Rail Track-Structure Interaction with Zero Longitudinal Resistance

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For LUSAS version:	21.1
For software product(s):	LUSAS *Bridge*
With product option(s):	Nonlinear, Rail Track
Note: The example exceeds the limits of the LUSAS Teaching and Training Version.	

Description

This example examines the track-structure interaction between a braking TGV train and a bridge which crosses the River Scheldt on the high-speed line between Brussels – Lille (junction for Paris/London). This formed a study conducted by Delhez, Esveld, Godart & Mijs entitled "Avoidance of expansion joints in high-speed CWR track on long bridges" and originally published in Rail Engineering International Edition 1995 Number 3 which has subsequently been made available again by Professor Esveld in an identical paper on his company website entitled "Design of High Speed Track on Long Bridges".

The original study considered solely the effects of the horizontal train loads on the structure and therefore this example replicates this limitation. The example considers the cases where there is Continuously Welded Rail (CWR) track and the case where 75m of Zero Longitudinal Resistance (ZLR) track is introduced along deck 6.
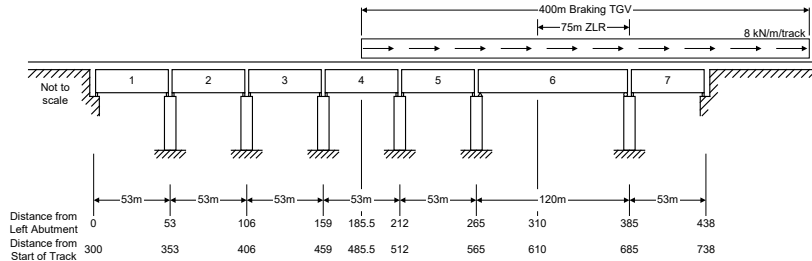
Objectives

The modelling requirements of the analysis are:

❑ Accurate modelling of the offset of the longitudinal behaviour of the bridge structure for CWR.

❑ Modelling of longitudinal behaviour of the bridge with the introduction of 75 m of ZLR track along approximately the right-hand two thirds of deck 6 of the bridge.

The output requirements of the analysis for all train configurations passing across the structure are:

❑ Maximum longitudinal displacement of the track

❑ Maximum relative displacement between the track and the structure in the longitudinal direction (relative railbed displacement).

❑ Peak axial rail stresses.

Keywords

UIC774-3, Track-Structure Interaction, TSI, Rail, Railbed, ZLR.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.

The following files are provided for copying to a project folder if a rail track model is to be built from scratch.

❑ **UIC_Template.xlsx** or **UIC_Template.xls** UIC774-3 Microsoft Excel input spreadsheet (unpopulated) for copying to a projects folder and using with this worked example.

These following files are provided for copying to a project folder if results processing only and not spreadsheet data input is of interest:

❑ **Esveld-ForwardTGV.xlsx** or **Esveld-ForwardTGV.xls** UIC774-3 Microsoft Excel input spreadsheet populated with data defined in this example. If used, continue at the section titled *Modelling / Running an Analysis*.

Defining Model Data

The LUSAS Rail Track Analysis software option automatically builds LUSAS models suitable for track/structure interaction analysis. It does so from data defined in Microsoft Excel spreadsheets.

If you wish to build the model used in the worked example from a predefined populated spreadsheet continue at the section titled ***Modelling / Running an Analysis***.

Otherwise, to see the processes involved in defining data to build a model from scratch:

- Copy the Microsoft Excel spreadsheet named **UIC_Template.xlsx** (use **UIC_Template.xls** if using an older version of Microsoft Excel) to a working projects folder (such as **<LUSAS Installation Folder>\Projects>)** where the track-structure interaction model is to be built.

- Rename the spreadsheet to **Esveld-ForwardTGV.xlsx** if using Microsoft Excel 2007 and above or rename to **Esveld-ForwardTGV.xls** if the other file was copied and you are using an older version of Microsoft Excel.

- Open the spreadsheet in Microsoft Excel.

The modelling spreadsheet contains six worksheets titled:

❑ **Decks, Tracks and Embankment**
❑ **Structure Definition**
❑ **Geometric Properties**
❑ **Material Properties**
❑ **Interaction and Expansion Joint**
❑ **Loading**

Note. Data should only be entered into the yellow regions of the Microsoft Excel spreadsheet to define the modelling and analysis requirements. Numeric values in the

white cells are automatically populated according to data entered in other worksheets. These cells are protected from editing or user input. Data tips and other details relating to cells can often be seen by hovering over a cell.

Note. Whilst it is recommended that an unpopulated spreadsheet is used with this example, populated spreadsheets are supplied for those not wishing to enter all details as listed or for use if any errors are encountered with user-input into the general spreadsheet that cannot easily be fixed. Populated spreadsheets can be downloaded from the User Area of the LUSAS website as part of the "associated worked examples files" zip file. A spreadsheet compatible for an installed version of version of Microsoft Excel should be copied to the working folder where the track-structure interaction example model is to be created.

Defining Decks, Tracks and Embankment Lengths

- Pick the **Decks, Tracks and Embankment** worksheet.

- Enter **7** for the **Number of Decks**.

- Enter **2** for the **Number of Tracks**.

- Enter **300** for both the **Left Embankment Length** and **Right Embankment Length**.

- Only a single ballast type will be defined for both the track-embankment-interaction and the track-structure-interaction in the model. Enter **1** for the ID number of the **Left Embankment Ballast Type** and the **Right Embankment Ballast Type**.

Note that the **Length of Decks Only** and **Total Length** cells are populated using data on this and another worksheet. These cells are protected on this worksheet.

Defining the Structure

Referring to the illustration at the start of the example the structure definition will now be entered into the Microsoft Excel spreadsheet. From the structure definition in the original publication decks 1 to 5 and 7 all have a longitudinal bearing stiffness of 15 kN/mm and deck 6 has a fixed bearing at its left end and a roller bearing at its right end. Both abutments are fully restrained and all piers have a longitudinal stiffness of 15000 kN/mm.

- Pick the **Structure Definition** worksheet.

- The left-hand abutment is fully restrained. Enter **R** for the **Spring Support for each Abutment/Pier** for the left end of the deck.

- The bearing on the top of the pier has a longitudinal stiffness of 15 kN/mm. Enter **15** for the **Bearing Springs on Top of each Pier** for the left-hand end of the deck.

- The pier has a longitudinal stiffness of 15000 kN/mm. Enter **15000** for the **Spring Support for each Abutment/Pier** for the pier located at the right-hand end of Deck 1.

- The bearing on the top of the pier has a longitudinal stiffness of 15 kN/mm. Enter **15** for the **Bearing Springs on Top of each Pier** for the right-hand end of the deck.

- Enter **53** for the **Span Length** of Deck 1.

- Enter **1** for the **Geometric Assignment** for the span of the deck. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. This ID will match a material definition in the **Material Properties** worksheet covered later.

- Enter **1** for the **Ballast Type**. This ID will match a ballast definition in the **Interaction and Expansion Joint** worksheet covered later.

This completes the structure definition for the first deck of the structure. The same procedure is followed for the definition of the second deck of the structure. The structure definition for the supporting pier at start of the next deck must exactly match the definition for the previous deck and therefore the **Spring Support for each Abutment/Pier** must be identical for the left-hand end of Deck 2 and the right-hand end of Deck 1.

- For the left-hand end of Deck 2, enter **15000** for the **Spring Support for each Abutment/Pier** to match the data entered for the right-hand end of Deck 1.

- The bearing on the top of the pier has a longitudinal stiffness of 15 kN/mm. Enter **15** for the **Bearing Springs on Top of each Pier** for the left-hand end of the deck.

- The pier has a longitudinal stiffness of 15000 kN/mm. Enter **15000** for the **Spring Support for each Abutment/Pier** for the pier located at the right-end of Deck 2.

- The bearing on the top of the pier has a longitudinal stiffness of 15 kN/mm. Enter **15** for the **Bearing Springs on Top of each Pier** for the right-hand end of the deck.

- Enter **53** for the **Span Length** of Deck 2.

- Enter **1** for the **Geometric Assignment** for the span of the deck. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. This ID will match a material definition in the **Material Properties** worksheet covered later.

- Enter **1** for the **Ballast Type**. This ID will match a ballast definition in the **Interaction and Expansion Joint** worksheet covered later.

This completes the structure definition for Deck 2 of the structure. The structural / bearing / support configurations are identical for Deck 3 to Deck 5 so the same procedure is followed for the definition of the next three decks of the structure. Once completed the worksheet input for the first five decks should appear as illustrated in the following two images.

		Spring Support for each Abutment /Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign.	Bearing Springs on Top of each Pier	Bearing Offset from End of Deck	Span Length	Geo. Assign.	Mat. Assign.	Ballast Type		
		Structure Definition			Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m								
29	Deck 3	Span 3												
30		Span 4												
31		Span 5												
32		Span 6												
33		Span 7												
34		Span 8												
35		Span 9												
36		Number of Supports for the Deck / Length	2				2		53					
37	Deck 4	Left End	15000				15							
38		Span 1	15000				15		53	1	1	1		
39		Span 2												
40		Span 3												
41		Span 4												
42		Span 5												
43		Span 6												
44		Span 7												
45		Span 8												
46		Span 9												
47		Number of Supports for the Deck / Length	2				2		53					
48	Deck 5	Left End	15000				15							
49		Span 1	15000				15		53	1	1	1		
50		Span 2												
51		Span 3												
52		Span 4												
53		Span 5												
54		Span 6												
55		Span 7												
56		Span 8												
57		Span 9												
58		Number of Supports for the Deck / Length	2				2		53					

Decks, Tracks and Embankment   **Structure Definition**   Geometric Properties ... ⊕

Deck 6 differs from all of the other decks in the structure in both length and its support conditions. The 120 m long deck is restrained longitudinally at its left-hand end and is supported by a roller bearing at its right-hand end. At this roller bearing an additional friction force of 1350 kN also acts to the left (this friction force cannot be included in the structural definition worksheet but it will be incorporated into the model in *Adding the Longitudinal Friction Load for Deck 6*).

- For the left-hand end of Deck 6, enter **15000** for the **Spring Support for each Abutment/Pier** to match the data entered for the right-hand end of Deck 5.

- The bearing for the left-hand end of Deck 6 is restrained so enter **R** for the **Bearing Springs on Top of each Pier** for the left-hand end of the deck.

- The pier has a longitudinal stiffness of 15000 kN/mm. Enter **15000** for the **Spring Support for each Abutment/Pier** for the pier located at the right-end of Deck 6.

- The bearing for the right-hand end of Deck 6 is a roller bearing so enter **F** for the **Bearing Springs on Top of each Pier** for the right-hand end of the deck.

- Enter **120** for the **Span Length** of Deck 6.

- Enter **2** for the **Geometric Assignment** for the span of the deck which will have different properties to the other decks of the structure. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. This ID will match a material definition in the **Material Properties** worksheet covered later.

- Enter **1** for the **Ballast Type**. This ID will match a ballast definition in the **Interaction and Expansion Joint** worksheet covered later.

The final deck, Deck 7, matches the first five decks in its construction and bearings. The deck is supported by the final pier and the right-hand abutment.

- The pier has a longitudinal stiffness of 15000 kN/mm. Enter **15000** for the **Spring Support for each Abutment/Pier** for the pier located at the left-hand end of Deck 7.

- The bearing on the top of the pier has a longitudinal stiffness of 15 kN/mm. Enter **15** for the **Bearing Springs on Top of each Pier** for the left-hand end of the deck.

- The right-hand abutment is fully restrained. Enter **R** for the **Spring Support for each Abutment/Pier** for the right-hand end of Deck 7.

- The bearing on the top of the pier has a longitudinal stiffness of 15 kN/mm. Enter **15** for the **Bearing Springs on Top of each Pier** for the right-hand end of Deck 7.

- Enter **53** for the **Span Length** of Deck 7.

- Enter **1** for the **Geometric Assignment** for the span of the deck. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. This ID will match a material definition in the **Material Properties** worksheet covered later.

- Enter **1** for the **Ballast Type**. This ID will match a ballast definition in the **Interaction and Expansion Joint** worksheet covered later.

The final two decks in the worksheet (Deck 6 and 7) should look like this:

This completes the definition of the structure.

Defining the Geometric Properties for the Structure

✏️ **Note.** The original software / analyses in the publication only appeared to consider axial / longitudinal effects in the structure with no bending considered within the decks or the track since the area of the deck section was the only geometric property used in the analysis. This limitation has been replicated in this example by using large second moments of area for both the decks and the track with the key input only relating to the axial behaviour of the decks and track.

- Pick the **Geometric Properties** worksheet.

The first line of data should always be called **Rail** and contains the geometric properties for the rail track. All other lines define the geometric properties for the unique IDs used in the **Structure Definition** worksheet.

The track is formed of two UIC 60 rails and for this example. Axial properties were only provided by the original publication, therefore higher values will be entered for the second moments of area and torsional constant. Enter the following values for the rail track:

- Enter **0.015372** for the area (**A**) in m^2 of the two rails of the track.

- Enter **1** for the second moment of inertia about the horizontal y-axis (**Iyy**) in m^4.

- Enter **1** for the second moment of inertia about the vertical z-axis (**Izz**) in m^4.

- Enter **1** for the torsional constant (**J**) in m^4.

- Enter **15.372** for the shear area for the y-direction (**Asy**) in m^2. The shear deformations have been ignored by setting the shear area to 1000*A in accordance with the *Element Reference Manual*. The shear deformations have been removed from the calculation since the original study potentially uses simple code.

- Enter **15.372** for the shear area for the z-direction (**Asz**) in m^2.

- Enter **0** for the **Eccentricity** in the rail in m.

- Enter **2xUIC60 rails** in the **Description** for the rails.

The deck geometric properties are now defined in the **Geometric Properties** worksheet. As for the track rails, only axial properties were supplied in the original publication therefore higher values will be entered for the second moments of area and torsional constant. Within the structure there are two deck construction types that need to be defined, one for Decks 1 to 5 and Deck 7 (this was identified as ID = 1 in the **Structural Definition** worksheet) plus a separate definition for Deck 6 (this was identified as ID = 2 in the **Structural Definition** worksheet).

The geometric properties for Decks 1 to 5 and Deck 7 are defined first. Enter the following values for the deck:

- Enter **1** for the ID in the first column to match the geometric assignment ID for Decks 1 to 5 and Deck 7 in the **Structure Definition** worksheet.

- Enter **0.1** for the **Depth of Section** in m.

- Select **Concrete Deck** from the Component Type list. The deck is constructed from concrete and this type will be used later in the **Loading** worksheet to apply the temperature loadings to the model.

- Enter **26** for the area (**A**) in m^2.

- Enter **1.0E+6** for the second moment of inertia about the horizontal y-axis (**Iyy**) in m^4.

- Enter **1.0E+6** for the second moment of inertia about the vertical z-axis (**Izz**) in m^4.

- Enter **1.0E+6** for the torsional constant (**J**) in m^4.

- Enter **26000** for the shear area for the y-direction (**Asy**) in m^2. The shear deformations have been ignored by setting the shear area to 1000*A in accordance with the *Element Reference Manual*. The shear deformations have been removed from the calculation since the original study potentially uses simple code.

- Enter **26000** for the shear area for the z-direction (**Asz**) in m^2.

- Enter **0** for the **Eccentricity** in the deck in m.

- Enter **Decks (spans) 1-5,7** in the **Description** for the deck.

The geometric properties for Deck 6 are now defined in the **Geometric Properties** worksheet. Enter the following values for the deck:

- Enter **2** for the ID in the first column to match the geometric assignment ID for the piers in the **Structure Definition** worksheet.

- Enter **0.1** for the **Depth of Section** in m.

- Select **Concrete Deck** from the Component Type list. The deck is constructed from concrete and this type will be used later in the **Loading** worksheet to apply the temperature loadings to the model.

- Enter **10.13** for the area (**A**) in m^2.

- Enter **1.0E+6** for the second moment of inertia about the horizontal y-axis (**Iyy**) in m^4.

- Enter **1.0E+6** for the second moment of inertia about the vertical z-axis (**Izz**) in m^4.

- Enter **1.0E+6** for the torsional constant (**J**) in m^4.

- Enter **10130** for the shear area for the y-direction (**Asy**) in m^2 to exclude shear deformations in accordance with the *Element Reference Manual*.

- Enter **10130** for the shear area for the z-direction (**Asz**) in m^2 to exclude shear deformations in accordance with the *Element Reference Manual*.

- Enter **0** for the **Eccentricity** in the deck in m.

- Enter **Deck (span) 6** in the **Description** for the deck.

Defining the Material Properties for the Structure

- Pick the **Material Properties** worksheet.

The first line of data should always be called **Rail** and contains the material properties for the rail track. All other lines define the material properties for the unique IDs used in the **Structure Definition** worksheet.

Enter the following values for the rail:

- Enter **210000** for the Young's modulus (**E**) in N/mm^2 which is equivalent to a value of 210 GPa.

- Enter **0.3** for the Poisson's ratio (**ν**).

- Enter **0** for the mass density (**ρ**). Setting this to the representative value allows the self-weight deflections to be calculated for the structure and track system if they are required but it is not used for the track-structure interaction analysis.

- Enter **1.20E-5** for the coefficient of thermal expansion (**α**).

- Enter **2xUIC60 rails** in the **Description** for the rails.

Enter the following values for the decks:

- Enter **1** for the ID in the first column to match the material assignment ID for the deck in the **Structure Definition** worksheet.

- Enter **34750** for the Young's modulus (**E**) in N/mm^2.

- Enter **0.2** for the Poisson's ratio (**ν**).

- Enter **0** for the mass density (**ρ**).

- Enter **1.2E-5** for the coefficient of thermal expansion (α).

- Enter **Concrete Decks** in the **Description** for the material properties.

Defining the Track-Structure Interaction and Expansion Joint Properties for the Structure

- Pick the **Interaction and Expansion Joint** worksheet.

- Enter **0** for the eccentricity between the rail and slab.

- Enter **0.5** for the Parametric Distance of Interaction Joint from Rail. For the modelling of the eccentricity between the rail and the slab this will place the interaction joints halfway between the track and slab – there is no eccentricity but this field should generally not be blank.

In the publication there is no change in bilinear spring characteristics between unloaded and loaded ballast, therefore in the modelling the properties for both conditions will be identical.

Enter the following values for the longitudinal bilinear spring characteristics for **Ballast Type ID 1** – (Only ballast type ID 1 has been assigned in the **Decks, Tracks and Embankment** and the **Structure Definition** worksheets):

- Enter **10** for the **Unloaded Elastic Spring Stiffness** in the longitudinal direction in kN/m/mm.

- Enter **20** for the **Unloaded Yield Force** in the longitudinal direction in kN/m.

- Enter **1.0E-6** for the **Unloaded Hardening Stiffness** in the longitudinal direction in kN/m/mm. Zero cannot be entered but a very small hardening stiffness will maintain the force in the interaction joints at the unloaded yield force.

- Enter **10** for the **Loaded Elastic Spring Stiffness** in the longitudinal direction in kN/m/mm.

- Enter **20** for the **Loaded Yield Force** in the longitudinal direction in kN/m.

- Enter **1.0E-6** for the **Loaded Hardening Stiffness** in the longitudinal direction in kN/m/mm. Again, zero cannot be entered but a very small hardening stiffness will maintain the force in the interaction joints at the loaded yield force.

Note. The interaction springs are modelled using nonlinear joints with elastic-perfectly plastic behaviour in the longitudinal direction. This is achieved using the elasto-plastic uniform tension and compression material where the hardening stiffness should always be set to a very small value to avoid numerical instabilities.

Defining the Trainset Loading for the Structure

The analysis includes the effects of a 400m braking TGV train positioned from midway across Deck 4 which extends onto the right-hand embankment. This trainset configuration will be defined in a Train Loading Group within the **Loading** worksheet. The temperature loading to the tracks and decks is also defined within the **Loading** worksheet.

- Pick the **Loading** worksheet.

The temperature loading will be defined first. Enter the following values for the temperature loading:

- Enter **30** for the **Temperature** variation of the **Concrete Deck** in °C.

- Enter **40** for the **Temperature** variation of the **Rails** in °C.

The braking TGV train loading will now be defined.

- Enter **3** for the **Number of Train Loading Groups to Analyse** in the train loads section of the worksheet.

Enter the following values for Train Loading Group 1:

- Enter **1** for the **Number of Track Loading Locations** for the passage of the SW/0 trainset from the left-hand abutment to the right-hand abutment. This is a low value for example purposes and a true analysis would require more locations to fully describe the passage of the trainset loading across the structure.

- Enter **Braking TGV** for the **Loading Type** in the first row of loading. The type of loading is defined by the first character of the description, thus allowing more detailed descriptions for more complex loading configurations.

- Enter **1** in the **Track Selection to be Loaded** since we are applying the braking TGV to a first track of the structure.

- Enter **0** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the left UDL vertical loading.

- Enter **400** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the left UDL vertical loading.

- Enter **8** for the **Amount (per unit length)** to apply 8kN/m horizontally to the right for the braking TGV travelling from left to right.

- Enter **485.5** for the **Starting Location of Loading for First Analysis** to place the back of the braking TGV at the mid-span of Deck 4 (locations are defined from the left-hand extent of the model including the embankment).

- Enter **485.5** for the **Finishing Location of Loading for Last Analysis** to place the trainset again at the mid-span of Deck 4 because we are analysing a single trainset position.

This completes the definition for the braking TGV loading.

This completes the definition of the Microsoft Excel spreadsheet input for the main definition of the track-structure-interaction problem. The additional friction force at the roller bearing of Deck 6 still needs to be defined in the analysis but this will be added as a customisation to the temperature only analysis once this has been defined by the Rail Track Analysis software.

- **Save** the spreadsheet and close the Microsoft Excel application.

Modelling / Running an Analysis

All of the model construction and analysis is automatically performed by the Rail Track Analysis software option but, to do so, a blank LUSAS model must be initially created or a suitable existing LUSAS model (that was created by the Rail Track Analysis option) must be opened.

Running LUSAS Modeller

For details of how to run LUSAS Modeller, see the heading ***Running LUSAS Modeller*** in the *Introduction to LUSAS Worked Examples* document.

Creating the Temperature Only Model for Full CWR

An initial temperature-only analysis can form the basis for carrying out more than one track-structure interaction analysis with different trainset loading configurations in different input spreadsheets (see the *Rail Track-Structure Interaction to UIC774-3* worked example). The other main advantage of an initial temperature-only analysis is that it allows the application of additional loading to the model or customisation of the model (the addition of extra structural members to the decks such as a Warren truss) over and above the modelling available from the input Microsoft Excel spreadsheet. This additional loading capability will be used here to incorporate the additional longitudinal load from friction that acts at the location of the roller bearing for Deck 6 once the temperature-only model has been built.
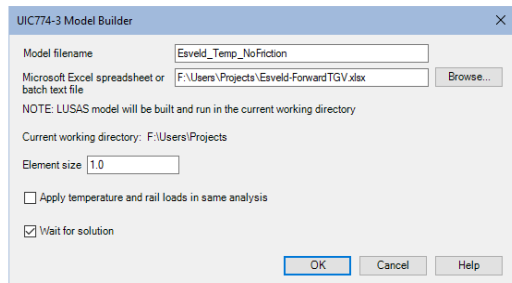
File
New…

- Enter **RTA_BlankModel** for the model name.

- Select an analysis category of **3D** and click **OK**.

This model is created solely to allow the Rail Track Analysis option to be selected. It is not used after the option has been run.

Bridge
Rail Track Analysis >
Build UIC774-3
Model…

- Enter a model filename of **Esveld_Temp_NoFriction**

- Enter the filename of the Microsoft Excel spreadsheet you created which contains the definition of the track-structure-interaction model and the loading to be applied in the Rail Track Analysis (e.g. **Esveld-ForwardTGV.xlsx**) or browse for it using the **Browse...** button in the Microsoft Excel spreadsheet. If the full folder information is not entered it will be assumed that the Microsoft Excel spreadsheet is in the current working folder which is reported in the dialog.

- If wanting to build the model from a supplied spreadsheet, select the file **Esveld-ForwardTGV.xlsx** that was downloaded and copid to a folder of your choosing.

- Ensure an Element size of **1** is specified which will create elements of a maximum length of 1m in the LUSAS model.

- Ensure that the **Apply temperature and rail loads in same analysis** option is <u>not</u> selected to create the temperature only model.

- Ensure the **Wait for solution option** is selected and click the **OK** button.
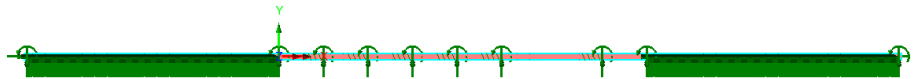

Assuming that there have been no errors in the input for the Microsoft Excel spreadsheet the Rail Track Analysis software option will automatically generate a LUSAS model similar to the one above from the spreadsheet data and run a rail track analysis for the temperature loading alone.

If the Rail Track Analysis software option detected errors with modelling data these will be reported and must be corrected prior to re-running the Rail Track Analysis option.

Adding the Longitudinal Friction Load for Deck 6

The effect of friction at the roller bearing for Deck 6 (1350 kN longitudinal force) must be added to the temperature-only model because it could not be included within the original input Microsoft Excel spreadsheet.

The model created by the Rail Track tool contains several groups that were defined when the model was built. One of these groups is the Deck 6 group which includes all of the features used for the modelling of the deck in the analysis. This group will be used to assign the friction load to the correct location in the model.
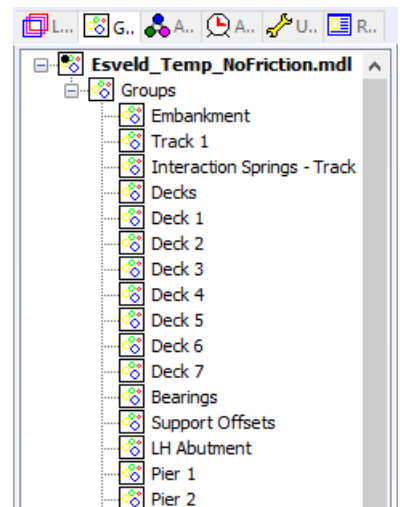
- In the ⬚ Treeview, right-click on the **Deck 6** group and **Set as Only Visible**

- In the ⬚ Treeview, right-click on the **Deformed Mesh** and turn off **Display**. Also right-click on the **Attributes** layer and turn off **Display**. This will make the model easier to view.

- Zoom into the right-hand end of the deck as indicated in the image below

The zoomed display should have resulted in the model displaying the right-hand end of Deck 6 in a similar manner to the image below if the zooming was successful. If the view of the model does not look similar to the image below then zoom out with the ⬚ button and retry.

The friction force is defined using a concentrated load which will be applied at the location of the roller bearing.

Attributes
  Loading…   >

- Select the **Concentrated** option and click **Next**

- Enter **-1350E3** (in N) for the **Concentrated load in X Dir** as the 1350 kN friction force acts to the left.

- Enter the attribute name as **Load due to Friction at Roller of Deck 6** .

- Click the **Finish** button to define the loading attribute.

| Concentrated | × |
| Analysis category | 3D |

Component	Value
Concentrated load in X Dir	-1350E3
Concentrated load in Y Dir	
Concentrated load in Z Dir	
Moment about X axis	
Moment about Y axis	
Moment about Z axis	

Name Load due to Friction at Roller of Deck 6   (new)

< Back   Next >   Finish   Cancel   Apply   Help

Select this point

- Select the point indicated in the image above – this is the top of the roller bearing at the right-hand end of Deck 6.

- Assign the **Load due to Friction at Roller of Deck 6** concentrated load to the selected point.

Note. No loading will be displayed since the displaying of the attributes layer was disabled earlier in the example.

- Click on the [icon] to display the loading which will update the view and display the newly assigned friction load (and the temperature loading) as shown in the image below.

The temperature only model complete with the friction load at the roller bearing is now complete. All that needs to be done now is to return the visibility of the model back to its original settings and save the model under a different filename to ensure that we preserve the original model that was built with the input Microsoft Excel spreadsheet.

- Deselect the point by clicking on a blank part of the display.

- In the [icon] Treeview, right-click on the **Deformed Mesh** layer and turn on **Display**.

- In the main display view, right-click on the screen and choose **All Visible** .

- Zoom out to view the whole model by clicking the [icon] button.
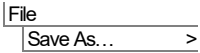
File
| Save As… | > |

- Save the model as a different filename, selecting **Yes** to continue when informed that all results files will be closed.

- Enter the filename as **Esveld_Temp_WithFriction** .

The temperature only model with friction loads can now be solved, click the ▤ button and click **OK** to run the analysis.

If errors were detected...

If errors were detected with the modelling data, or the post-processing in the next section gives different results, the values in the spreadsheet should be corrected before re-selecting the previous Rail Track Analysis menu item. If it proves impossible for you to correct the errors reported a populated spreadsheet file is provided to enable you to create the model and run an analysis successfully.

❑ **Esveld-ForwardTGV.xlsx (.xls)** is a populated spreadsheet containing all input data for the example.

A spreadsheet compatible for an installed version of version of Microsoft Excel should be copied to the working project folder where the track-structure interaction example model is to be created, and the **Adding the Longitudinal Friction Load for Deck 6** process repeated.

Viewing the Results

When the results are loaded after carrying out the Rail Track Analysis the 🔍 Treeview will be populated with just the results for the temperature only condition for the CWR track since no train loading has been applied to the track-structure-interaction model yet.

Automatic Extraction of Results into Microsoft Excel

The Rail Track Analysis option provides a post-processing tool that automatically extracts the results of all of the analyses (all positions of all Train Loading Groups when train loading has also been defined) into tabular form in Microsoft Excel and generates commonly required graphs and tables of quantities that can be compared against prescribed limits for the track-structure interaction.

Bridge
Rail Track Analysis >
Extract Results to
Excel…

- Enter **Esveld_Temp_WithFriction-PP** for the **Filename**. Note that no *.xlsx or *.xls extension is required.

- Ensure the **Working folder** is set to **Current** to place the post-processing Microsoft Excel spreadsheet into the same folder as the analyses.

- Ensure the **Output Control** is reporting that "**All tracks : All Train Loading Groups : All track length**" are included in the model extent.

For a new model being post-processed for the first time this should always be the case. If previous selective post-processing has been carried out on the model and the model saved that choice will have been stored for use again by the post-processor. The included model extent must be updated by clicking the **Modify** button and revising the selection. Clicking the **Defaults** button in the **Modify Included Output** dialog will return the included model extent to "All tracks : All Train Loading Groups : All track length" if needed.

- Ensure the **Output Control** is reporting that the **Generate charts in Microsoft Excel** option is selected.

If previous customised post-processing has been carried out on the model and the model saved the choice of charts created may have been changed from the defaults and will have been stored for use again by the post-processor. The choice of charts created must be updated by clicking the **Options** button and the included charts revised. Clicking the **Defaults** button in the **Chart Options** dialog will return the chart options to the defaults.

Prior to clicking the **OK** button, please note the following cautions:

Caution. You should not have any other Microsoft Excel windows open while the post-processing is carried out. Starting Microsoft Excel or opening another Microsoft Excel spreadsheet while the post-processing is running will break the connection between Modeller and Microsoft Excel resulting in an error and termination of the post-processing.

Caution. Do not carry out any Copy or Paste actions <u>in any application</u> whilst results are being extracted during the post-processing process as this could lead to incorrect extraction and processing of the results by Microsoft Excel.

- Click the **OK** button.

The automatic Rail Track Analysis post-processor will now extract the results from the loaded results and generate the Microsoft Excel spreadsheet in the working folder.

- Open the spreadsheet **Esveld_Temp_WithFriction-PP** in Microsoft Excel.

Since the analysis was only conducted for the temperature only condition of the track-structure-interaction model the spreadsheet will only contain three worksheets.

The worksheets created are titled:

- ❑ **Track 1**
- ❑ **Track 2**
- ❑ **Decks**

The two tracks have construction symmetry therefore only one track needs to be inspected.

- Select the **Track 1** worksheet in the Microsoft Excel spreadsheet it is not already active.
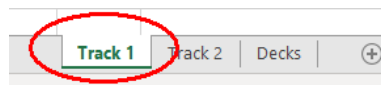
From the **Track 1** worksheet the chart for the longitudinal relative railbed / track / deck displacement indicated in the following image can be obtained.
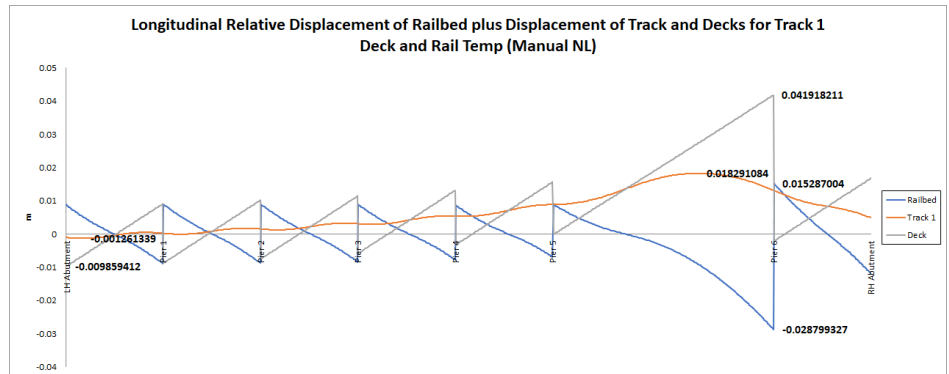
This indicates that the longitudinal displacement of the track has a maximum of 0.0183m or 18.3mm which agrees with the published value of 18.4mm. The relative railbed displacement indicates a maximum of -0.0288m or 28.8mm which again agrees with the published value of 28.6mm. The displacements of the decks themselves are not given in the Esveld publication but comparison of the results across the structure indicates that there is good agreement between the model and the publication.

The post-processing also generates a chart of the axial rail stress in the track which is shown in the following figure. From this peak of 153.31 MPa the peak axial force in the rails of $\sigma \times A_{track} = 153.31E3 \times 0.015372 = 2356.7$ kN which compares well with the published figure of 2300 kN.
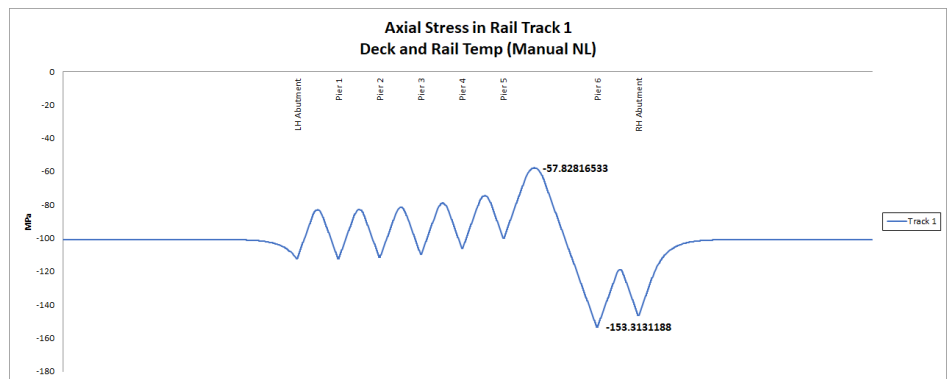
The final checks on the structure modelling with CWR track against the published results are for the bridge forces.

- Select the **Decks** worksheet in the Microsoft Excel spreadsheet.
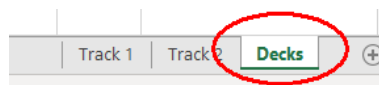
From the **Decks** worksheet the chart for the deck axial force in the following image can be obtained. This chart indicates that the maximum axial force is 4305.6 kN in Deck 6 which compares well with the published figure of 4320 kN with all of the remaining decks showing similarly close results (although no numerical values are provided in the publication).
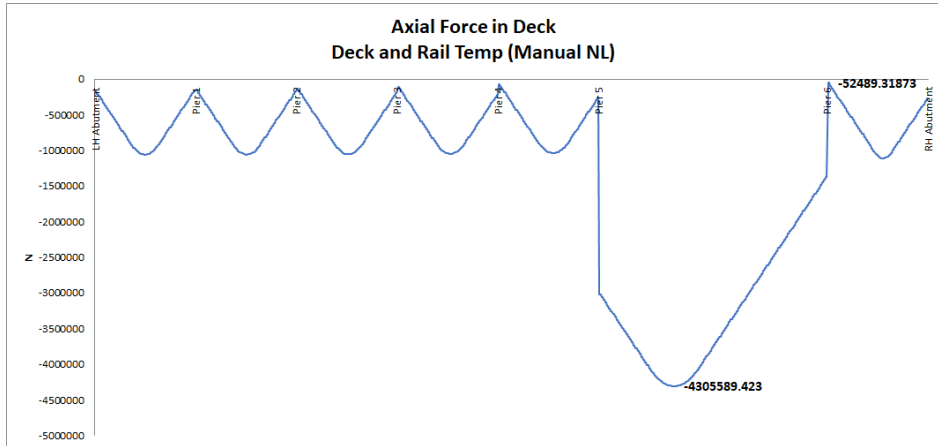
From the comparison the behaviour of the temperature only CWR model the LUSAS model considering longitudinal effects only is behaving very similarly to the original PROLIS20 software of Delft University of Technology which was used for the published study from 1995.

- Close the **Esveld_Temp_WithFriction-PP** spreadsheet and the Microsoft Excel application.

Application of Braking TGV to Full CWR Temperature Model

The previous analysis and post-processing considered only the effects of temperature loading on the track-structure-interaction for the full CWR model (as was considered in the Esveld publication). For completeness and prior to the consideration of the consequence of the introduction of Zero Longitudinal Resistance (ZLR) track the effect of the braking TGV train on the CWR model will be analysed to allow a comparison of the results to be carried out later in the example.

Bridge
  Rail Track Analysis >
    Apply Rail
    Loads…

- Select the **Apply train loads to current model** option as we have just performed the temperature only analysis and will apply the braking TGV train directly to this model.

- Enter **Esveld_TempAndTGV** as the **Rail load model filename**.

UIC774-3 Apply Rail Loads

☑ Apply train loads to current model

Original model filename

Rail load model filename   Esveld_TempAndTGV

Rail load Microsoft Excel   F:\Users\Projects\Esveld-ForwardTGV.xlsx   Browse...
spreadsheet or batch text file

☑ Wait for solution

OK   Cancel   Help

- Enter the **Esveld-ForwardTGV.xlsx** (or Esveld-Forward.xls) filename of the Microsoft Excel spreadsheet created for the analysis or browse for it using the **Browse...** button in the **Microsoft Excel spreadsheet or batch text file** input. If the full folder information is not entered it will be assumed that the Microsoft Excel spreadsheet is in the current working folder.

- If wanting to apply train loads from a supplied spreadsheet, select the file **Esveld-Forward.xlsx** that was downloaded and copied to a folder of your choosing.

- Ensure the **Wait for solution** option is selected.

- Click the **OK** button and choose **No** to saving the changes to the current model as no manual changes have been made.
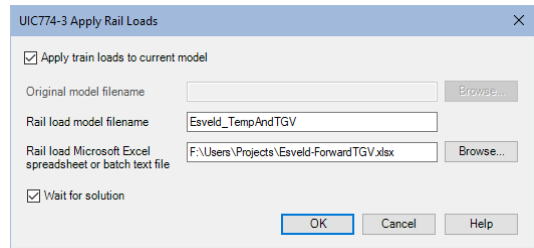
Assuming that there have been no errors in the trainset loading input for the Microsoft Excel spreadsheet the Rail Track Analysis software option will now automatically generate a LUSAS model with a single analysis for the braking TGV position being considered.

Post-Processing of the Braking TGV for the Full CWR

When the results are loaded after carrying out the Rail Track Analysis the 🔍 Treeview will be populated with the results for both the temperature only condition and the combined temperature and braking TGV for the CWR track. The automatic post-processing tool within the Rail Track Analysis option will again be used to quickly extract the key results from the track-structure-interaction analysis.

- Enter **Esveld_TempAndTGV-PP** for the **Filename**. Note that no *.xlsx or *.xls extension is required.

- Ensure the **Working folder** is set to **Current** to place the post-processing Microsoft Excel spreadsheet into the same folder as the analyses.

- Ensure the **Output Control** is reporting that "**All tracks : All Train Loading Groups : All track length**" are included in the model extent.

- Ensure the **Output Control** is reporting that the **Generate charts in Microsoft Excel** option is selected.

- Click the **OK** button.

The automatic Rail Track Analysis post-processor will again extract the results from the loaded results and generate the Microsoft Excel spreadsheet in the working folder.

- Open the spreadsheet **Esveld_TempAndTGV-PP** in Microsoft Excel.

The analysis was only conducted for the temperature condition combined with a single position for the braking TGV in the track-structure-interaction model so the spreadsheet will only contain the three worksheets for the tracks and decks again. From the **Track 1** worksheet the chart for the longitudinal relative railbed / track / deck displacement indicated in the following image can be obtained for the braking TGV condition.
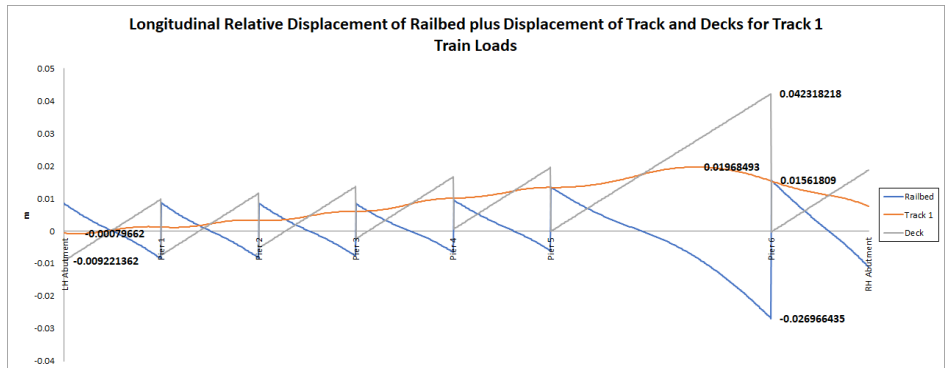
This indicates that the longitudinal displacement of the track has a maximum value of 0.0197m or 19.7mm. The relative railbed displacement indicates a maximum value of -0.0270m or 27.0mm.

The post-processing also generates a chart of the axial rail stress in the track which is shown in the following figure. From this peak of 145.83 MPa the peak axial force in the rails of $\sigma \times A_{track} = 145.83\text{E}3 \times 0.015372 = 2241.7$ kN.
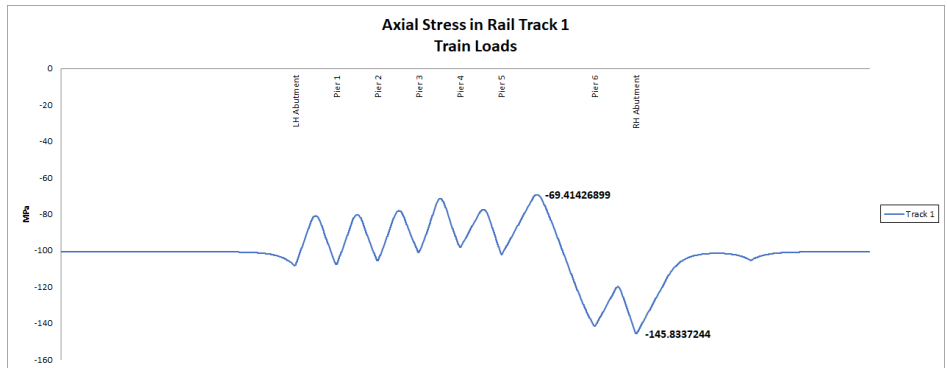
The final quantity that was investigated in the Esveld publication was the force in the deck of the structure. From the **Decks** worksheet the chart for the deck axial force in the following image can be obtained. This chart indicates that the maximum axial force is 3154.8 kN in Deck 6.
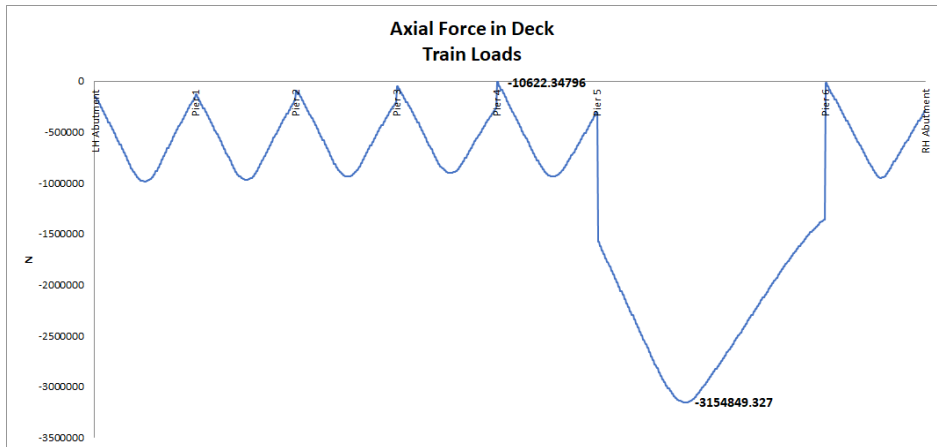
These results for the braking TGV will be used to compare the behaviour of the structure with full CWR and the structure with the introduction of the ZLR which is modelled in the following section.

- Close the **Esveld_TempAndTGV-PP** spreadsheet and the Microsoft Excel application.

Creating a Zero Longitudinal Resistance Model

A track-structure-interaction analysis once it has been built using the Rail Track Analysis software can be modified to include one or more zones of Zero Longitudinal Resistance (ZLR) and / or Reduced Longitudinal Resistance (RLR). The structure representing the bridge across the River Scheldt will be reanalysed with the introduction of 75m of ZLR installed from the right-hand end of Deck 6 along approximately two thirds of its length as illustrated below.
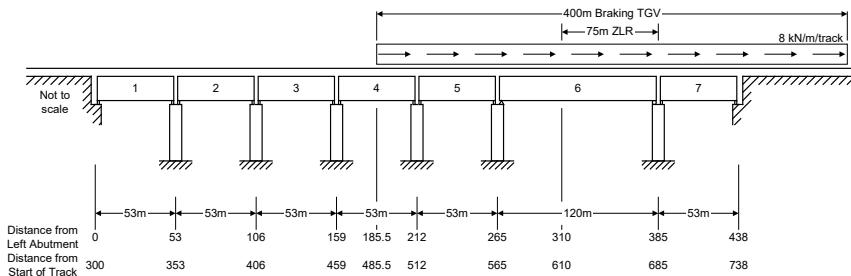
To build the ZLR model we take the full CWR model as the starting point and define the ZLR properties and regions we wish to analyse.

If the **Esveld_TempAndTGV.mdl** model is not loaded with its results,

- Select the **Esveld_TempAndTGV.mdl** model from the location where it has been saved,

- Select either **Yes** or **No** when Modeller asks if you would like to load the results, the results are not going to be used during the creation of the ZLR model.

Defining the ZLR Properties and Regions

- Select **Zero Longitudinal Resistance** as the resistance type.

- Select the **Use same definition for unloaded and loaded interaction properties** option to ensure that both the unloaded and loaded interaction properties are identical – the ZLR behaviour will be identical for temperature only and combined temperature and train loading conditions (see note below).

ZLR / RLR Properties

Select longitudinal resistance type
- ◉ Zero Longitudinal Resistance
- ○ Reduced Longitudinal Resistance
☑ Use same definition for unloaded and loaded interaction properties

	Unloaded/loaded
Elastic spring stiffness (kN/mm ...	1.0
Yield force (kN per m track)	1.0E-6
Hardening stiffness (kN/mm pe...	1.0E-6

Name ZLR   (new)

Defaults   OK   Cancel   Apply   Help

- Ensure that the **Elastic spring stiffness** is set to **1.0** kN/mm per m track (default).

- Ensure that the **Yield force** is set to **1.0E-6** kN per m track (default).

- Ensure that the **Hardening stifness** is set to **1.0E-6** kN/mm per m track (default).

- Enter the attribute name as **ZLR** .

- Click **OK** to define the ZLR property in the 🔧Treeview.

Note. ZLR can provide some longitudinal resistance to braking/traction forces applied to the rails of the tracks. If resistance is to be modelled under the loaded condition the **Use same definition for unloaded and loaded interaction properties** option can be turned off and appropriate values entered for the loaded condition.
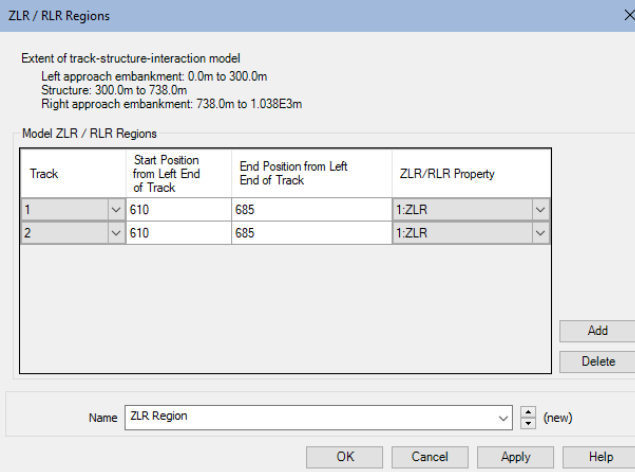
From the illustration above, the end of the region of ZLR is at the right-hand end of the 120m Deck 6 which is after five decks that are all 53m in span. The left-hand approach embankment for the model was taken as 300m. The right-hand end of the region of ZLR is therefore

$$300 + 5 \times 53 + 120 = 685\text{m from the left-hand end of the model}$$

and, given that the region is 75m in length, the left-hand end of the region of ZLR is therefore 610m from the left-hand end of the model. The ZLR will be applied to both tracks over the region.

Bridge
  Rail Track Analysis >
    Define ZLR/RLR
    Regions…

ZLR / RLR Regions   ✕

Extent of track-structure-interaction model
  Left approach embankment: 0.0m to 300.0m
  Structure: 300.0m to 738.0m
  Right approach embankment: 738.0m to 1.038E3m

Model ZLR / RLR Regions

Track	Start Position from Left End of Track	End Position from Left End of Track	ZLR/RLR Property
1	610	685	1:ZLR
2	610	685	1:ZLR

Add

Delete

Name   ZLR Region   (new)

OK   Cancel   Apply   Help

- Click **Add** to add a new row to the region definition.

- Select the **Track** as **1**, enter the **Start Position from Left End of Track** as **610**, enter the **End Position from Left End of Track** as **685** and select the **ZLR/RLR Property** as **ZLR** .

- Click **Add** to add a new row to the region definition.

- Select the **Track** as **2**, enter the **Start Position from Left End of Track** as **610**, enter the **End Position from Left End of Track** as **685** and select the **ZLR/RLR Property** as **ZLR** .

- Enter the attribute name as **ZLR Region** .

- Click **OK** to define the ZLR region in the Treeview.
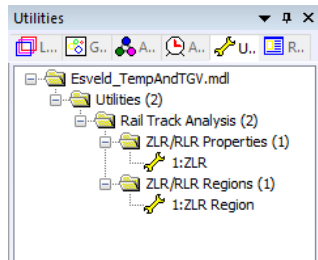
Once the ZLR property and region have been defined in the model they will both be visible in the ✏Treeview as shown in the image above. If more than one property and/or region was defined then these would all be listed in the treeview. The ZLR has not been set active within the model yet and therefore if the model was solved it would still behave as just a CWR track.

- Right-click on the **ZLR Region** attribute in the ZLR/RLR Regions and select **Set Active** .
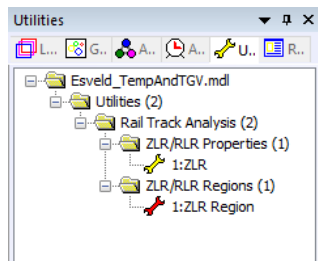
rail loading model for this example.

File
Save As…

- If results were loaded on top of the model, select **Yes** to continue when informed that "All results files will be closed"

- Enter **EsveldZLR_TempAndTGV** for the model name.

The modified model with the ZLR can not be solved. Click the button and click OK to run the analysis.

Viewing the Zero Longitudinal Resistance Model Results

When the results are loaded after carrying out the Rail Track Analysis the ⌕ Treeview will be populated with the results for both the temperature only condition and the condition where the braking TGV trainset is applied to the structure. These two conditions will be considered separately in the following sections.

Behaviour under Temperature Only Conditions

The automatic post-processing tool is used to easily and quickly extract all the results and charts from the temperature only condition into Microsoft Excel.

Bridge
  Rail Track Analysis >
    Extract Results to
    Excel…

- Enter **EsveldZLR_TempAndTGV-PP** for the **Filename**. Note that no *.xlsx or *.xls extension is required.

- Ensure the **Working folder** is set to **Current** to place the post-processing Microsoft Excel spreadsheet into the same folder as the analyses.

- Ensure the **Output Control** is reporting that "**All tracks : All Train Loading Groups : All track length**" are included in the model extent.

- Ensure the **Output Control** is reporting that the **Generate charts in Microsoft Excel** option is selected.

- Click the **OK** button.

The automatic Rail Track Analysis post-processor will again extract the results from the loaded results and generate the Microsoft Excel spreadsheet in the working folder.

- Open the spreadsheet **EsveldZLR_TempAndTGV-PP** in Microsoft Excel.

The Microsoft Excel spreadsheet that is created by the post-processing will include the three results worksheets as before ("Track 1", "Track 2" and "Decks") along with an additional summary worksheet "ZLR-RLR Summary" due to the inclusion of the ZLR modelling within the analysis. This summary sheet, shown below, ensures that the ZLR/RLR definitions always accompany the Railtrack Analysis results if the Microsoft Excel spreadsheet is passed one without knowledge of the accompanying Finite Element model.

The ZLR/RLR summary contains both the definitions of the region and the properties that were defined for the model. For a more complex configuration the summary would include all other property definitions that were used in the definition of the active ZLR/RLR region of the analysis that had been post-processed.

Note. Within the region definition it notes that there may be some minor differences between the start and end positions of the ZLR/RLR zones that have been defined within the region definition once the finite element mesh discretisation for the track-structure-interaction joint modelling has been created. This is a consequence of the selection of the element size for the overall modelling and is discussed in the Rail Track Analysis User Manual.

Utilising the knowledge that the two tracks have construction symmetry only one track needs to be inspected. From the **Track 1** worksheet the chart for the longitudinal relative railbed / track / deck displacement indicated in the following image can be obtained.
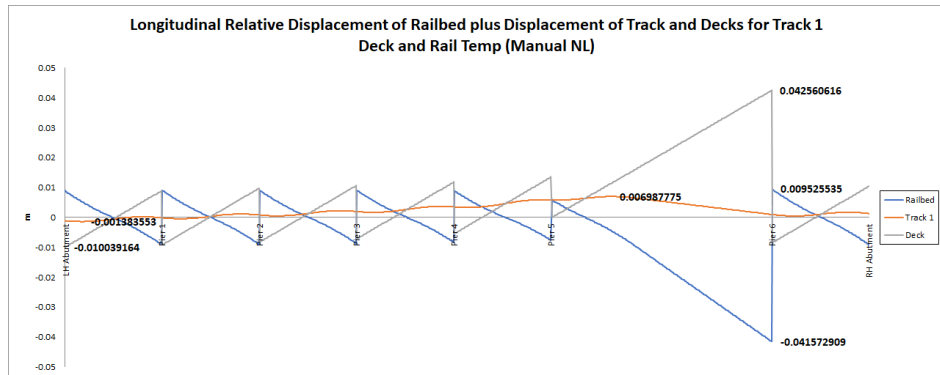
This indicates that the longitudinal displacement of the track has a maximum displacement of 0.00699m or 7.0mm under the action of temperature loading alone with the introduction of the ZLR, a reduction from the 18.3mm observed for the CWR track. This maximum longitudinal displacement of 7.0mm is in exact agreement with the published figure of 7.0mm from the Esveld publication.

The peak relative displacement of railbed predicted under the action of temperature loading alone with the introduction of the ZLR is -0.041573m or 41.6mm. This amount of relative displacement of railbed is much larger than the 28.8mm that was observed for the CWR track due to the lack of restraint caused by the introduction of the ZLR. The peak relative displacement of railbed of 41.6mm agrees with the published figure of 41.7mm from the Esveld publication.

From the **Track 1** worksheet the chart of the axial stress in the track shown in the following image can be obtained. Immediately the behaviour of the chart shows that where the region of ZLR has been placed on the structure there is a zone where the is constant axial stress in the rail track (since no longitudinal track-structure-interaction is taking place). The peak axial stress observed in the rail track has also been reduced from the introduction of the ZLR and the distribution changed. The peak axial stress of 116.27 MPa gives a peak axial force in the rails of $\sigma \times A_{track} = 116.27E3 \times 0.015372 = 1787.3$ kN which compares well with the Esveld publication.
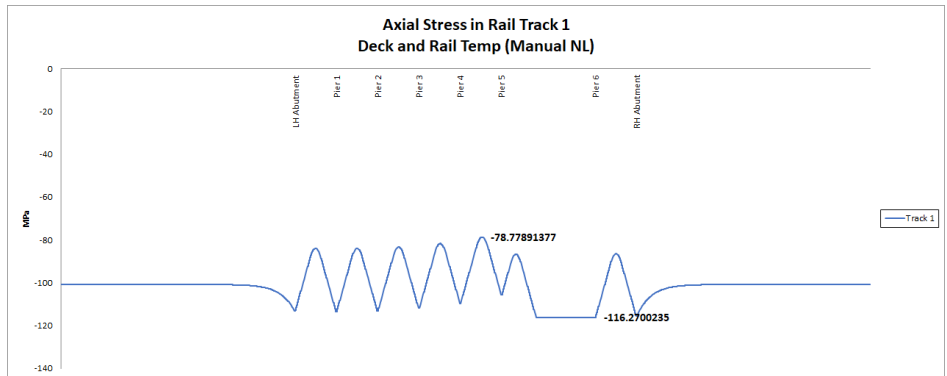
In addition to reducing the axial stress / axial force in the rail tracks the introduction of ZLR can reduce the axial forces within the decks of the structure itself. From the **Decks** worksheet the chart of the axial force in the decks shown in the following image can be obtained. Comparison of this axial force chart with the chart for the CWR track under temperature only conditions shows the presence of the zone of constant axial force within Deck 6 that corresponds to the region of ZLR which was observed previously as a zone of constant axial stress in the rail track (again because there is no longitudinal track-structure-interaction taking place along this length due to the presence of the ZLR). The peak axial force observed within the structure, which is still within Deck 6, has also reduced from 4305.6 kN to 2277.4 kN.
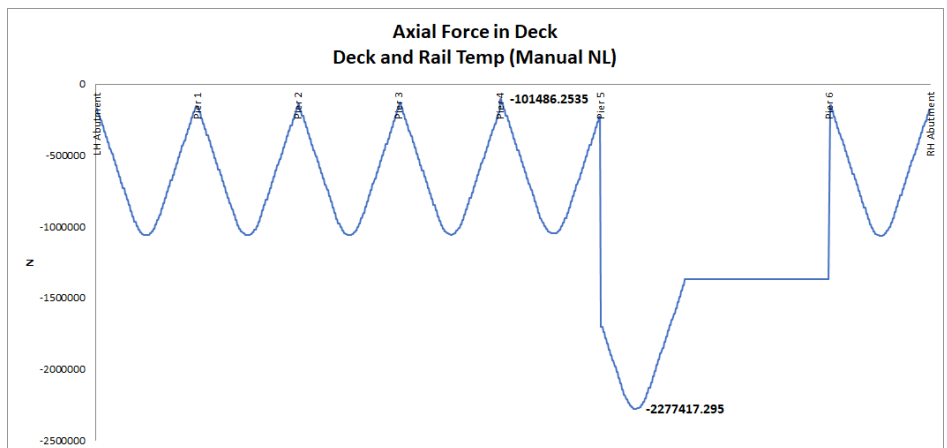
Within the post-processing the track results are output in chart and in raw numerical form. At the top of each results set this raw data is presented in the form of a summary table but below the charts the full tabular output is provided for each element/node within the analysis as indicated in the image below with separate columns for each quantity. When a ZLR/RLR analysis has been carried out the extra legend at the top of

the tabular data is included in the worksheet and the colours within the legend used to highlight cells of the rail stress column that correspond to ZLR and RLR regions.

Indicates Zero Longitudinal Resistance regions of track
Indicates Reduced Longitudinal Resistance regions of track

Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ Railbed (rad)	Rel. Disp of Railbed (m)	FX (N)	FZ (N)	My (Nm)	Rail Stress (MPa)	Element	Node
32	23		0	-300	0	0	0	0	0	0	-1549497.6	6.9018E-26	-2.441E-25	-100.8	32	23
32	27		1	-299	0	0	-6.802E-12	6.6424E-37	1.1625E-36	-6.802E-12	-1549497.6	6.9018E-26	-2.441E-25	-100.8	32	27
36	27		1	-299	0	0	-6.802E-12	6.6424E-37	1.1625E-36	-6.802E-12	-1549497.6	6.9682E-26	-1.748E-25	-100.8	36	27
36	31		2	-298	0	0	-1.362E-11	2.3267E-36	1.9948E-36	-1.362E-11	-1549497.6	6.9682E-26	-1.748E-25	-100.8	36	31
39	31		2	-298	0	0	-1.362E-11	2.3267E-36	1.9948E-36	-1.362E-11	-1549497.6	7.2009E-26	-1.039E-25	-100.8	39	31
39	34		3	-297	0	0	-2.049E-11	4.6556E-36	2.4898E-36	-2.049E-11	-1549497.6	7.2009E-26	-1.039E-25	-100.8	39	34
44	34		3	-297	0	0	-2.049E-11	4.6556E-36	2.4898E-36	-2.049E-11	-1549497.6	7.6664E-26	-2.96E-26	-100.8	44	34
44	36		4	-296	0	0	-2.742E-11	7.308E-36	2.6307E-36	-2.742E-11	-1549497.6	7.6664E-26	-2.96E-26	-100.8	44	36
47	36		4	-296	0	0	-2.742E-11	7.308E-36	2.6307E-36	-2.742E-11	-1549497.6	8.3972E-26	5.0719E-26	-100.8	47	36
47	38		5	-295	0	0	-3.443E-11	9.9189E-36	2.3892E-36	-3.443E-11	-1549497.6	8.3972E-26	5.0719E-26	-100.8	47	38
52	38		5	-295	0	0	-3.443E-11	9.9189E-36	2.3892E-36	-3.443E-11	-1549497.6	9.3891E-26	1.3965E-25	-100.8	52	38
52	41		6	-294	0	0	-4.155E-11	1.2088E-35	1.7242E-36	-4.155E-11	-1549497.6	9.3891E-26	1.3965E-25	-100.8	52	41
56	41		6	-294	0	0	-4.155E-11	1.2088E-35	1.7242E-36	-4.155E-11	-1549497.6	1.0598E-25	2.3959E-25	-100.8	56	41
56	44		7	-293	0	0	-4.88E-11	1.337E-35	5.8331E-37	-4.88E-11	-1549497.6	1.0598E-25	2.3959E-25	-100.8	56	44
60	44		7	-293	0	0	-4.88E-11	1.337E-35	5.8331E-37	-4.88E-11	-1549497.6	1.1935E-25	3.5225E-25	-100.8	60	44
60	47		8	-292	0	0	-5.62E-11	1.3258E-35	-1.094E-36	-5.62E-11	-1549497.6	1.1935E-25	3.5225E-25	-100.8	60	47
63	47		8	-292	0	0	-5.62E-11	1.3258E-35	-1.094E-36	-5.62E-11	-1549497.6	1.3261E-25	4.7823E-25	-100.8	63	47
63	51		9	-291	0	0	-6.377E-11	1.1184E-35	-3.371E-36	-6.377E-11	-1549497.6	1.3261E-25	4.7823E-25	-100.8	63	51
68	51		9	-291	0	0	-6.377E-11	1.1184E-35	-3.371E-36	-6.377E-11	-1549497.6	1.4379E-25	6.1643E-25	-100.8	68	51
68	53		10	-290	0	0	-7.155E-11	6.5183E-36	-6.307E-36	-7.155E-11	-1549497.6	1.4379E-25	6.1643E-25	-100.8	68	53
72	53		10	-290	0	0	-7.155E-11	6.5183E-36	-6.307E-36	-7.155E-11	-1549497.6	1.5031E-25	7.6348E-25	-100.8	72	53
72	58		11	-289	0	0	-7.954E-11	-1.426E-36	-9.942E-36	-7.954E-11	-1549497.6	1.5031E-25	7.6348E-25	-100.8	72	58
76	58		11	-289	0	0	-7.954E-11	-1.426E-36	-9.942E-36	-7.954E-11	-1549497.6	1.4888E-25	9.1308E-25	-100.8	76	58

Sheet tabs: ZLR-RLR Summary | Track 1 | Track 2 | Decks

For the model representing the bridge across the River Scheldt the region of ZLR was defined from 610m to 685m from the left-hand end of the model. Inspection of the tabular data in Track 1 confirms that this is indicated by the worksheet with the highlighted cells as shown in the following two images and this provides visual feedback of the resistance type associated with the results at that location within the model. The red line annotated onto the two images traces across to the column which records the distance from the left-hand end of the track. In each case this red line matches the limit of the ZLR region.

Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ Railbed (rad)	Rel. Disp of Railbed (m)	FX (N)	FZ (N)	My (Nm)	Rail Stress (MPa)	Element	Node
2758	1843		604	304	0	0	0.00686175	6.877E-09	9.3084E-11	-0.0068558	-1667300.8	-0.0003227	0.9446672	-108.46349	2758	1843
2764	1843		604	304	0	0	0.00686175	6.877E-09	9.3084E-11	-0.0068558	-1687300.8	-0.000396	0.94430786	-109.76456	2764	1843
2764	1846		605	305	0	0	0.00681906	6.9678E-09	8.8587E-11	-0.007254	-1687300.8	-0.000396	0.94430786	-109.76456	2764	1846
2768	1846		605	305	0	0	0.00681906	6.9678E-09	8.8587E-11	-0.007254	-1707300.8	-0.0005192	0.94385028	-111.06563	2768	1846
2768	1847		606	306	0	0	0.00677018	7.0541E-09	8.4093E-11	-0.0076586	-1707300.8	-0.0005192	0.94385028	-111.06563	2768	1847
2774	1847		606	306	0	0	0.00677018	7.0541E-09	8.4093E-11	-0.0076586	-1727300.8	-0.0006697	0.94325586	-112.36669	2774	1847
2774	1852		607	307	0	0	0.0067151	7.136E-09	7.9601E-11	-0.0080694	-1727300.8	-0.0006697	0.94325586	-112.36669	2774	1852
2778	1852		607	307	0	0	0.0067151	7.136E-09	7.9601E-11	-0.0080694	-1747300.8	-0.0008304	0.94250582	-113.66776	2778	1852
2778	1855		608	308	0	0	0.00665382	7.2134E-09	7.5113E-11	-0.0084866	-1747300.8	-0.0008304	0.94250582	-113.66776	2778	1855
2783	1855		608	308	0	0	0.00665382	7.2134E-09	7.5113E-11	-0.0084866	-1767300.8	-0.000989	0.94159611	-114.96883	2783	1855
2783	1858		609	309	0	0	0.00658635	7.2862E-09	7.0629E-11	-0.00891	-1767300.8	-0.000989	0.94159611	-114.96883	2783	1858
2789	1858		609	309	0	0	0.00658635	7.2862E-09	7.0629E-11	-0.00891	-1787300.8	-0.0011371	0.94053307	-116.26989	2789	1858
2789	1861		610	310	0	0	0.00651269	7.3546E-09	6.6151E-11	-0.0093398	-1787300.8	-0.0011371	0.94053307	-116.26989	2789	1861
2794	1861		610	310	0	0	0.00651269	7.3546E-09	6.6151E-11	-0.0093398	-1787300.8	-0.0012694	0.93932985	-116.2699	2794	1861
2794	1862		611	311	0	0	0.00643902	7.4185E-09	6.1678E-11	-0.0097696	-1787300.8	-0.0012694	0.93932985	-116.2699	2794	1862
2800	1862		611	311	0	0	0.00643902	7.4185E-09	6.1678E-11	-0.0097696	-1787300.8	-0.0013833	0.93800352	-116.2699	2800	1862
2800	1865		612	312	0	0	0.00636536	7.478E-09	5.7211E-11	-0.0101994	-1787300.8	-0.0013833	0.93800352	-116.2699	2800	1865
2804	1865		612	312	0	0	0.00636536	7.478E-09	5.7211E-11	-0.0101994	-1787300.8	-0.0014779	0.93657291	-116.2699	2804	1865
2804	1870		613	313	0	0	0.00629169	7.5329E-09	5.2751E-11	-0.0106291	-1787300.8	-0.0014779	0.93657291	-116.2699	2804	1870
2808	1870		613	313	0	0	0.00629169	7.5329E-09	5.2751E-11	-0.0106291	-1787300.9	-0.0015539	0.93505699	-116.2699	2808	1870
2808	1872		614	314	0	0	0.00621802	7.5835E-09	4.8298E-11	-0.0110589	-1787300.9	-0.0015539	0.93505699	-116.2699	2808	1872
2813	1872		614	314	0	0	0.00621802	7.5835E-09	4.8298E-11	-0.0110589	-1787300.9	-0.0016126	0.93347376	-116.2699	2813	1872
2813	1874		615	315	0	0	0.00614436	7.6295E-09	4.3853E-11	-0.0114887	-1787300.9	-0.0016126	0.93347376	-116.2699	2813	1874
2819	1874		615	315	0	0	0.00614436	7.6295E-09	4.3853E-11	-0.0114887	-1787300.9	-0.0016559	0.93183956	-116.2699	2819	1874
2819	1878		616	316	0	0	0.00607069	7.6712E-09	3.9416E-11	-0.0119185	-1787300.9	-0.0016559	0.93183956	-116.2699	2819	1878
2824	1878		616	316	0	0	0.00607069	7.6712E-09	3.9416E-11	-0.0119185	-1787300.9	-0.001686	0.93016865	-116.2699	2824	1878
2824	1882		617	317	0	0	0.00599702	7.7084E-09	3.4986E-11	-0.0123482	-1787300.9	-0.001686	0.93016865	-116.2699	2824	1882
2830	1882		617	317	0	0	0.00599702	7.7084E-09	3.4986E-11	-0.0123482	-1787300.9	-0.0017051	0.92847314	-116.2699	2830	1882
2830	1883		618	318	0	0	0.00592336	7.7411E-09	3.0565E-11	-0.012778	-1787300.9	-0.0017051	0.92847314	-116.2699	2830	1883
2833	1883		618	318	0	0	0.00592336	7.7411E-09	3.0565E-11	-0.012778	-1787300.9	-0.0017153	0.92676295	-116.2699	2833	1883
2833	1888		619	319	0	0	0.00584969	7.7695E-09	2.6152E-11	-0.013207	-1787300.9	-0.0017153	0.92676295	-116.2699	2833	1888
2840	1888		619	319	0	0	0.00584969	7.7695E-09	2.6152E-11	-0.013207	-1787300.9	-0.0017186	0.92504602	-116.2699	2840	1888
2840	1888		620	320	0	0	0.00577603	7.7934E-09	2.1747E-11	-0.0136376	-1787300.9	-0.0017186	0.92504602	-116.2699	2840	1888
2844	1889		620	320	0	0	0.00577603	7.7934E-09	2.1747E-11	-0.0136376	-1787301	-0.0017165	0.92332849	-116.2699	2844	1889

Sheet tabs: ZLR-RLR Summary | Track 1 | Track 2 | Decks

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1424	3113	2052		674	374	0	0	0.00179804	2.7046E-09	-2.137E-10	-0.0368454	-1787302.4	-0.1965302	0.66104138	-116.27	3113	2052	
1425	3113	2054		675	375	0	0	0.00172437	2.4891E-09	-2.168E-10	-0.0372752	-1787302.4	-0.1965302	0.66104138	-116.27	3113	2054	
1426	3119	2054		675	375	0	0	0.00172437	2.4891E-09	-2.168E-10	-0.0372752	-1787302.4	-0.2620962	0.43172817	-116.27	3119	2054	
1427	3119	2058		676	376	0	0	0.00165071	2.2709E-09	-2.189E-10	-0.0377049	-1787302.4	-0.2620962	0.43172817	-116.27	3119	2058	
1428	3124	2058		676	376	0	0	0.00165071	2.2709E-09	-2.189E-10	-0.0377049	-1787302.5	-0.3356132	0.13287348	-116.27	3124	2058	
1429	3124	2060		677	377	0	0	0.00157704	2.0513E-09	-2.195E-10	-0.0381347	-1787302.5	-0.3356132	0.13287348	-116.27	3124	2060	
1430	3130	2060		677	377	0	0	0.00157704	2.0513E-09	-2.195E-10	-0.0381347	-1787302.5	-0.4145589	-0.2422126	-116.27	3130	2060	
1431	3130	2064		678	378	0	0	0.00150337	1.8318E-09	-2.184E-10	-0.0385645	-1787302.5	-0.4145589	-0.2422126	-116.27	3130	2064	
1432	3134	2064		678	378	0	0	0.00150337	1.8318E-09	-2.184E-10	-0.0385645	-1787302.5	-0.494821	-0.6969025	-116.27001	3134	2064	
1433	3134	2066		679	379	0	0	0.00142971	1.6145E-09	-2.151E-10	-0.0389943	-1787302.5	-0.494821	-0.6969025	-116.27001	3134	2066	
1434	3139	2066		679	379	0	0	0.00142971	1.6145E-09	-2.151E-10	-0.0389943	-1787302.6	-0.570321	-1.2294734	-116.27001	3139	2066	
1435	3139	2069		680	380	0	0	0.00135604	1.4017E-09	-2.092E-10	-0.039424	-1787302.6	-0.570321	-1.2294734	-116.27001	3139	2069	
1436	3145	2069		680	380	0	0	0.00135604	1.4017E-09	-2.092E-10	-0.039424	-1787302.6	-0.6326318	-1.8309498	-116.27001	3145	2069	
1437	3145	2073		681	381	0	0	0.00128237	1.1961E-09	-2.005E-10	-0.0398538	-1787302.6	-0.6326318	-1.8309498	-116.27001	3145	2073	
1438	3148	2073		681	381	0	0	0.00128237	1.1961E-09	-2.005E-10	-0.0398538	-1787302.7	-0.6706182	-2.4825748	-116.27001	3148	2073	
1439	3148	2075		682	382	0	0	0.00120871	1.0008E-09	-1.887E-10	-0.0402836	-1787302.7	-0.6706182	-2.4825748	-116.27001	3148	2075	
1440	3153	2075		682	382	0	0	0.00120871	1.0008E-09	-1.887E-10	-0.0402836	-1787302.7	-0.6701397	-3.1529538	-116.27002	3153	2075	
1441	3153	2078		683	383	0	0	0.00113504	8.188E-10	-1.736E-10	-0.0407134	-1787302.7	-0.6701397	-3.1529538	-116.27002	3153	2078	
1442	3159	2078		683	383	0	0	0.00113504	8.188E-10	-1.736E-10	-0.0407134	-1787302.7	-0.6138691	-3.7949582	-116.27002	3159	2078	
1443	3159	2082		684	384	0	0	0.00106137	6.5346E-10	-1.556E-10	-0.0411431	-1787302.7	-0.6138691	-3.7949582	-116.27002	3159	2082	
1444	3164	2082		684	384	0	0	0.00106137	6.5346E-10	-1.556E-10	-0.0411431	-1787302.8	-0.4812947	-4.3425401	-116.27002	3164	2082	
1445	3164	2084 Pier 6		685	385	0	0	0.00098771	5.0765E-10	-1.349E-10	-0.0415729	-1787302.8	-0.4812947	-4.3425401	-116.27002	3164	2084 Pier 6	
1446	3171	2084		685	385	0	0	0.00098771	5.0765E-10	-1.349E-10	0.00952554	-1787302.8	-0.1397806	-4.6530777	-116.27002	3171	2084	
1447	3171	2088		686	386	0	0	0.00091404	3.8367E-10	-1.127E-10	0.00909203	-1787302.8	-0.1397806	-4.6530777	-116.27002	3171	2088	
1448	3176	2088		686	386	0	0	0.00091404	3.8367E-10	-1.127E-10	0.00909203	-1767302.8	0.17876862	-4.6335837	-114.96896	3176	2088	
1449	3176	2092		687	387	0	0	0.00084657	2.8218E-10	-9.067E-11	0.00866477	-1767302.8	0.17876862	-4.6335837	-114.96896	3176	2092	
1450	3181	2092		687	387	0	0	0.00084657	2.8218E-10	-9.067E-11	0.00866477	-1744730.8	0.38801156	-4.3501936	-113.66789	3181	2092	
1451	3181	2094		688	388	0	0	0.00078529	2.0234E-10	-6.995E-11	0.00824375	-1744730.8	0.38801156	-4.3501936	-113.66789	3181	2094	
1452	3186	2094		688	388	0	0	0.00078529	2.0234E-10	-6.995E-11	0.00824375	-1722730.8	0.50996221	-3.9012067	-112.36682	3186	2094	
1453	3186	2098		689	389	0	0	0.00073021	1.4228E-10	-5.138E-11	0.00782896	-1722730.8	0.50996221	-3.9012067	-112.36682	3186	2098	
1454	3191	2098		689	389	0	0	0.00073021	1.4228E-10	-5.138E-11	0.00782896	-1707302.8	0.56478701	-3.3638321	-111.06575	3191	2098	
1455	3191	2100		690	390	0	0	0.00068133	9.9595E-11	-3.536E-11	0.00742042	-1707302.8	0.56478701	-3.3638321	-111.06575	3191	2100	
1456	3196	2100		690	390	0	0	0.00068133	9.9595E-11	-3.536E-11	0.00742042	-1687302.8	0.57022444	-2.7963264	-109.76469	3196	2100	
1457	3196	2104		691	391	0	0	0.00063864	7.158E-11	-2.204E-11	0.00701811	-1687302.8	0.57022444	-2.7963264	-109.76469	3196	2104	

ZLR-RLR Summary   **Track 1**   Track 2   Decks   ⊕

Behaviour with Combined Temperature and Braking TGV

The analysis includes the condition where the 400m braking TGV trainset is partially present on the structure and these results are also present in the Microsoft Excel post-processing. From the **Track 1** worksheet the chart for the longitudinal relative railbed / track / deck displacement indicated in the following image can be obtained for the braking TGV condition.
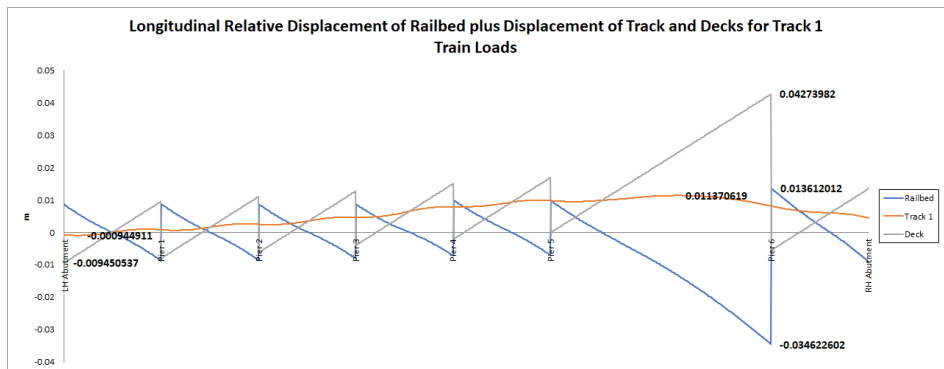
This chart indicates that the longitudinal displacement of the track has a maximum value of 0.01137m or 11.4mm which agrees exactly with the value in the Esveld publication.

The relative railbed displacement over the length of Deck 6 that does not have ZLR assigned varies from 0.00982m or 9.82mm to -0.00535m or -5.35mm, albeit with opposite sign conventions. This variation agrees with the variation in the Esveld publication. Furthermore, the behaviour throughout Deck 6 where the ZLR region is

assigned up to the limit at the right-hand end of Deck 6 agrees with the same limit of -0.03462m or 34.6mm.

The post-processing also generates a chart of the axial rail stress in the track which is shown in the following figure. Comparison of this axial rail stress chart with the earlier chart for the CWR track with no ZLR will show a reduction in the peak compressive axial rail stress at the right-hand abutment from 145.83 MPa to 131.85 MPa. It will also show the alteration of the behaviour of the axial rail stresses along the structure itself, particularly in the region near Pier 5 after which the ZLR region comes into effect.

The peak axial rail stress of 131.85 MPa is equivalent to a peak axial force in the rails of $\sigma \times A_{track} = 131.85E3 \times 0.015372 = 2026.8$ kN.
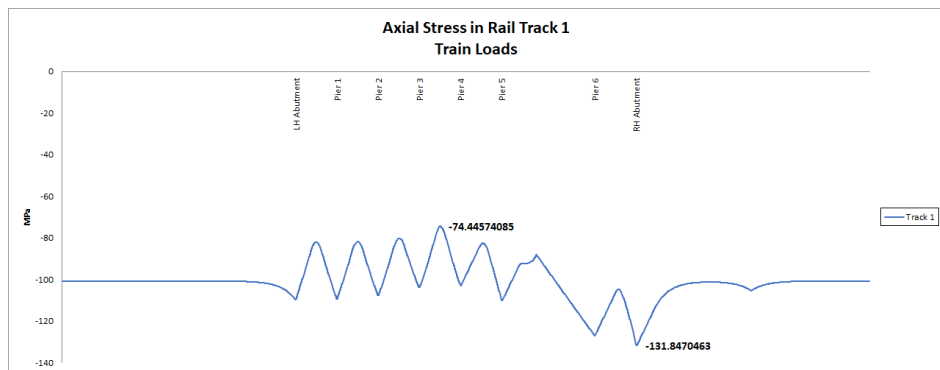
The ZLR region was assumed in the analysis to be unable to resist any longitudinal loading with the presence of a trainset and therefore the bilinear properties of the track-structure-interaction remained perfectly frictionless over the ZLR region when the braking TGV was considered. This is reflected in the axial force within the decks when this is viewed in the **Decks** worksheet. From the **Decks** worksheet the chart for the deck axial force in the following image can be obtained. The chart shows the presence of the zone of constant axial force within Deck 6 that corresponds to the region of ZLR because there is no longitudinal track-structure-interaction taking place along this length. There is however an increase in the axial rail stress along this length unlike the temperature only case because the braking TGV is applying braking loads to the track whereas in the temperature only condition the temperature loading was only applied to the structure (for CWR no temperature loading needs to be applied to the track).

The deck axial force chart indicates that the maximum axial force is 1.396 MN in Deck 6.
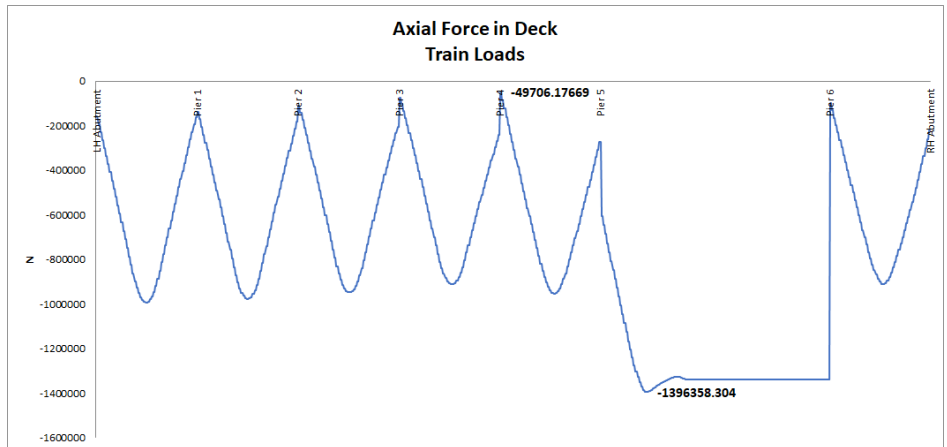
- Close the **EsveldZLR_TempAndTGV-PP** spreadsheet and the Microsoft Excel application.

File
Close

- Choose **No** when asked to save the changes to the current model since there have been no manual changes to it and we want to preserve the original model built by the Rail Track Analysis software.

This completes the example.