commands. Commands are case-insensitive.

Navigation Commands

ZOOM (Z)
: Enters zoom mode. Follow with a sub-command:

  - E – Zoom extents (fit all objects in the viewport)
  - W – Zoom window (draw a rectangle to zoom into)
  - + – Zoom in
  - - – Zoom out

PAN (P)
: Enters pan mode. Click and drag to move the viewport.

Editing Commands

SELECT
: Enters selection mode. Click entities to select them.

UNDO (U)
: Undo the last action.

REDO
: Redo the last undone action.

10.1.2 Mouse Interaction

Left click
: Select an entity. In selection mode, clicking an entity selects it and deselects all others.

Shift + left click
: Add the clicked entity to the current selection, or remove it if already selected.

Right click
: Open the context menu for the current selection or canvas area.

Scroll wheel
: Zoom in (scroll up) or zoom out (scroll down), centered on the cursor position.

Middle button drag
: Pan the viewport by clicking and dragging with the middle mouse button.

10.1.3 Ribbon Keyboard Access

Press the Alt key to activate ribbon keytips. Letter overlays appear on each ribbon tab and button. Type the displayed letters to activate the corresponding tab or command.

10.1.4 Standard Keyboard Shortcuts

Shortcut	Action
Ctrl+N	New project
Ctrl+O	Open project
Ctrl+S	Save project
Ctrl+Z	Undo
Ctrl+Y	Redo
F1	Open the user manual PDF (from `<exe-dir>/TunnelCAD_Manual.pdf`)
Escape	Cancel current command / deselect all

10.2 Coordinate and Measurement Conventions

This page documents the sign conventions, coordinate systems, and units used throughout TunnelCAD.

10.2.1 Coordinate Systems

World Coordinates

TunnelCAD uses a standard surveying coordinate system:

- Northing = Y axis
- Easting = X axis
- Elevation = Z axis

The Alignment canvas tab displays data in world coordinates.

Section Local Coordinates

Cross-sections are displayed in a local coordinate system relative to the alignment axis at that station:

- X = horizontal offset from the alignment axis
- Y = elevation

10.2.2 Offset Convention

Offsets are measured perpendicular to the alignment, looking in the direction of increasing chainage:

- Positive (+) = right of the alignment axis
- Negative (-) = left of the alignment axis

This convention applies to all offset values in section data, template definitions, and setout calculations.

10.2.3 Angular Conventions

ALM arc/spiral sign
: Positive (+) = right turn (clockwise). Negative (-) = left turn (counter-clockwise).

Bearing display
: Bearings shown in the interface use the surveying convention, converted from the internal math angle via: `surveying bearing = Pi/2 - math angle`.

10.2.4 Gradient

Gradient values are stored and displayed in percent (%). The value read from the alignment engine is already in percent – it must not be multiplied by 100 again.

10.2.5 Deviation Radial (DR)

The deviation radial is the difference between the measured section and the design template at a given angular position:

- Positive DR = overbreak (the measured point is outside the template envelope)
- Negative DR = underbreak (the measured point is inside the template envelope)

DR text labels use a default height of 0.15 m in model units.

10.2.6 Section Point Ordering

Section points are ordered clockwise starting from the bottom (negative Y axis direction) after radial sorting around the section center.

10.2.7 Template Bulge

Template line segments may include an arc defined by a bulge value:

- Positive bulge = arc bulging to the left
- Negative bulge = arc bulging to the right

> **Note**
>
> When constructing templates programmatically, the bulge value must be set after adding the end point of the segment, because the bulge array requires at least two points to exist.

10.2.8 Elevation in Setout Calculations

Two related but distinct elevation values appear in setout offset data:

Elevation
: The elevation of the alignment offset axis at the section station. This value is constant for a given station regardless of lateral position.

PointHeight
: The actual elevation at a specific lateral offset, which varies according to superelevation (cross-fall) applied at that station.

10.3 Licensing

TunnelCAD is distributed under a modular license. The license state is stored locally in `license.json` inside the application's per-user config directory:

- Windows: `%APPDATA%\TunnelCAD\license.json`
- Linux: `~/.config/TunnelCAD/license.json`

The application ships with a bundled IQ License engine that supports three operating modes: Basic (free feature set), Trial (time-limited access to trial-enabled modules) and Activated (serial-bound, module-specific entitlements). The dialog surfacing these states is available from Home → Help → License (ribbon) or Help → License Manager… (menu).

10.3.1 License Manager dialog

The dialog is divided into three blocks:

1. Status strip (top) — Mode, expiry date (if any), and a short machine-ID fingerprint for identification with your reseller. Status colouring:
    - Green — Activated;
    - Olive — Trial with days remaining;
    - Red — Expired;
    - Default — Basic.
2. Modules list (middle) — One line per module registered by the application (Sections, Point Cloud, Analytics). Each line shows the module's active/inactive state and, if the module is module-time-limited, its individual expiry date.
3. Edit panel (bottom) — Server URL, Serial Key, and action buttons.

Server URL

The Server URL field shows the base URL the engine uses to reach the activation server (for example `https://license.iqsoft.gr/api/v1` or a self-hosted endpoint). Editing the field is non-destructive — the new value is committed to the in-memory config when the user clicks Activate, Deactivate or Close. The URL is persisted into the application's settings file on dialog close so that the next run of TunnelCAD uses the new endpoint without re-prompting.

Typical reasons to edit the URL:

- Switching between production and staging servers during evaluation.

- Pointing at a self-hosted activation server on an internal network.
- Working against a different deployment region.

Serial Key

Paste your serial (the letter case is normalised automatically) and click Activate. The engine sends an activation request to <ServerURL>/activate carrying the serial, the product ID and the machine fingerprint. On success the reply is written to license.json, the status strip flips to Activated, and the dialog refreshes its module list.

Buttons

Button	Behaviour
Activate	Commits the URL edit, then calls /activate on the server. Requires a serial in the Serial Key field. Shows a message dialog with the result.
Deactivate	Standard online deactivation. Commits the URL, confirms with the user, then calls /deactivate. On success the license file is removed and the server frees up the activation slot. This is the preferred path when the machine is online.
Clear License	Local-only wipe. Removes license.json from this PC without contacting the activation server. Use this when the server is not reachable (machine offline, endpoint decommissioned, server migration). The server will still count this machine as activated until it is contacted again, so the regular Deactivate path is preferable whenever possible. The button fires only after a confirmation dialog that warns about the side effect.
Close	Persists the edited URL and dismisses the dialog.

> **Warning**
>
> Clearing a license locally does not free up the activation slot on the server. If you later want to re-activate the same serial on a different machine, you may need to contact your reseller to manually release the slot.

10.3.2 Troubleshooting

"Serial format invalid" — The serial-key format validator rejects the key shape before any network round-trip. Re-check the serial on your license certificate; serials are hyphen-grouped and case-insensitive.

"Activation failed: cannot reach server" — The URL is wrong or the network cannot reach it. Verify the Server URL, then check connectivity with a browser or curl to <ServerURL>/health (or the equivalent health endpoint your server exposes).

"Already activated on another machine" — The serial is bound to a different fingerprint. Either deactivate the other machine (online) or contact support to release the slot.

"Activated but modules are still marked inactive" — Some serials entitle only a subset of modules; the About dialog and the License Manager modules list both show which modules are

active. Check the expiry dates: expired modules show as inactive even when the license is otherwise valid.

10.3.3 End-User Licence Agreement

TunnelCAD ships with an End-User Licence Agreement that the user must accept on first run (and on every material version bump).

Where the text lives:

- `EULA.md` — authoritative Markdown source in the repository root.
- `EULA.txt` — plain-text rendering shipped next to the binary; the in-app dialog reads this file at startup.

Acceptance record:

On acceptance, TunnelCAD writes a small JSON file alongside `license.json`:

- Windows: `%APPDATA%\TunnelCAD\eula.json`
- Linux: `~/.config/TunnelCAD/eula.json`

The file records the accepted EULA version, the acceptance timestamp (ISO-8601 UTC), the OS username, and the Device fingerprint. It is only ever written on user click-through and read to decide whether the dialog needs to appear again after a version bump.

Re-prompt triggers:

- `eula.json` is missing (e.g. fresh install).
- `eula.json` exists but its `version` field is older than the current `EULA_VERSION` compiled into the application (material amendment).

Decline behaviour:

Declining the EULA exits the application without creating the main window. No telemetry is sent on decline.

TODO: the installer scripts (to be authored) must ship `EULA.txt` alongside the binary — the dialog will otherwise display a diagnostic message in place of the EULA text.

10.4 Troubleshooting

This page covers common issues and their solutions.

10.4.1 Display Issues

Entities disappear after moving
: The internal spatial index may have stale position data. The application handles index invalidation automatically, but if entities become invisible after an operation, type ZOOM E in the command line to zoom to extents and refresh the display.

Colors look wrong or lines are invisible on a dark background
: Line styles set to use ByLayer colors may default to black, which is invisible against a dark canvas background. Check that line styles in the Style Libraries use colors appropriate for your background setting. You can change the canvas background color in Settings.

10.4.2 Resource and File Issues

Hatch patterns not rendering
: TunnelCAD requires a `resources` folder located next to the application executable. This folder must contain the hatch pattern files (`.pat`), linetype files (`.lin`), and font files (`.shx`). If the folder is missing or incomplete, hatches will fail to render without an error message.

Point cloud not loading
: Point cloud support requires external libraries in the application directory:

  - Linux: `libE57CWrapper.so` and `liblaszip.so`
  - Windows: the corresponding `.dll` files alongside the `.exe`

  If these libraries are missing, point cloud import will fail.

Settings not saving
: Verify that the application has write permissions to the settings file location:

  - Linux: `~/.config/TunnelCAD/settings.json`
  - Windows: `%APPDATA%\TunnelCAD\settings.json`

  If the directory does not exist, TunnelCAD creates it on first run. File permission issues can prevent this.

10.4.3 Import and Export Issues

LandXML import missing data
: Ensure the correct items are checked in the import dialog before proceeding. Some data – such as widening, cant, line definitions, and DR measurements – is stored in TunnelCAD-specific `<Feature>` extensions within the LandXML file. Files exported from other software will not contain these extensions, so only standard alignment, profile, and cross-section geometry will be available.

TCM conversion shows garbled characters
: Older TCM files may use Windows-1253 (Greek) character encoding. The converter performs automatic cleanup of non-UTF8 characters, but some characters may not convert perfectly. Review the converted project for any remaining encoding artifacts in names and descriptions.

10.4.4 Template and Section Issues

Templates not applying to new sections
: Templates are assigned to chainage ranges via Station Definitions in the project tree. If a newly created section does not receive the expected template, check that a Station Definition exists whose chainage range covers that section's station. Sections outside all defined ranges will have no template assigned.

10.4.5 Debug Logging

If you encounter an issue that requires deeper investigation, enable debug logging:

1. Open the settings file (`settings.json` at the path listed above) in a text editor
2. Set `"debugLog": true`

3. Restart TunnelCAD

The application writes timestamped log entries to `iqcad_debug.log` in the same directory as the executable. The log flushes on every write, so entries are preserved even if the application crashes. Share this file when reporting issues.