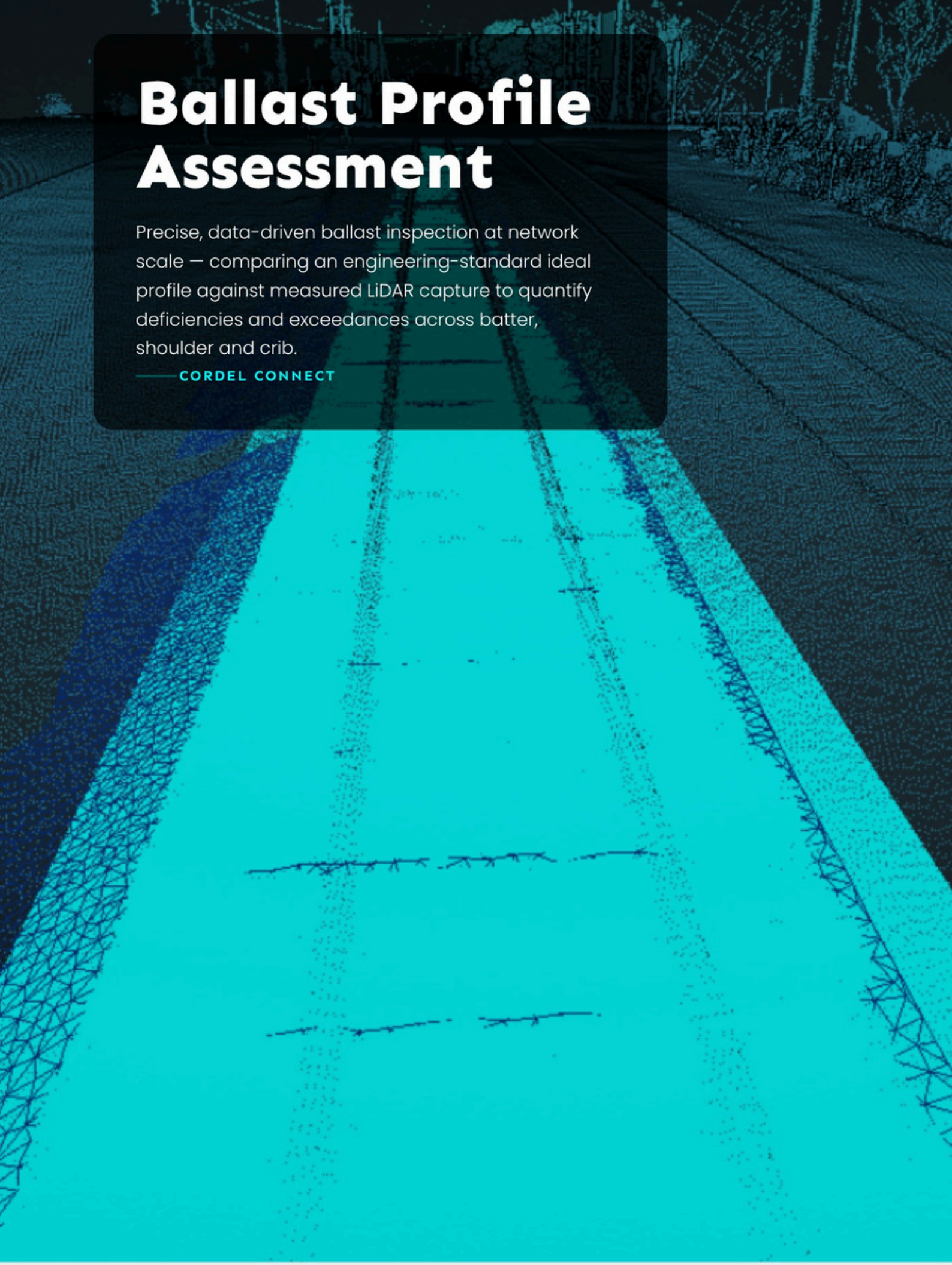


Ballast Profile Assessment

Precise, data-driven ballast inspection at network scale — comparing an engineering-standard ideal profile against measured LiDAR capture to quantify deficiencies and exceedances across batter, shoulder and crib.

CORDEL CONNECT

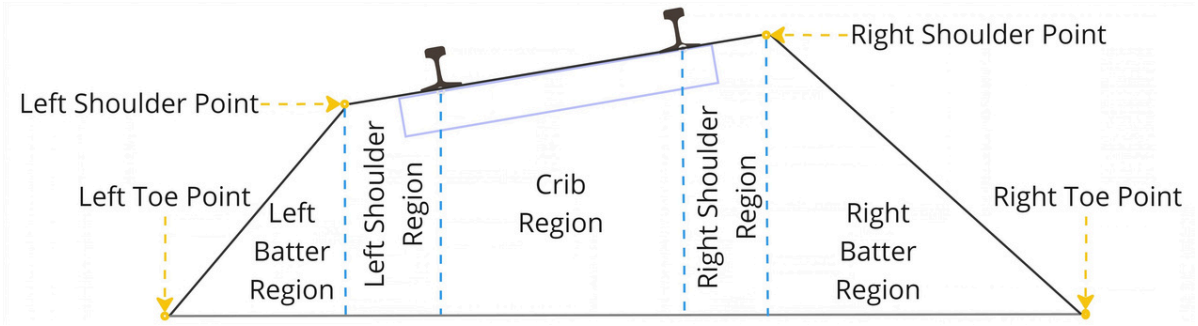
Introduction

Ballast condition is fundamental to track stability and long-term asset performance, specifically designed to:

- Transmit and distribute the load of the track and railroad rolling equipment to the subgrade;
- Restrain the track laterally, longitudinally, and vertically under dynamic loads imposed by railroad rolling equipment and thermal stress exerted by the rails;
- Provide adequate drainage for the track; and
- Maintain proper track crosslevel, surface, and alignment. (Maintain geometry)Traditional ballast inspections are time-consuming, subjective and often reactive.

The Cordel Ballast Profiling Assessment enables precise, data-driven inspection processes. Using client-defined engineering standards, Cordel generates an “ideal” ballast profile and compares it against the measured ballast condition captured in the corridor, calculating volume and height deltas at regular intervals. The result is a clear, quantitative view of deficiencies and exceedances across batter, shoulder and crib regions – supported by visual overlays, QA video and GIS-ready reporting. This enables rail networks to move from manual inspection to scalable digital assessment, prioritising maintenance based on measurable risk and ensuring ballast performance is maintained to standard.

Information

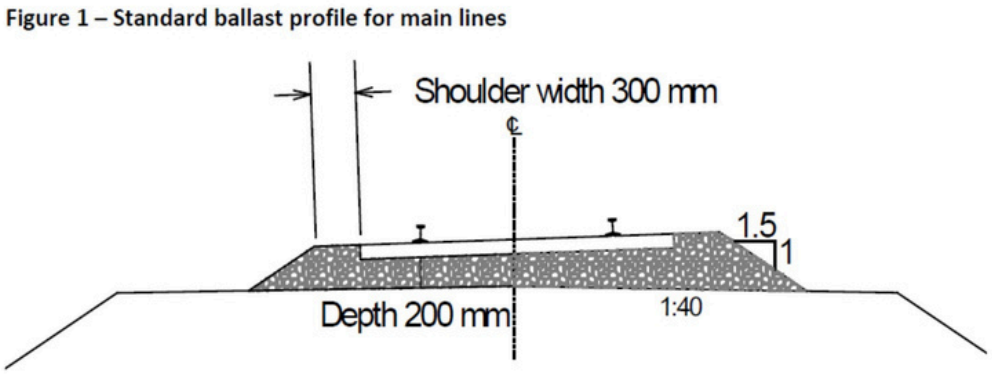


Labeled sections and regions of a typical ballast profile

Summary

This module allows Cordel Connect users to compare the "ideal ballast profile" (client specified) to the "measured ballast profile" (or the 'actual' ballast profile using captured data), providing insight into excess/deficiencies in volume, and delta height.
The ballast module empowers rail networks to make data driven decisions and prioritise ballast maintenance schedules effectively.

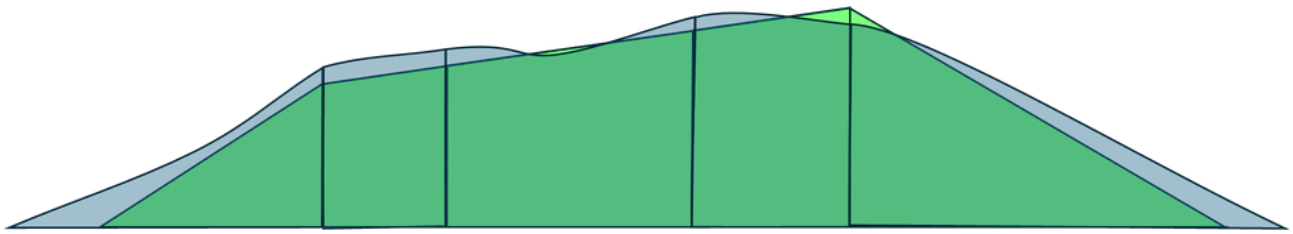
How does this module work?



An example of a client's ideal ballast profile - aka 'engineering standards'

Cordel generates an 'ideal ballast profile' based on client supplied engineering standards. The ideal ballast profile is a .PLY (mesh) file that represents the ballast in perfect condition.
The ideal ballast profile is tied to the scene using the detected rail head position - this means the ground plane is inferred (not measured) from the rail position.
This is configured for each client, based on individual standard operating processes.
The captured data is then analysed and Cordel generates the 'actual ballast profile' - a .PLY (mesh) file that represents the ballast volume and height as it actually is in the corridor.
An actual ballast profile can be generated from Cordel captured data or client-supplied BYOD.
The ideal and actual ballast profiles are then overlaid and the difference between them (delta) is calculated at 1 meter intervals.

An example



Cross-sectional view comparing the ideal profile (green) and the inferred profile (blue)

This visual example depicts the key characteristics of a track's ballast geometry. Two noteworthy characteristics shown in this example are:

- Left Batter [Slope] Region: The inferred profile shows an excess volume compared to the ideal profile, resulting in a positive volume delta. This indicates the ballast has accumulation beyond the ideal profile.
- Right Shoulder [Slope] Region: The deviation is minimal. Because the excess in this region is slightly larger than the deficiency, the result is a minimal positive volume delta.

Delta: The delta calculations provide a quantitative measurement of ballast volume/height variations, enabling precise, consistent assessment of the ballast geometry.

Delta Volume calculation:

```
Delta Volume = Ballast Volume - Ideal Volume
```

Delta Height calculation:

```
Delta Height = Ballast Height - Ideal Height
```

Ballast Profiling Payload Data

.CSV Reports

The Ballast Profiling solution includes three .CSV reports. These reports include the standard information contained in all Cordel generated .CSV files - such as positional information, capture details, mission information and links to the Cordel Connect platform.

The Ballast Volume Report

```
*_BallastVolumeReport.csv
```

The Ballast Volume report (BallastVolumeReport.csv) compares the ideal ballast profile to the measured ballast profile for the batter (left and right) shoulder (left and right) and crib and calculates the delta between the two profiles. A measurement of the delta is provided for each of these areas (batter, shoulder and crib) for each cross-section (typically 1m, though this is configurable based on client requirements) of track. Negative measurements indicate ballast deficiencies and positive measurements indicate ballast excess.

Batter (either left or right) measurements are not included in the report if an adjacent track is detected.

Column Name	Description
Data_VolumeBatter LeftBallast_m3	Left batter [slope] inferred ballast volume estimate for the cross-section
Data_VolumeBatter LeftIdeal_m3	Left batter [slope] volume of the ideal profile for the cross-section
Data_VolumeBatter LeftDelta_m3	Left batter [slope] delta between the inferred ballast volume estimate and the ideal volume value for the cross-section
Data_VolumeShoulder LeftBallast_m3	Left shoulder inferred ballast volume estimate for the cross-section (track linear distance of 1m)
Data_VolumeShoulder LeftIdeal_m3	Left shoulder ballast volume of the ideal profile for the cross-section (track linear distance of 1m)
Data_VolumeShoulder LeftDelta_m3	Left shoulder delta between the inferred ballast volume estimate and the ideal ballast volume for the cross-section (track linear distance of 1m)
Data_VolumeCribBallast _m3	Crib inferred ballast volume estimate for the cross-section (track linear distance of 1m)
Data_VolumeCribIdeal _m3	Crib volume of the ideal profile for the cross-section (track linear distance of 1m)
Data_VolumeCribDelta _m3	Crib delta between the inferred ballast volume estimate and the ideal volume value for the cross-section (track linear distance of 1m)
Data_VolumeBatter RightBallast_m3	Right batter [slope] inferred ballast volume estimate for the cross-section (track linear distance of 1m)

The Ballast Volume Report (Cont'd)

Column Name	Description
Data_VolumeBatter RightIdeal_m3	Right batter [slope] volume of the ideal profile for the cross-section (track linear distance of 1m)
Data_VolumeBatter RightDelta_m3	Right batter [slope] delta between the inferred ballast volume estimate and the ideal volume value for the cross-section (track linear distance of 1m)
Data_VolumeShoulder RightBallast_m3	Right shoulder inferred ballast volume estimate for the cross-section (track linear distance of 1m)
Data_VolumeShoulder RightIdeal_m3	Right shoulder ballast volume of the ideal profile for the cross-section (track linear distance of 1m)
Data_VolumeShoulder RightDelta_m3	Right shoulder delta between the inferred ballast volume estimate and the ideal ballast volume for the cross-section (track linear distance of 1m)
Data_VolumeTotalBallast _m3	The total inferred ballast volume estimate for the cross-section (track linear distance of 1m)
Data_VolumeTotalIdeal _m3	The total volume of the ideal profile for the cross-section (track linear distance of 1m)
Data_VolumeTotalDelta _m3	The total delta between the inferred ballast volume estimate and the ideal volume value for the cross-section (track linear distance of 1m)

The Ballast Delta Height Report

`ballast_delta_height.csv`

The Delta Height report measures the height offset between the top of sleeper and the ballast formation. This report provides raw values at every meter for the height delta across the network.

These measurements are then used to define the threshold at which an infringement is generated (for example delta_height > 50mm) that can then be visualised in Cordel Connect. The data contained in this report details the delta in height between the ideal profile and the inferred ballast profile - for the left and right shoulder point as well as the crib.

Column Name	**Description**
HeightRightShoulder Delta_m	Average height delta between the ideal and inferred profile for the right shoulder
HeightCribDelta_m	Average height delta between the ideal and inferred profile for the crib
HeightLeftShoulder Delta_m	Average height delta between the ideal and inferred profile for the left shoulder

Video Files

`*_ballast.mp4`

The QA Video is also available for download as part of the OLE Vegetation Infringement payload data.

Visual Tools

Report Graphing Tool

Cordel Connect provides a customizable graphing visualisation tool to enable users to visually understand the data provided in the Ballast .CSV reports.

This example is configured to show the Left Batter & Shoulder; Crib and Right Batter and Shoulder data found in the The Cluster Volume report. The Ballast Delta Height report can also be graphed in a similar way (configuration by Cordel required).

Users can view all nominated data on a single graph, and data can be toggled on and off. Users also have the option view data in individual graphs using the 'separate graphs' option.

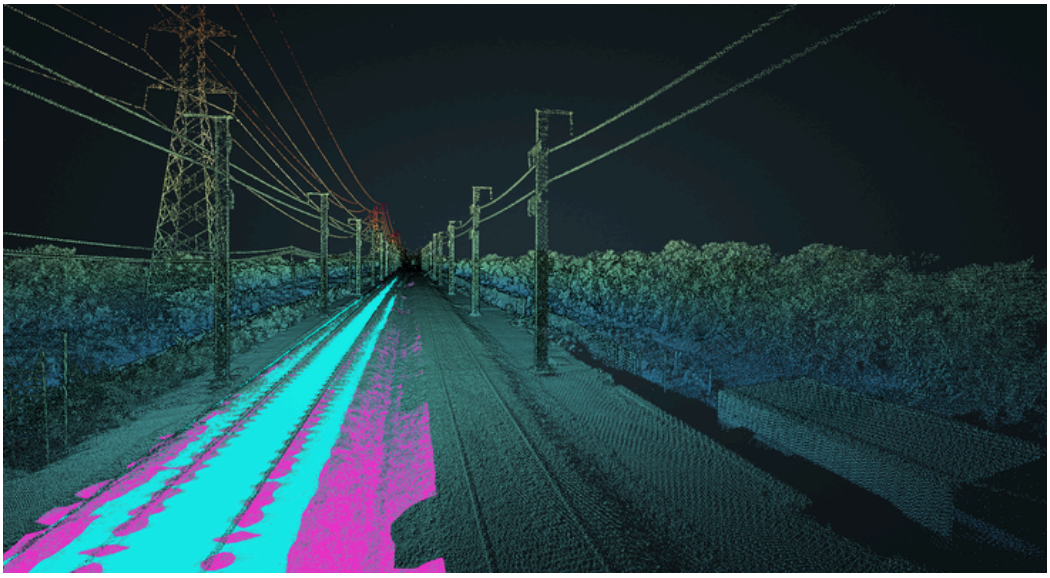


Ballast Cluster Volume Graph

Any ballast report can be configured in this way. Please speak with your Cordel account manager for more information.

LiDAR Viewer

The Ballast Profiling Solution provides the ideal ballast and measured ballast profiles as .PLY mesh files. These can be viewed withing Cordel Connect using the point cloud viewer. Specifically, users can overlay the ideal and measured ballast .PLY mesh profiles over the top of each other, allowing them to visually assess ballast deficiencies and exceedances at a glance:



Visually compare the ideal ballast point cloud (blue) to the inferred ballast point cloud (pink)

More information on how to view and manipulate ballast LiDAR files in the LiDAR Viewer is available in the Cordel Connect User Guide in the FAQ section: How To Utilise Ballast Connect LiDAR Artefacts

Forward Facing Video

The video footage captured by Cordel hardware is a powerful tool when conducting digital assessments of ballast volume.

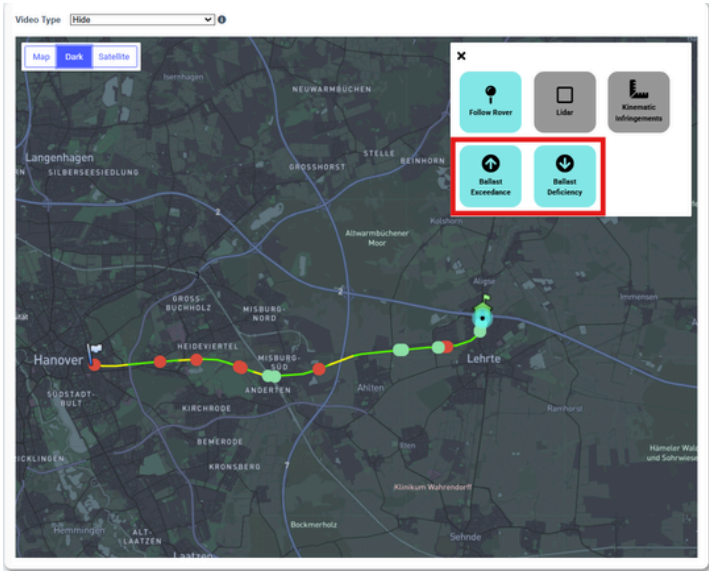


Map Layers

Ballast Exceedance/Deficiency Layer

Cordel Connect users are able to view the location of ballast exceedances and deficiencies in the Mission Viewer using the layers functionality.

- Ballast Deficiencies have been detected
- Ballast Exceedances have been detected

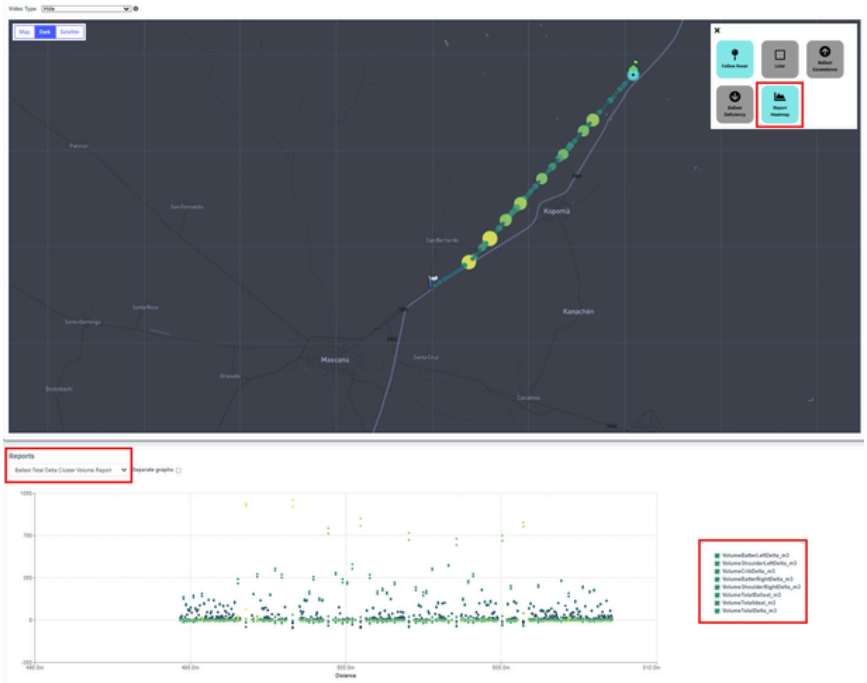


Toggle exceedances and deficiencies on and off using the map layers

Report Heatmap Layer

The Report Heatmap analyses the values in .CSV report selected, applying a scale to the data and then plotting the scaled values as a heatmap - providing a visual representation of the severity of each datapoint in the selected .CSV report.

Users can manipulate the data displayed on the heatmap by selecting/de-selecting data on the scatter graph data.

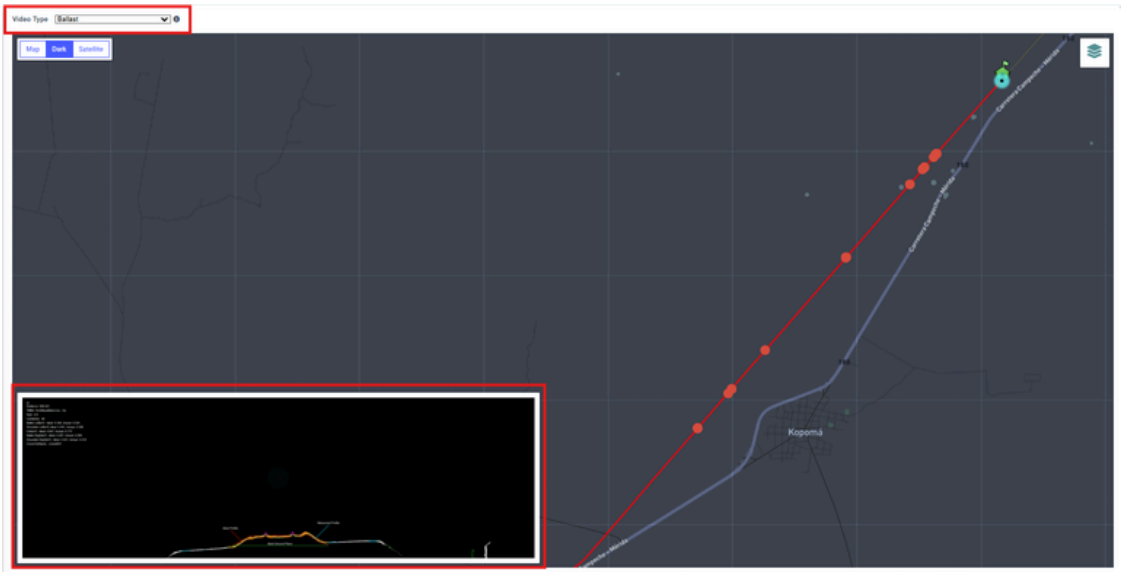


Display report data as a heatmap using the heatmap layer

Ballast Infringements (Mission Viewer)

Ballast QA Video

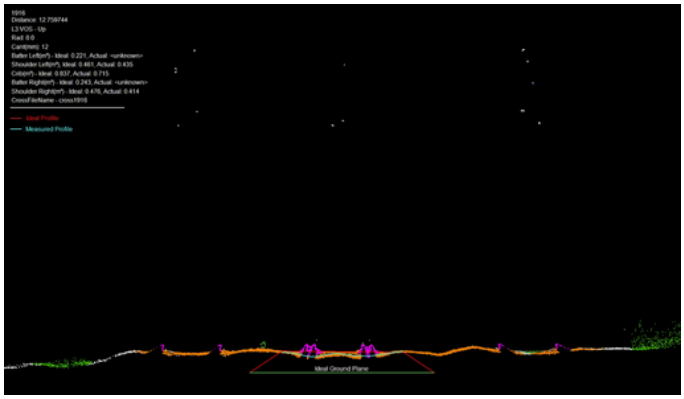
Each 1 meter 2D cross-section is 'stitched together' and presented in the ballast module as a QA video. This QA video is synced to the Network Model and can be reviewed in the Mission Viewer by selecting the 'Ballast" video type.



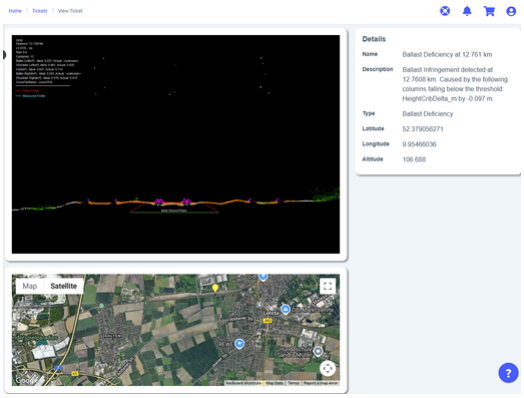
Select the ballast video type to review ballast cross-sections.

Ballast Infringement Details

To review the exact details of a deficiency or exceedance, users can click the corresponding infringement marker. To view the classified cross section associated with a particular exceedance or deficiency select 'View' or to open the Infringement Details select 'Details'



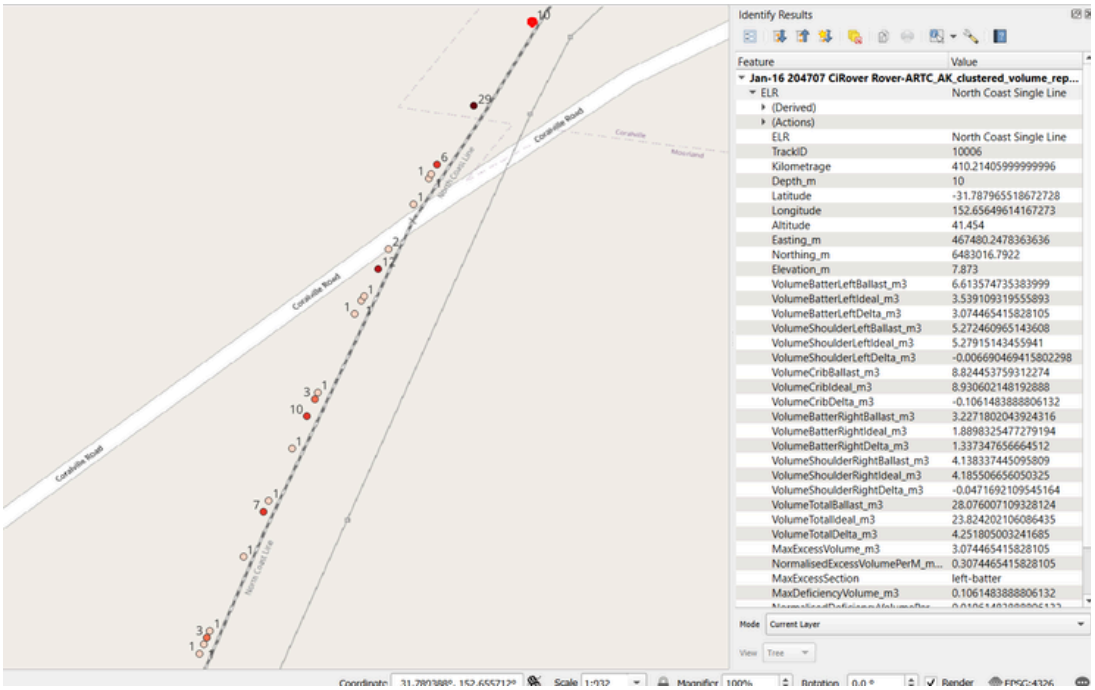
The infringement cross-section



The infringement details

Third Party Integration

The standard Ballast .CSV reports are able to be viewed and manipulated in GIS software. Users that prefer to manipulate data in GIS platforms are able to directly ingest reports (via API if desired) to interact with the assessments provided. Cordel also has experience exporting reports in a multitude of GIS compatible formats and can provide this service upon request.



Example of a Cluster Volume Report in GIS software