Rail Track Analysis
User Manual

LUSAS Version 22.0 : Issue 1

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Rail Track Analysis

Introduction

The passage of one or more trains crossing a rail bridge causes forces and moments to occur in the rails that, in turn, induce displacements in the supporting bridge deck, bearings and piers. As part of the design process for rail bridges it is necessary to ensure that any interaction between the track and the bridge as a result of temperature and train loading is within specified design limits.

UIC774-3 Code of Practice

According to the Union Internationale des Chemins de fer (International Union of Railways) UIC774-3 Code of Practice, the track-structure interaction effects should be evaluated in terms of the longitudinal reactions at support locations, rail stresses induced by the temperature and train loading effects in addition to the absolute and relative displacements of the rails and deck. To accurately assess the behaviour these interaction effects should be evaluated through the use of a series of nonlinear analyses where all thermal and train loads are taken into account. These loads should be:

- **Thermal loading on the bridge deck**
- **Thermal loading on the rail if any rail expansion devices are fitted**
- **Vertical loads associated with the trainsets**
- **Longitudinal braking and/or acceleration loads associated with the trainsets**

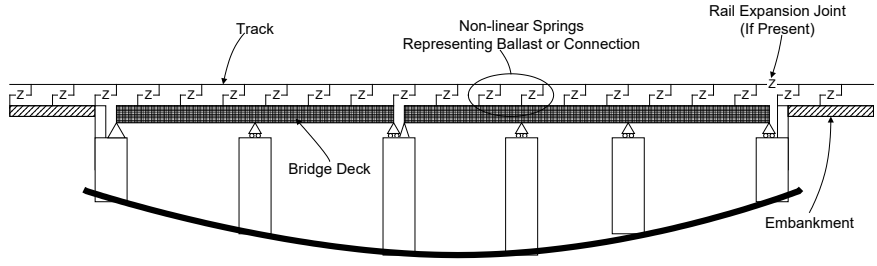


Figure 1: Representation of Structural System for Evaluation of Interaction Effects

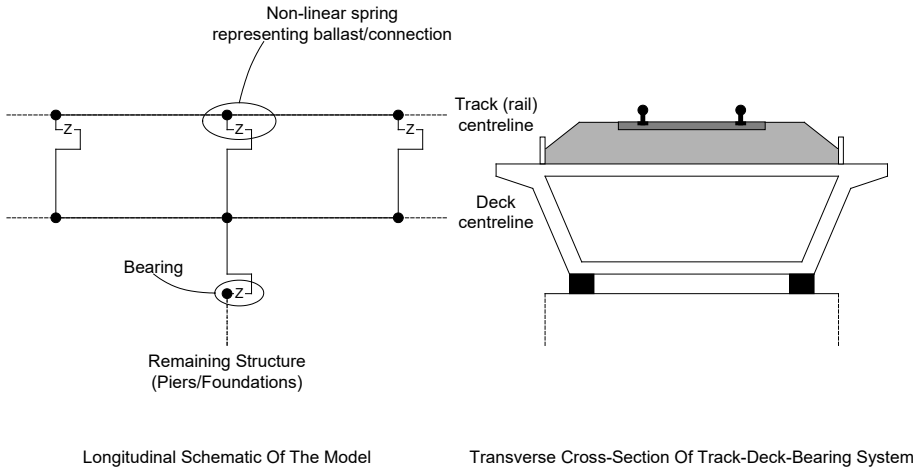


Figure 2: Typical Model of Track-Deck-Bearing System

The interaction between the track and the bridge is approximated in the UIC774-3 Code of Practice by a bilinear relationship as indicated in the following figure. The resistance of the track to the longitudinal displacements for a particular track type is a function of both the relative displacement of the rail to the supporting structure and the loading applied to the track. If the track is subjected to no train loads, then the ultimate resistance of the track to relative movement is governed by the lower curve in the figure (based on the track type). Application of train loads increases the resistance of the track to the relative displacements and the upper curve should be used for the interaction between the track and bridge where these train loads are present – unloaded resistance is still used for all other locations.

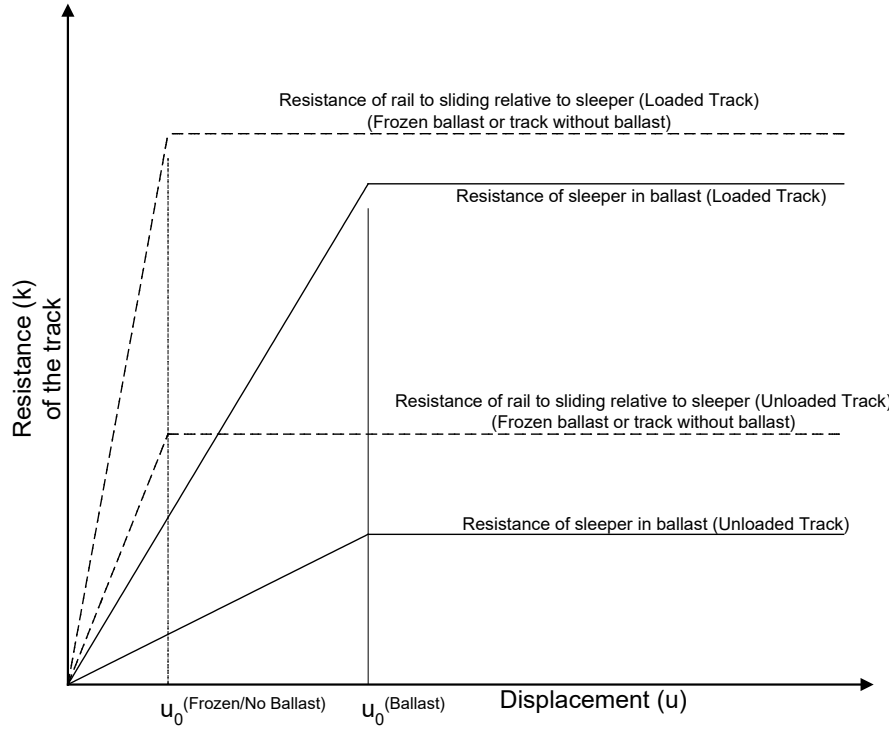


Figure 3: Resistance (k) of the Track per Unit Length versus Longitudinal Relative Displacement of Rails

The values of displacement and resistance to use in these bilinear curves are governed by the track structure and maintenance procedures adopted and will be specified in the design specifications for the structure. Typical values are listed in the Code of Practice for ballast, frozen ballast and track without ballast for moderate to good maintenance and are repeated below.

Displacement between the elastic and plastic zones, u_o:

Resistance of the rail to sliding relative to sleeper = 0.5 mm

Resistance of sleeper in the ballast = 2.0 mm

Resistance in the plastic zone, k:

Resistance of sleeper in ballast (unloaded track), moderate maintenance = 12 kN/m

Resistance of sleeper in ballast (unloaded track), good maintenance = 20 kN/m

Resistance of loaded track or track with frozen ballast = 60 kN/m

Resistance of unloaded track for unballasted track = 40 kN/m

Resistance of loaded track for unballasted track = 60 kN/m

According to the UIC774-3 Code of Practice there is no requirement to consider a detailed model of the substructure (bearing-pier-foundation and bearing-abutment-foundation systems) when 'standard' bridges are considered, instead this can be modelled simply through constraints and/or spring supports that approximate the horizontal flexibility due to pier translational, bending and rotational movement. The LUSAS Rail Track Analysis option allows this type of analysis to be carried out where the behaviour of the bearing and the pier/abutment-foundation are individually specified but also provides the capability of explicitly modelling the bearing-pier/abutment-foundation systems where each component is defined, including the height and properties of the pier/abutment.

The approach outlined in the UIC774-3 Code of Practice is also incorporated in the "Eurocode 1: Actions on Structures – Part 2: Traffic loads on bridges" (EN 1991-2:2003).

LUSAS Rail Track Analysis

The Rail Track Analysis option in LUSAS provides the means to automate the finite element analyses required for conducting bridge/track interaction analyses in accordance with the UIC774-3 Code of Practice. The key features are:

- LUSAS finite element models are automatically built from general arrangement, deck/abutment/pier properties, expansion joints, supports, interaction effects, and thermal and train loading data defined in an Excel or compatible XLSX format spreadsheet file.
- Zero Longitudinal Resistance (ZLR) and Reduced Longitudinal Resistance (RLR) fastening systems can be included in the interaction analyses
- Batch capabilities allow both multiple structures to be built and multiple rail load configurations to be analysed to investigate the interaction effects on different structures, the results of which can be enveloped to determine worst effects
- Rail and structure results are automatically extracted to an XLSX format spreadsheet for presentation purposes and optional further processing by users.

Worked Examples

A worked example "Track-Structure Interaction to UIC774-3" is provided. This examines the track-structure interaction between a braking train and a single span bridge to replicate (as far as the original test data allows) testcase E1-3 which can be found in Appendix D.1 of the UIC774-3 Code of Practice.

Enhanced features of the Rail Track Analysis tool are demonstrated in additional worked examples such as the “Rail Track-Structure Interaction with Offset Bearings and Train Loading Groups” worked example which provides an example of more complex trainset configuration modelling, and the “Rail Track-Structure Interaction with Zero Longitudinal Resistance” worked example which provides an example of the use of Zero Longitudinal Resistance rail fasteners.

The Rail Track Analysis Spreadsheet

An Excel or compatible XLSX format spreadsheet is used to define the data from which a LUSAS finite element model is built and a track/bridge interaction analysis is carried out. The spreadsheet is separated into a number of worksheets that relate to particular aspects of the Rail Track Analysis input requirements. These worksheets cover:

- **Number of Decks, Tracks and Embankment Lengths**
- **Structure Definition**
- **Geometric Properties**
- **Material Properties**
- **Interaction and Expansion Joint Properties**
- **Loading**

For each worksheet comments are included to advise on the appropriate input to the spreadsheet. These can be seen when hovering the mouse cursor over the cell of interest.

The template for the input spreadsheet is located in the **\<Lusas Installation Folder>\Programs\Scripts\User** folder. This template should be edited and saved under a different file name in the working folder in order to carry out analyses.

SI units / US units

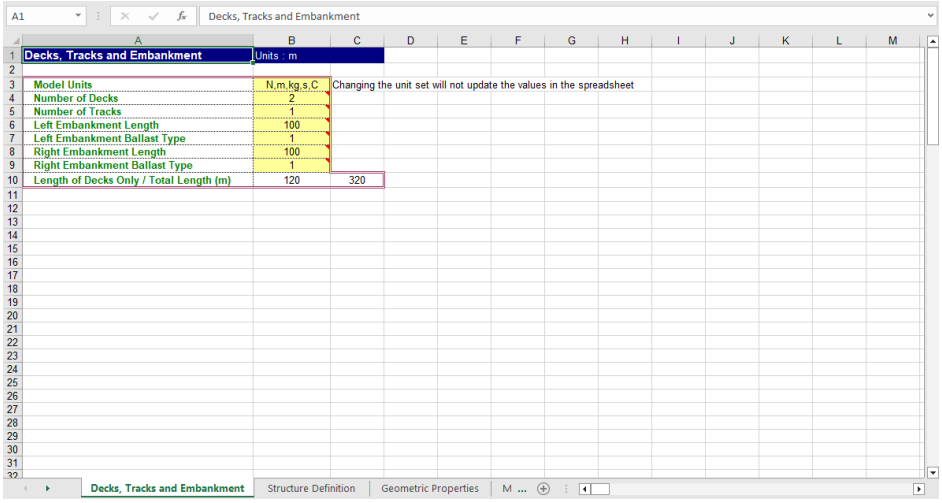
Model data is entered in the spreadsheet in “convenient” SI or US units. The required units are indicated in the various sections of the spreadsheet and should be adhered to for the correct modelling of the interaction analysis. When the model is built from the data in the spreadsheet, all input is converted to consistent SI units of N,m,kg,s and C, or as consistent US units of kip,ft,kslug,s,F, if specified.

Screenshots and dialogs shown in this manual will generally show SI units.

Non-standard unit conversion during import of data from Excel or compatible XLSX format spreadsheet

Quantity description	Metric units		US customary units	
	Input units	**Standard units**	**Input units**	**Standard units**
Bearing spring stiffness	kN/mm	N/m	kip/in	kip/ft
Young's modulus	N/mm^2	N/m^2	kip/in^2	kip/ft^2
Density	kg/mm^3	kg/m^3	$kslug/in^3$	$kslug/ft^3$
Interaction joint spring stiffness	kN/mm per m of track	N/m per m of track	kip/in per ft of track	kip/ft per ft of track
Interaction joint yield force	kN per m of track	N per m of track	kip per ft of track	kip per ft of track
Expansion joint initial gap	mm	m	in	ft
Train loading	kN/m	N/m	kip/ft	kip/ft
Bearing spring stiffness	kN/mm	N/m	kip/in	kip/ft

Worksheet 1: Decks, Tracks and Embankment Lengths



	A	B	C
1	Decks, Tracks and Embankment	Units : m	
2			
3	Model Units	N,m,kg,s,C	Changing the unit set will not update the values in the spreadsheet
4	Number of Decks	2	
5	Number of Tracks	1	
6	Left Embankment Length	100	
7	Left Embankment Ballast Type	1	
8	Right Embankment Length	100	
9	Right Embankment Ballast Type	1	
10	Length of Decks Only / Total Length (m)	120	320

Figure 4: Definition of Number of Decks, Tracks and Embankment Lengths

This worksheet defines the global arrangement details of the bridge structure. The inputs to the worksheet are:

Model Units

Model units can be specified as either 'N,m,kg,s,C' or 'kip,ft,kslug,s,F'. The first row of each worksheet states the units in use.

Within the worksheets, model data is entered in "convenient" SI or US units. When the model is built from the data supplied, all input is converted to consistent SI units or to consistent US units as specified.

Note that, by design, changing the model units in use (on this 'Decks, Tracks and Embankments' worksheet) does not convert the values in the spreadsheet.

Number of Decks

This defines the number of decks in the structure and controls the importing of the structure layout in the ***Structure Definition*** worksheet. The number of decks is initially limited to 100 but this number can be increased by modifying the ***Structure Definition*** worksheet as outlined in the following section.

Number of Tracks

This defines the number of railway tracks that pass along the structure and embankments. The number of tracks must be equal to one or more. For two or more tracks, one track should take the braking load of a trainset and another the acceleration load of a separate trainset in accordance with the UIC77-3 Code of Practice (Clause

1.4.3). In addition, Code of Practice such as “Eurocode 1: Actions on Structures – Part 2: Traffic loads on bridges (EN 1991-2:2003)” have additional conditions when two or more tracks have the same permitted direction of travel.

Each track consists of two rails which act together (see the ***Geometric Properties*** section).

Left and Right Embankment Length

This defines the lengths of the left and right embankments in the model illustrated in the figure below. These lengths should be sufficiently long to allow enough of the trainset loading to be placed on the embankment to model the approach of the trainset to the structure. For very long trainset definitions the embankment does not have to be long enough to accommodate the whole trainset, the Rail Track Analysis tool will allow train loading to remain outside of the model for some trainset positions of the analysis (a warning will be issued before the model is built).

The lengths of the embankments should also be long enough to allow the rail stress to return to a constant value away from the abutments where additional stresses are typically introduced into the rails from temperature variations applied to the decks of the structure. Figure 6 shows typical rail stress variations for a simply supported deck for (a) where there is Continuously Welded Rail (CWR) and just a temperature increase has been applied to the deck and (b) where temperature increases have been applied to both the rails and the deck. For both models the embankment lengths are just sufficient for the rail stresses to be considered constant at the embankment limits.

When defining the lengths of the embankments the UIC774-3 Code of Practice states that these should be a minimum of 100m (Clause 1.7.3).

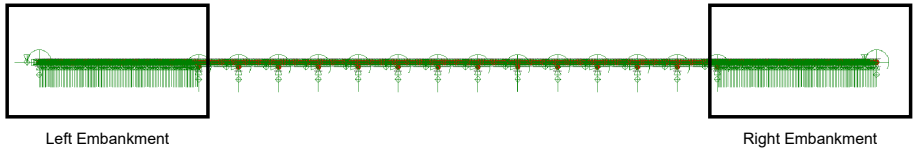
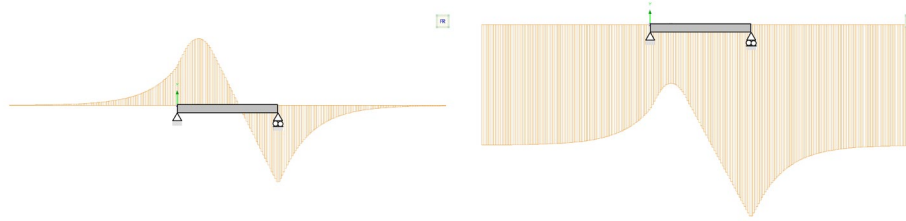


Figure 5: Left and Right Embankments in Model



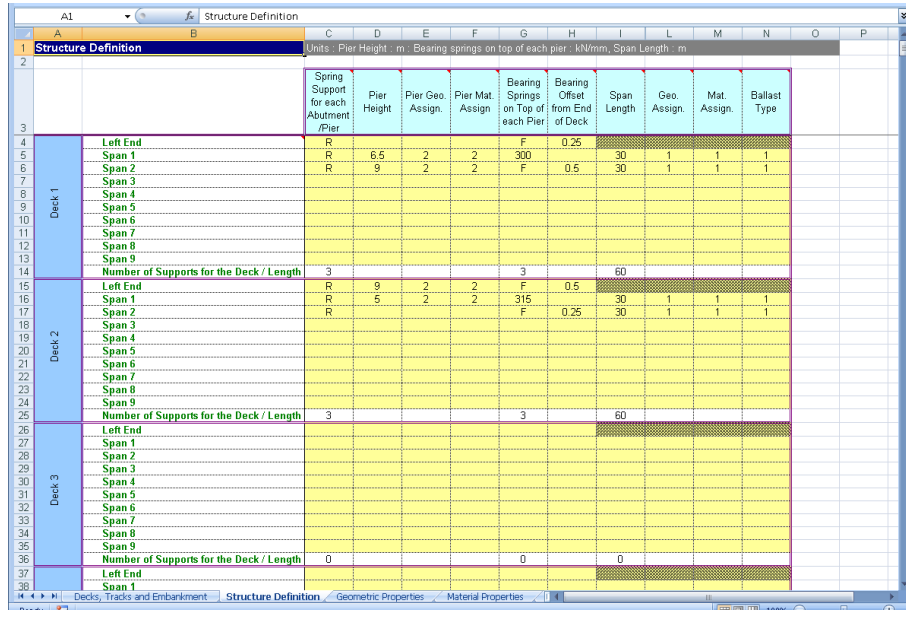
(a) (b)

Figure 6: Rail Stresses due to Temperature Variations for a Simply Supported Deck (a) Temperature Increase in the Deck Alone, (b) Temperature Increase in the Deck and Rail

Left and Right Embankment Ballast Type

This defines the type of ballast that characterises the interaction between the tracks and the left and right embankments of the model. The ballast type is defined through bilinear relationships that are input in the ***Interaction and Expansion Joint*** properties worksheet and the integer ID must correspond to one of the definitions in this worksheet.

Worksheet 2: Structure Definition



		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
1	Structure Definition	Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m									
4	Deck 1 – Left End	R				F	0.25				
5	Deck 1 – Span 1	R	6.5	2	2	300		30	1	1	1
6	Deck 1 – Span 2	R	9	2	2	F	0.5	30	1	1	1
7	Deck 1 – Span 3										
8	Deck 1 – Span 4										
9	Deck 1 – Span 5										
10	Deck 1 – Span 6										
11	Deck 1 – Span 7										
12	Deck 1 – Span 8										
13	Deck 1 – Span 9										
14	Deck 1 – Number of Supports for the Deck / Length	3				3		60			
15	Deck 2 – Left End	R	9	2	2	F	0.5				
16	Deck 2 – Span 1	R	5	2	2	315		30	1	1	1
17	Deck 2 – Span 2	R				F	0.25	30	1	1	1
18	Deck 2 – Span 3										
19	Deck 2 – Span 4										
20	Deck 2 – Span 5										
21	Deck 2 – Span 6										
22	Deck 2 – Span 7										
23	Deck 2 – Span 8										
24	Deck 2 – Span 9										
25	Deck 2 – Number of Supports for the Deck / Length	3				3		60			
26	Deck 3 – Left End										
27	Deck 3 – Span 1										
28	Deck 3 – Span 2										
29	Deck 3 – Span 3										
30	Deck 3 – Span 4										
31	Deck 3 – Span 5										
32	Deck 3 – Span 6										
33	Deck 3 – Span 7										
34	Deck 3 – Span 8										
35	Deck 3 – Span 9										
36	Deck 3 – Number of Supports for the Deck / Length	0				0		0			
37	Deck 3 – Left End										
38	Deck 3 – Span 1										

Figure 7: Structure Definition

The ***Structure Definition*** worksheet allows the geometry of the bridge to be input deck by deck. For each deck the worksheet allows the definition of the length, geometric, material and ballast type assignments of the internal spans plus pier/abutment arrangements along with their support and bearing characteristic. The input allows the modelling of the piers through equivalent springs using the method proposed in the UIC774-3 Code of Practice (see note below) or through the physical modelling of the piers by entering input of the pier heights plus geometric and material assignments. The inputs to the worksheet are:

Spring Support for each abutment/pier

This defines the longitudinal stiffness for the abutment or pier. The longitudinal stiffness for the abutment or pier should be entered as either free 'F', restrained 'R' or a positive stiffness in kN/mm.

For the equivalent spring approach, if the displacement behaviour of the support and the bearings are modelled separately the supports should be set to take account of the displacement at the top of the support due to elastic deformation, the displacement at the top of the support due to the rotation of the foundation and the displacement at the top of the support due to the longitudinal movement of the foundation. If instead the displacement behaviour of the support and bearings are lumped together, as illustrated in the example in Figure 7, the spring supports for the piers and abutments should be set to 'R' for restrained.

If the piers are physically modelled then the spring support for the pier should represent the longitudinal stiffness of the foundation at the base of the pier.

Note. The pier properties for the last pier of one deck must exactly match the properties defined for the next deck or an error will be reported when the spreadsheet is used to carry out the analysis.

Note. When the pier/foundation system is modelled as a spring this spring can be calculated by combining the component movements associated with the pier as indicated below and described further in the UIC774-3 Code of Practice:

$$\delta_{\text{total}} = \delta_{\text{p}} + \delta_{\varphi} + \delta_{\text{h}} \ [+ \delta_{\text{b}}]$$

where

δ_{p} = displacement at top of support due to elastic deformation

δ_{φ} = displacement at top of support due to rotation of the foundation

δ_{h} = displacement at top of support due to horizontal movement of the foundation

δ_b = relative displacement between the upper and lower parts of bearing (Only included if bearings effects lumped into support conditions)

and the total spring stiffness is calculated from:

$$K = \frac{H}{\delta_{total}} \quad \text{(in kN/mm)}$$

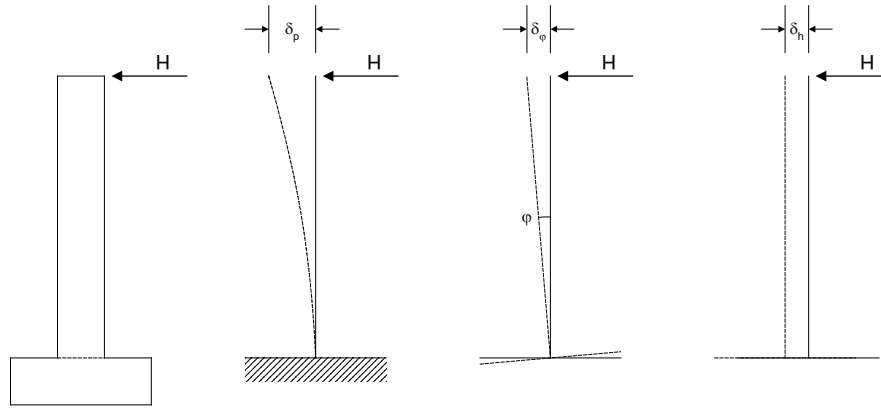


Figure 8: Component Behaviour for Calculating Support Stiffness

Note. If the piers are modelled in the analysis the rotation of the foundation is assumed to be zero in the analysis. This can be adjusted by modifying the support conditions manually after a temperature only analysis has been performed (see user interface discussions).

Bearing springs on top of each pier

This defines the longitudinal stiffness of the bearings between the top of the support and the deck. The longitudinal stiffness for the bearing should be entered as either free 'F', restrained 'R' or a positive stiffness in kN/mm.

For the equivalent spring approach where the stiffness of the support due to elastic deformation, rotation of the foundation and horizontal movement of the foundation are lumped with the bearing behaviour this input should include all of the stiffness contributions and the ***Spring support for each abutment/pier*** should be set to 'R'. If the bearing behaviour is separated from the behaviour of the support the input should match the requirements for the bearing alone.

When the piers are physically modelled in the model by setting their height and properties the longitudinal stiffness of the bearing alone should be input since the behaviour of the pier will be incorporated by the extra beam elements representing the pier in the model.

Bearing offset from end of deck

This defines the offset from the end of the deck for the longitudinal location of the bearing. The bearing offset should be in m.

The bearing at the end of the deck may not be at the end (or sufficiently close to the end) of the deck to be able to justify such modelling as contained in UIC774-3 where bearings are assumed to be at the end. If the bearing is inboard of the end of the deck this can have a significant effect on the displacement / bending behaviour of the deck which itself can have an effect on the track-structure interaction and the displacement behaviour between decks plus the deck ends and the abutments as illustrated below..

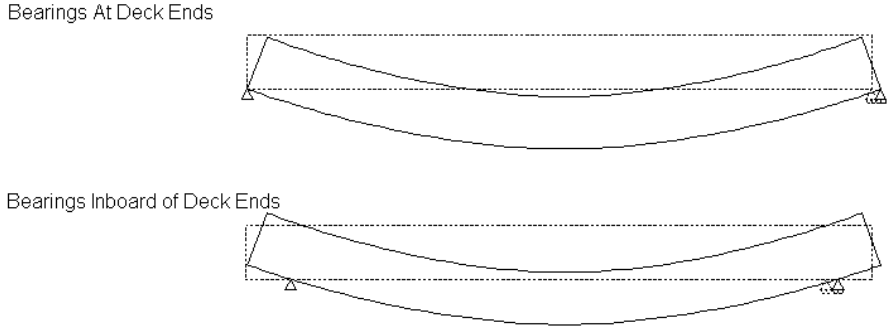


Figure 9: Effect of Bearings Inboards of the Deck Ends

When bearing offsets are used with physical pier modelling the physical geometry of the pier will be built with rigid offsets modelled to ensure the bearing bases are at both the correct longitudinal location relative to the pier and also at the correct elevation as shown in the image below. This modelling ensures the correct translational and rotational behaviours of the bases of the bearing for the displacement and rotation of the supporting pier.

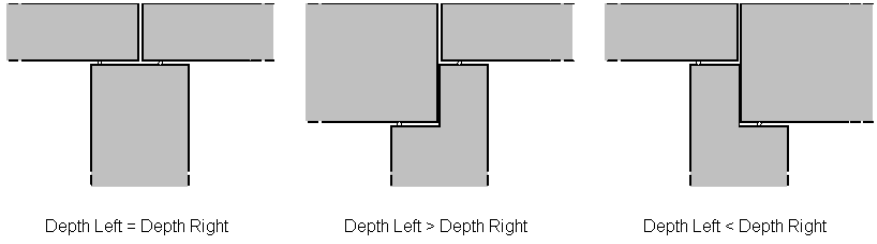


Figure 10: Pier Geometry Configurations for Bearing Elevations

This additional displacement from the correct longitudinal bearing offset modelling could increase the observed displacements of the decks themselves and could be more detrimental to the track-structure interaction.

Bearing offsets can be used when the equivalent spring pier modelling is being used but there is no ability to incorporate the additional rotation of the top of the pier and its effect on the bases of the bearings since the rotation behaviour of the pier is accounted for solely in the longitudinal stiffness used in the equivalent spring pier modelling and not through a degree of freedom in the analysis. It is therefore recommended that bearing offsets are **not** used when equivalent spring pier modelling in accordance with UIC774-3 is being used.

Span Length

This defines the span length between support locations for a deck. Up to nine spans can initially be defined for each deck but this can be increased (see the section on ***Increasing the number of spans modelled in the decks***). In the example illustrated in Figure 7 the first two decks have two 25m spans each and the third deck has three 25m spans.

Geometric Assignment

This defines the geometric properties that are assigned to the spans of the decks. The integer ID must match one of the geometric properties that is defined in the ***Geometric Properties*** worksheet. Different properties can be assigned to each span of the deck. Although the input only allows a single ID to be assigned to each span, continuously varying properties can also be modelled (see the section on ***Geometric Properties***).

Material Assignment

This defines the material properties that are assigned to the spans of the decks. The integer ID must match one of the material properties that is defined in the ***Material Properties*** worksheet.

Ballast Type

This defines the ballast type properties representing the track-structure-interaction that is assigned to the spans of the decks. The integer ID must match one of the bilinear interaction properties that is defined in the ***Interaction and Expansion Joint*** worksheet. The ballast type can be varied between decks and the input also allows different ballast types to be assigned to different spans within the same deck. This could be used if, for example, different bilinear interaction properties were required to represent different ballast conditions along a structure.

If physical modelling of the piers is to be included in the analysis then additional input is required for these piers. The inputs to the worksheet are:

Pier Height

This defines the height of the support / pier for the current location in the deck. If the pier height is blank the Rail Track Analysis tool assumes that the pier behaviour is represented solely by the spring supports and bearing springs.

Pier Geometric Assignment

This defines the geometric properties that are assigned to the support / pier for the current location in the deck. The integer ID must match one of the geometric properties that is defined in the ***Geometric Properties*** worksheet. Although the input only allows a single ID to be assigned to the support / pier, continuously varying properties can also be modelled (see the section on ***Geometric Properties***).

Pier Material Assignment

This defines the material properties that are assigned to the support / pier for the current location in the deck. The integer ID must match one of the material properties that is defined in the ***Material Properties*** worksheet.

Increasing the number of decks modelled

If more than 100 decks are required the spreadsheet can be modified. To do this, scroll to the end of the ***Structure Definition*** worksheet and select the last complete deck definition as indicated on the figure below.

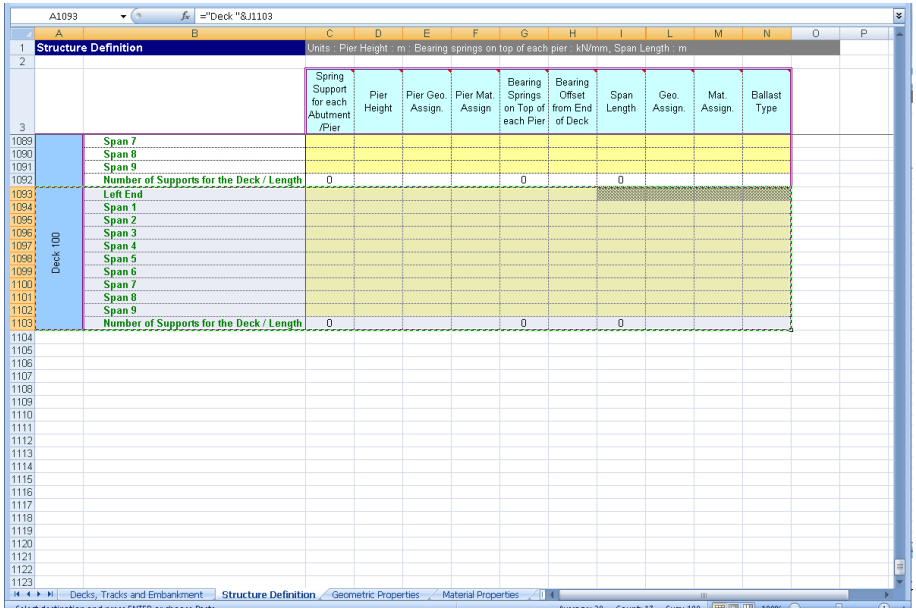


Figure 11: Selection and Copying of Structure Definition Worksheet to Increase Number of Decks

Copy and paste this section as many times as required at the end of the worksheet, ensuring that the row formatting is not altered as indicated below. If successful, the deck number should be correctly calculated for the added entries. The number of decks in the ***Decks, Tracks and Embankment*** worksheet of the spreadsheet can now be increased to the number of decks added to the structure definition.

Note. This may require the worksheet to be unprotected first. This worksheet protection should be turned back on immediately after the extra entries for additional decks have been inserted into the worksheet to avoid accidental changes to other parts of the worksheet that could cause errors when the spreadsheet is imported into the Rail Track Analysis tool.

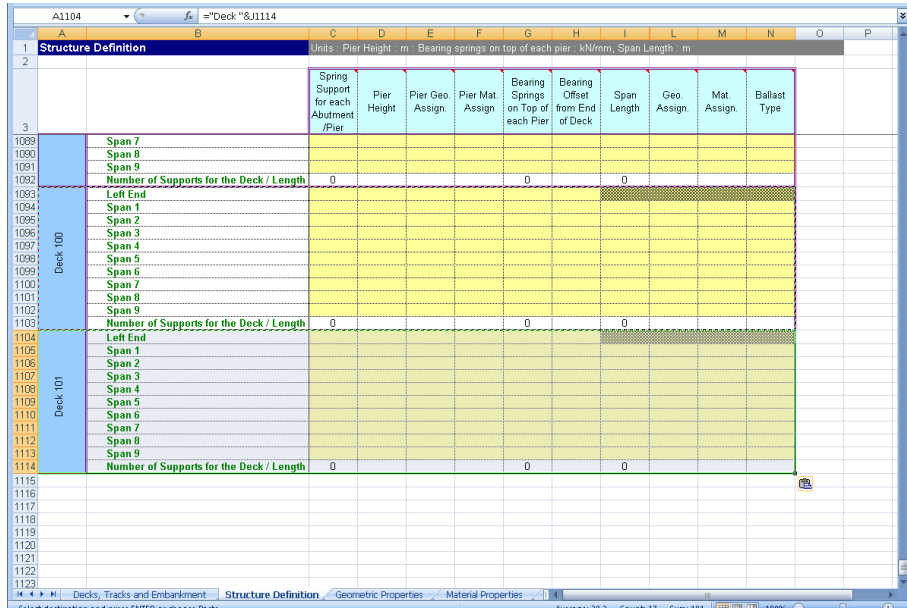
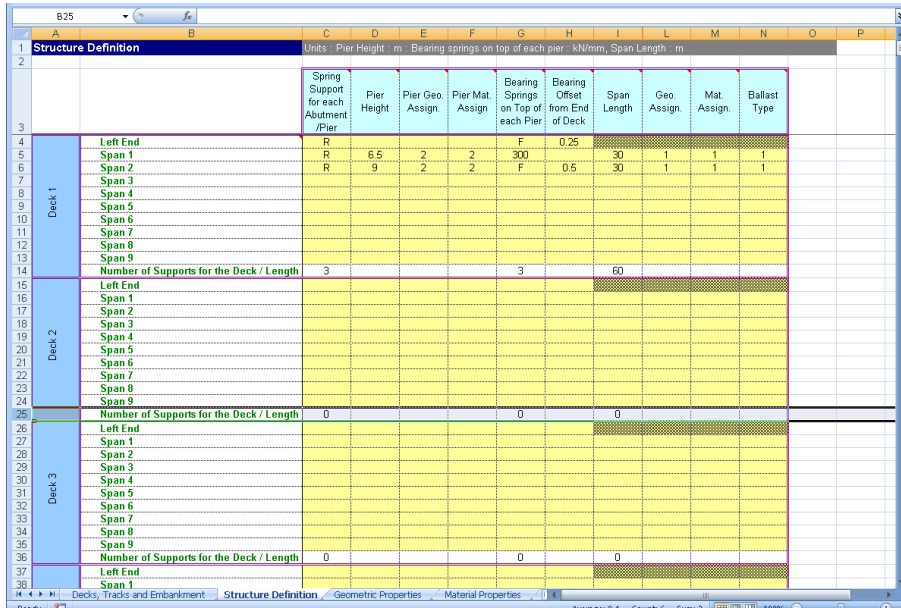


Figure 12: Pasting of Additional Decks to Ensure Formatting Maintained

Increasing the number of spans modelled in the decks

If more than 9 spans are required in any of the decks of a structure, then the spreadsheet can be modified. To do this, select the whole row containing the ***Structure Number of Supports for the Deck / Length*** cell for the deck you wish to increase the number of spans for within the spreadsheet as indicated on the figure below (in the figure we are adding spans to the second deck of a structure we are defining).



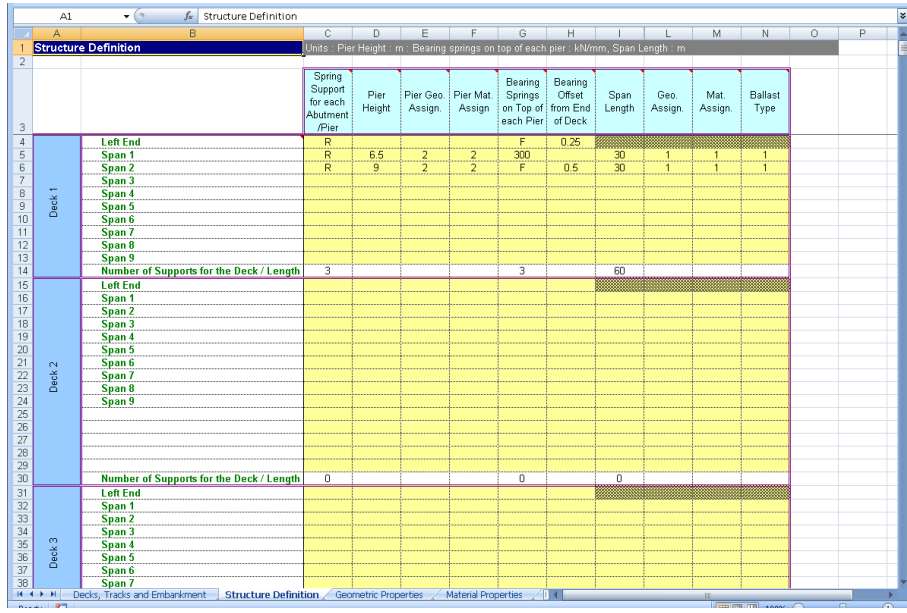
		Spring Support for each Abutment /Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign	Bearing Springs on Top of each Pier	Bearing Offset from End of Deck	Span Length	Geo. Assign.	Mat. Assign.	Ballast Type
Structure Definition		Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m									
Deck 1	Left End	R				F	0.25				
	Span 1	R	6.5	2	2	300		30	1	1	1
	Span 2	R	9	2	2	F	0.5	30	1	1	1
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	3				3		60			
Deck 2	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	0				0		0			
Deck 3	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	0				0		0			
	Left End										
	Span 1										

Figure 13: Selection of the Last Row in Deck Definition to Increase Number of Spans in Current Deck

Select to ***Insert Sheet Rows*** within the spreadsheet as many times as required for the number of additional spans that are required for the deck. If a single extra span is required then one extra row only needs to be inserted, if five extra spans are required then five extra rows need to be inserted. If more spans are inserted than are required and then structural data is not defined the extra rows will be ignored during the importing of the spreadsheet.

Note. This may require the worksheet to be unprotected first. This worksheet protection should be turned back on immediately after the extra rows for additional spans have been inserted into the worksheet to avoid accidental changes to other parts of the worksheet that could cause errors when the spreadsheet is imported into the Rail Track Analysis tool.

The extra spans that have been added will not have any labels as the spreadsheet cannot automatically create these when the extra rows were inserted as shown in the figure below when five rows were added to the second deck. These labels are not essential for the import process but for presentation purposes they can be corrected manually as shown in the subsequent figure.



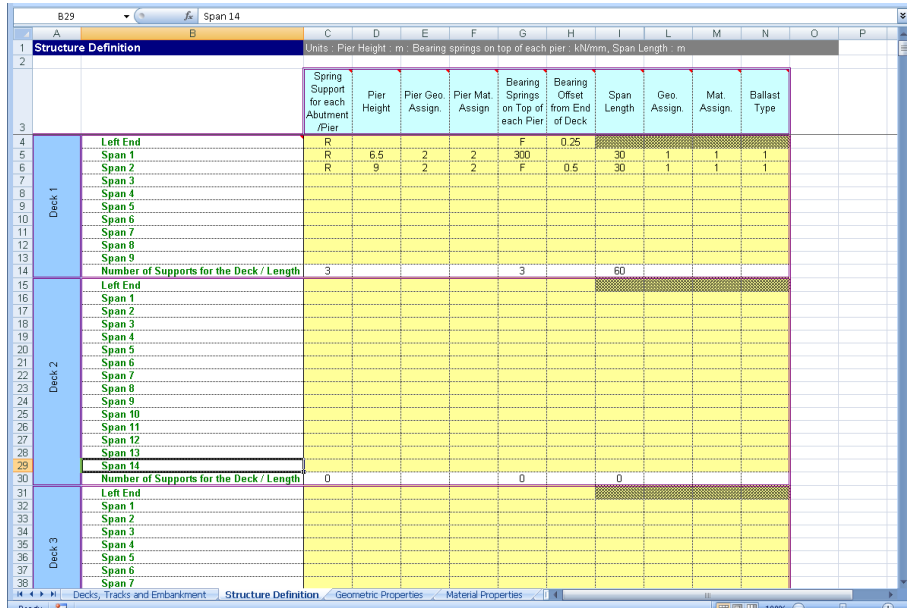
A1 | Structure Definition

Structure Definition — Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m

		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
Deck 1	Left End	R				F	0.25				
	Span 1	R	6.5	2	2	300		30	1	1	1
	Span 2	R	9	2	2	F	0.5	30	1	1	1
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	3				3		60			
Deck 2	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	0				0		0			
Deck 3	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										

Decks, Tracks and Embankment | Structure Definition | Geometric Properties | Material Properties

Figure 14: Inserted Spans Lack the Labelling of the Original Template



B29 | Span 14

Structure Definition — Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m

		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
Deck 1	Left End	R				F	0.25				
	Span 1	R	6.5	2	2	300		30	1	1	1
	Span 2	R	9	2	2	F	0.5	30	1	1	1
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	3				3		60			
Deck 2	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Span 10										
	Span 11										
	Span 12										
	Span 13										
	Span 14										
	Number of Supports for the Deck / Length	0				0		0			
Deck 3	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										

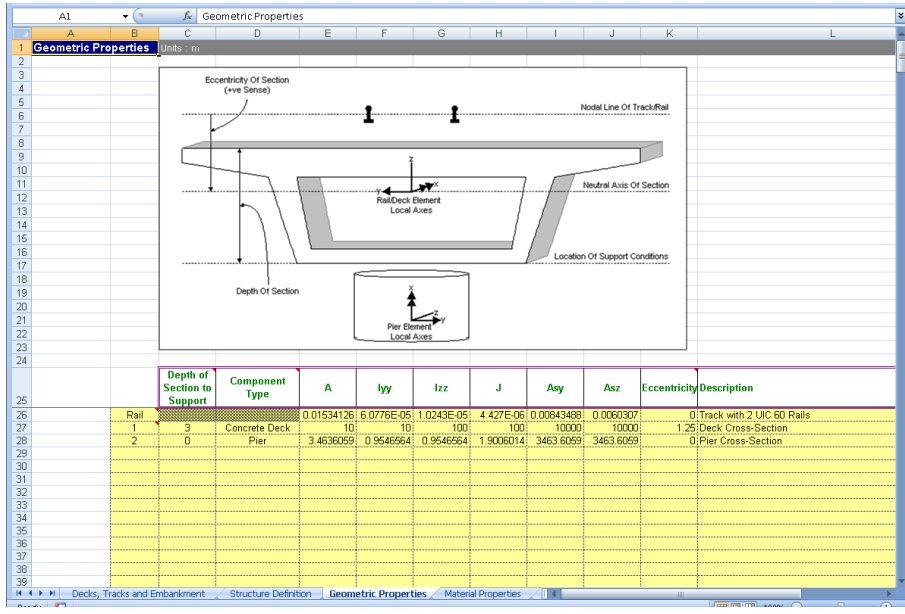
Decks, Tracks and Embankment | Structure Definition | Geometric Properties | Material Properties

Figure 15: Corrected Labels of Inserted Spans to Match Template

In addition to adding extra spans to the end of the deck definition it is also possible to insert spans part of the way through the definition of an existing deck should, for example, the arrangement of a deck need to be altered due to a design change and the analysis re-run. The span labelling will need to be corrected should this be done. It is generally advised that extra spans are inserted at the end of the deck definition prior to entering the structure details where possible.

While it is also possible to remove span rows from the deck definitions in the input spreadsheet this is not advisable and is also not necessary because the import of a deck stops when it detects the first blank row within a deck definition.

Worksheet 3: Geometric Properties



		Depth of Section to Support	Component Type	A	Iyy	Izz	J	Asy	Asz	Eccentricity	Description
Rail				0.01534126	6.0776E-05	1.0243E-05	4.427E-06	0.00843488	0.0060307	0	Track with 2 UIC 60 Rails
1		3	Concrete Deck	10	10	100	100	10000	10000	1.25	Deck Cross-Section
2		0	Pier	3.4636059	0.9546564	0.9546564	1.9006014	3463.6059	3463.6059	0	Pier Cross-Section

Figure 16: Geometric Properties Table for Structure

The geometric properties worksheet should list all of the section properties required for the modelling of the structure and the unique ID numbers must include all of the geometric properties that have been assigned in the ***Structure Definition*** worksheet. The properties should be entered in metres and are all standard LUSAS values except the ***Depth of Section*** to the support and the ***Component Type*** entries.

When the tracks are modelled the two rails of a track are assumed to behave together and the section properties should therefore take account of both rails.

Depth of Section to the Support

The ***Depth of Section*** to the support defines the distance from the top of slab / surface that the track interacts with to the elevation of the bearing supports for the deck and is required to ensure that the correct support conditions are maintained in combination with the overall interaction modelling. For different structure types the depth of section to support is defined slightly differently as indicated in the following figure. For a lot of structures it will often be the overall depth of the section as indicated by the left-hand and central images but for 'U'-shaped sections such at the right-hand image the depth of the section will just be the depth of the bottom slab.

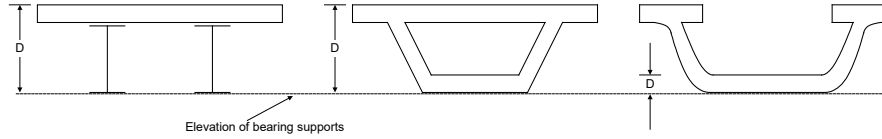


Figure 17: Depth of Section to the Support for Different Bridge Cross-Sections

Component Type

This defines the component type of the geometric property and is used for the application of the appropriate deck temperature loads defined in the ***Loading*** worksheet. The component type will usually be ***Concrete Deck***, ***Steel Deck*** or ***Pier***. A ***User Deck*** type is also provided and this can be used for a user-defined deck type.

Element Orientations

The orientations of the sectional properties should obey the axes indicated in the illustration within the worksheet and the element local axes indicated in the following figure where the double-headed arrow indicates the element local x-axis, the single headed arrow indicates the element local y-axis and the line without an arrowhead indicates the element local z-axis. For both the spans and the piers the element local y-axis is orientated into the lateral direction for the bridge with the local z-axis orientated vertically for the spans and in the longitudinal direction for the piers.

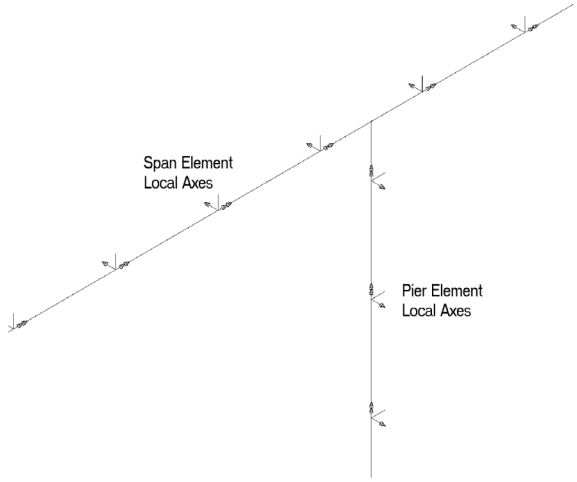


Figure 18: Beam Element Local Axes for Deck and Pier Modelling

For defining the geometric properties of the decks and rails the section axes are illustrated in Figure 19.

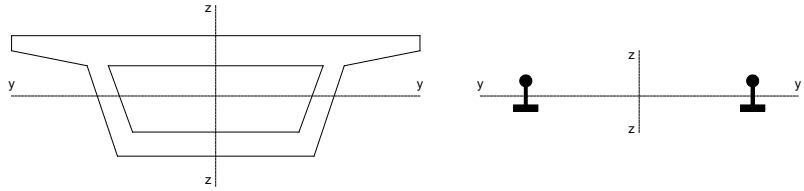


Figure 19: Section Axes for Deck and Rail Definitions

Eccentricity

All eccentricity in the modelling is defined relative to the nodal line of the track/rail and therefore a positive eccentricity will place a section below this line as indicated in the following figure. If an eccentricity is entered for the geometric property of the rail then the neutral axis of the rail will be offset from this nodal line based on the positive sense described. For this reason the eccentricity of the rail should generally be set to zero for all cases.

Notes

The number of entries can be increased by adding data to the bottom of the table. Data input will terminate on the first blank ID number in column B.

The depth of section should not be defined for geometric properties assigned to piers.

The eccentricity between the rail/slab indicated in the figure is defined later in the interaction worksheet and should not be defined as a geometric property.

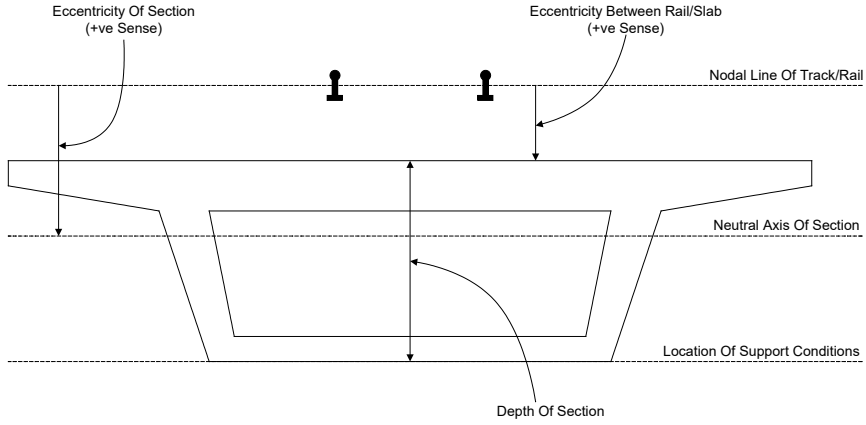


Figure 20: Eccentricity Definition for Geometric Properties and Depth of Section

Varying Section Geometric Properties

Although the spreadsheet does not allow the input of geometric properties with varying sections it is possible to analyse structures with varying sections by modifying the temperature loading only model after it has been built by the Rail Track Analysis tool before subsequently using the **Apply Rail Loads** dialog to include the trainset loading. To do this the model should be defined in the spreadsheet with an initial set of deck geometric properties.

All sections that will be used to define the varying sections of the deck must be defined externally in separate models using either the Precast Beam Section Generator, the Box Section Property Calculator or the Arbitrary Section Property Calculator and the sections added to either a local library or the server library. This will make these sections available to other models.

Note. The ***Depth of Section*** must be correctly set in the ***Geometric Properties*** worksheet for each of the deck support locations to ensure that the behaviour of the decks is correct. All other entries will be determined from the varying section.

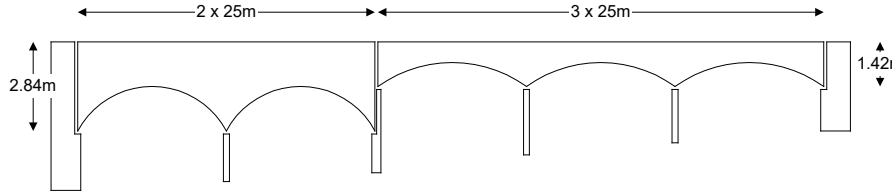
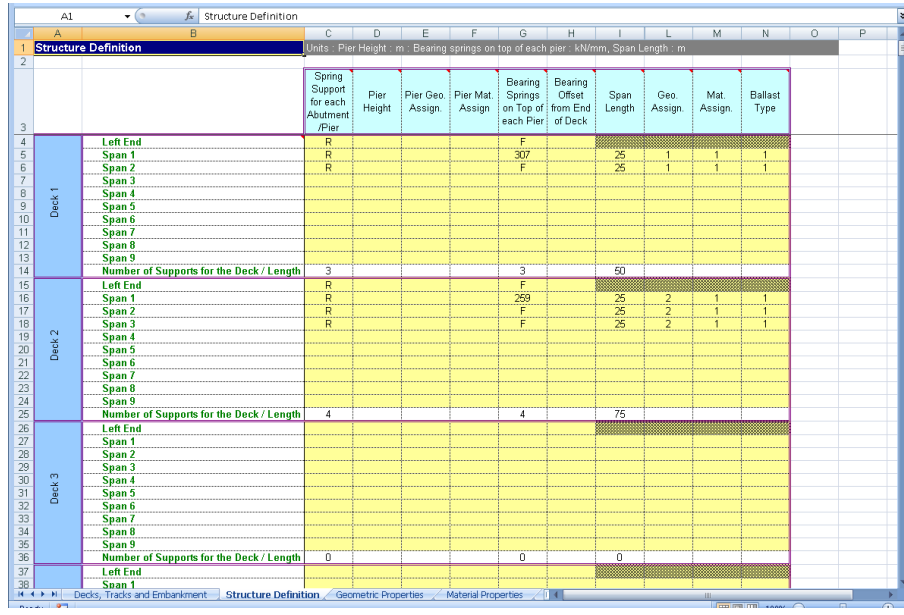


Figure 21: Example Varying Section Structure

If the structure in Figure 21 was required, the main track-structure interaction model could be set up using a spreadsheet with the ***Structure Definition*** and ***Geometric Properties*** indicated in Figure 22 and Figure 23. This would define the base model indicated in Figure 24.

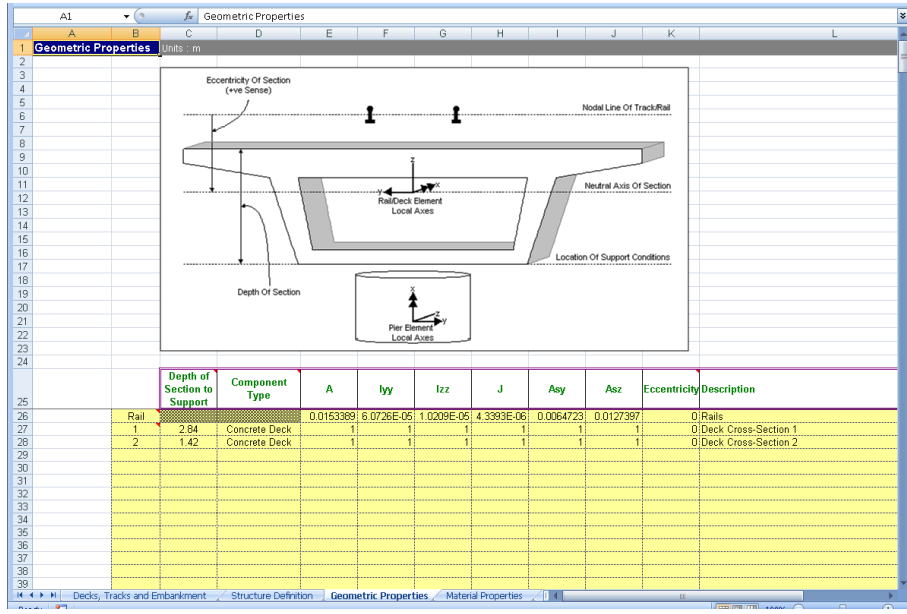


Structure Definition

Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m

		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
Deck 1	Left End	R				F					
	Span 1	R				307		25	1	1	1
	Span 2	R				F		25	1	1	1
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	3				3		50			
Deck 2	Left End	R				F					
	Span 1	R				259		25	2	1	1
	Span 2	R				F		25	2	1	1
	Span 3	R				F		25	2	1	1
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	4				4		75			
Deck 3	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length	0				0		0			
	Left End										
	Span 1										

Figure 22: Structure Definition for Sample Varying Section Structure



		Depth of Section to Support	Component Type	A	Iyy	Izz	J	Asy	Asz	Eccentricity	Description
	Rail			0.0153389	6.0726E-05	1.0209E-05	4.3393E-06	0.0064723	0.0127397	0	Rails
	1	2.84	Concrete Deck	1	1	1	1	1	1	0	Deck Cross-Section 1
	2	1.42	Concrete Deck	1	1	1	1	1	1	0	Deck Cross-Section 2

Figure 23: Geometric Properties for Sample Varying Section Structure

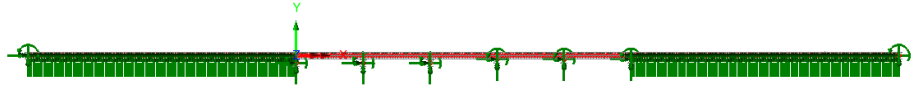


Figure 24: Base Model for Sample Varying Section Structure

In order to define the smooth variation for a single span of the decks the minimum number of sections for interpolation is five. For the 2.84m and 1.42m deep deck spans these sections are defined in separate models, calculated with the ***Arbitrary Section Property Calculator*** (as illustrated in the figure below for one of the sections from the 2.84m deep deck spans) and then added to the local library so they can be accessed from other models (NOTE: Only three actual sizes need to be defined for each due to symmetry).

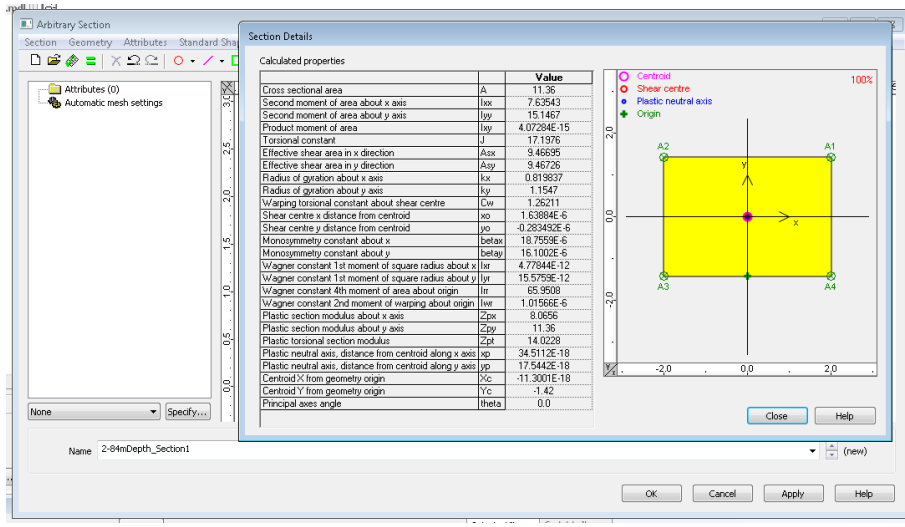


Figure 25: Arbitrary Section Property Calculation for 2.84m Depth of Section Span

These sections can now be used to define the ***Multiple Varying Section*** facility in Modeller. Before defining these multiple varying sections the reference paths along which the variation will take place must be defined. Define a reference path for each of the spans as illustrated in Figure 26 for the first span of the first deck. In this definition the X coordinates match the extent of the span and the Y coordinate has been set to 10 so it can be visualised easily. Four additional reference paths should also be defined, one for each of the other spans. On completion the model will resemble the one in Figure 27 where each reference path has been offset in the Y direction for visualisation purposes.

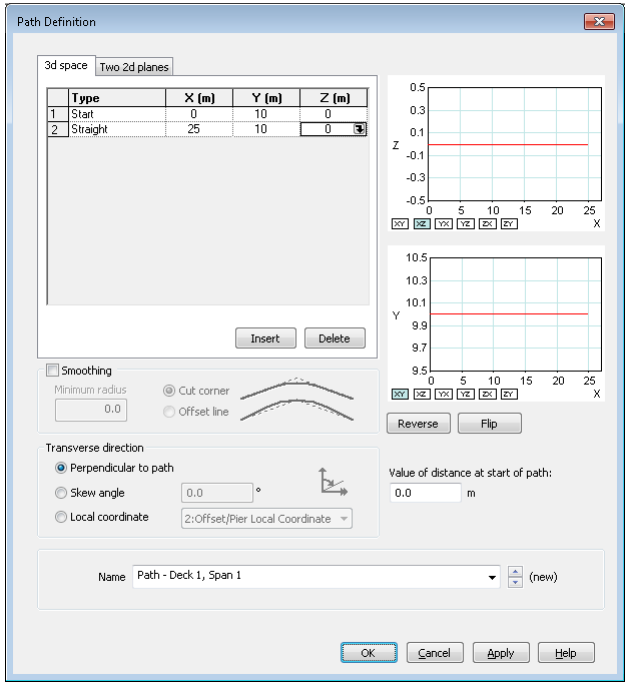


Figure 26: Definition of Reference Path for Deck 1, Span 1

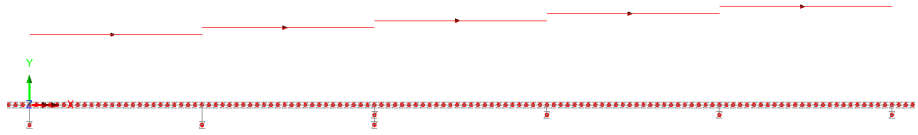


Figure 27: Reference Path for all Decks and Spans (Offset for Visualisation Purposes)

The varying sections can now be defined using the ***Multiple Varying Section*** dialog. For the definition of the varying section for the first span of the first deck the distance interpretation should be set to ***Along reference path*** and the path for the first span of the first deck selected ("Path – Deck 1, Span 1" in this example – see Figure 26). For the start of the varying section the 2.84m deep section ("2-84mDepth_Section1" in this case) should be selected from the arbitrary section library and the section edited. The eccentricity in the z direction (ez) <u>should be set to the required value of 1.42m</u> to obtain the required eccentricity of the neutral axis of the section from the nodal line of the track / rail which would have been entered into the ***Geometric Properties*** worksheet (to place the nodal line on the top of the slab). At this stage the Multiple Varying Section dialog will just have the starting section as illustrated in Figure 28.

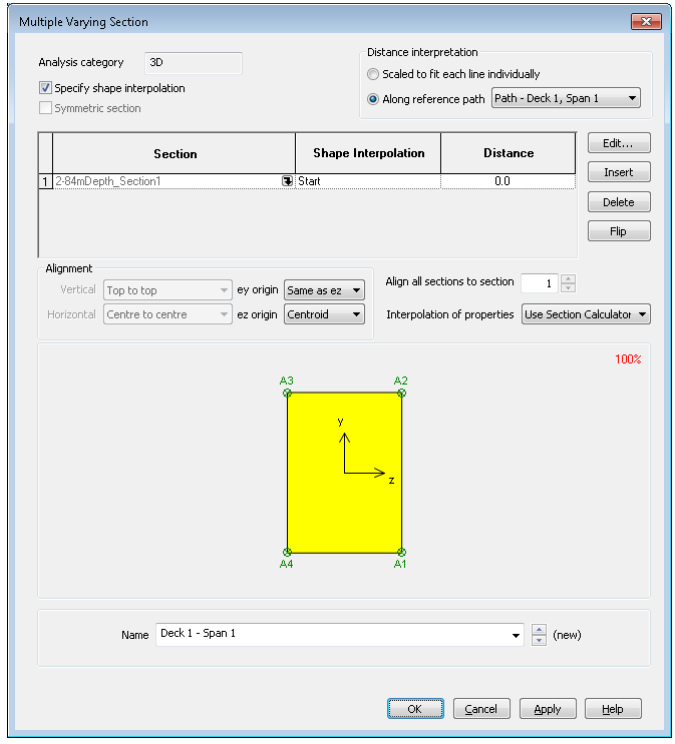


Figure 28: Definition of Multiple Varying Section for Deck 1, Span 1 (1 of 2)

The other sections defining the span also need to be added to the varying section definition and these are input as follows with the ***Vertical alignment*** set to ***Centre to centre*** and the ***Horizontal alignment*** set to ***Right to right***:

Section	Shape Interpolation	Distance
2-84mDepth_Section2	Smoothed	5.0
2-84mDepth_Section3	Smoothed	12.5
2-84mDepth_Section2	Smoothed	20.0
2-84mDepth_Section1	Smoothed	25.0

Table 1: Section Interpolation for Deck 1, Span 1

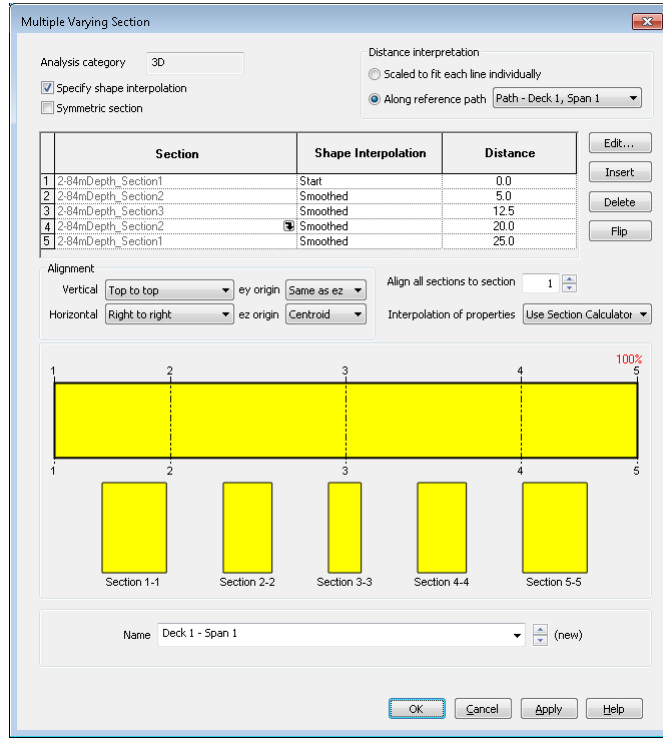


Figure 29: Definition of Multiple Varying Section for Deck 1, Span 1 (2 of 2)

This multiple varying section can now be assigned to all of the lines defining the first span of the first deck, overwriting the original assignment from the Rail Track Analysis tool. A similar multiple varying section can also be defined and assigned but using the appropriate reference path for the second span of the first deck.

The same procedure should also be followed for the 1.42m deep section using associated sections and a starting eccentricity in the z direction (ez) of 0.71m to obtain the required eccentricity of the neutral axis of the section from the nodal line of the track / rail which would have been entered into the ***Geometric Properties*** worksheet. On completion and assignment of the multiple varying section geometric attributes to the appropriate spans of the model the structure would look similar to the model in Figure 30.

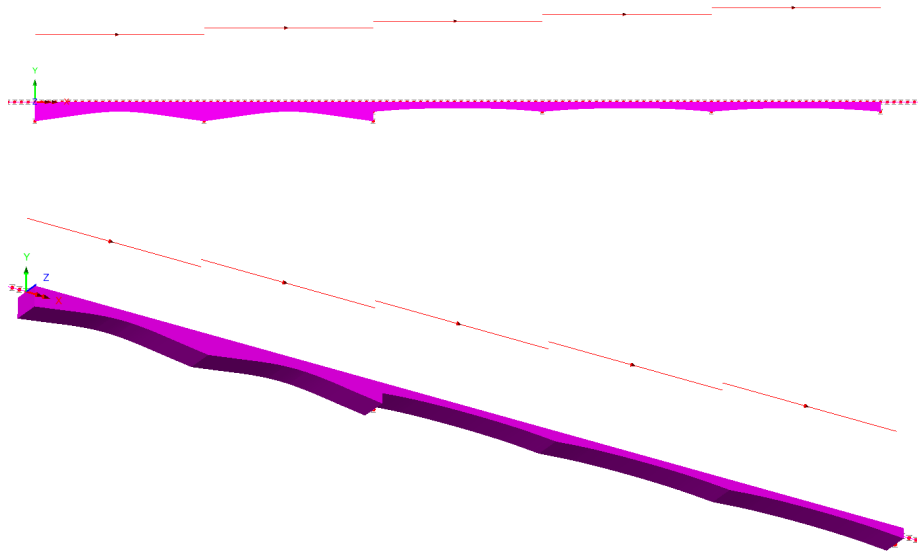


Figure 30: Model after Assignment of Multiple Varying Sections

Note. The multiple varying section could be defined with just two reference paths, one for each of the decks and the geometric attributes defined as indicated in Figure 31. When modelling structures where the sections do not vary smoothly, for example over a pier as indicated in Figure 21, caution should be exercised as using a single reference path per deck could lead to artificial smoothing of the section variation. This is illustrated in Figure 32 and Figure 33 which examine the behaviour at an intermediate pier of a deck when a single path is used for each deck. In Figure 33 the image on the left is from the use of a single reference path for the whole deck and shows the smoothing that has occurred over the pier when compared to the image on the right which is from the use of a single reference path for each span of the deck.

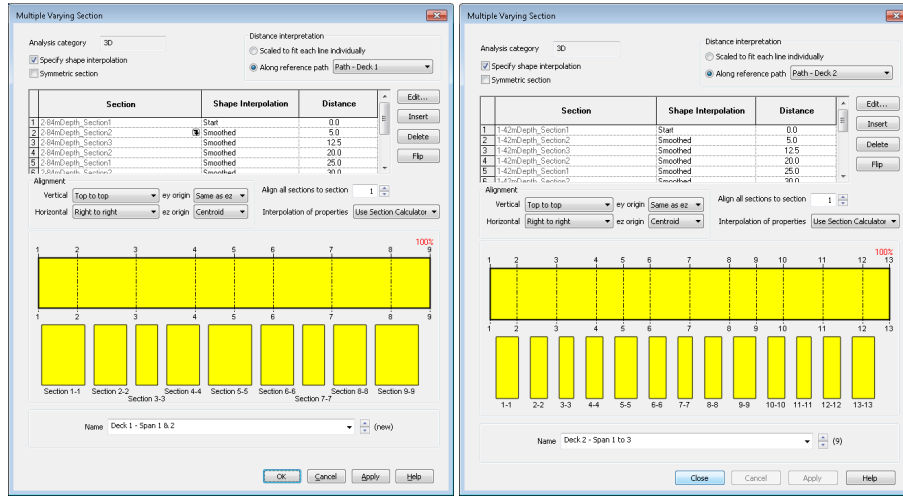


Figure 31: Definition of Multiple Varying Section for Deck 1 and Deck 2 for Two Reference Paths

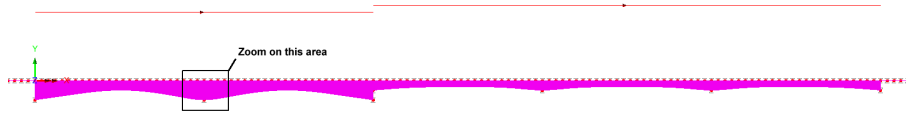
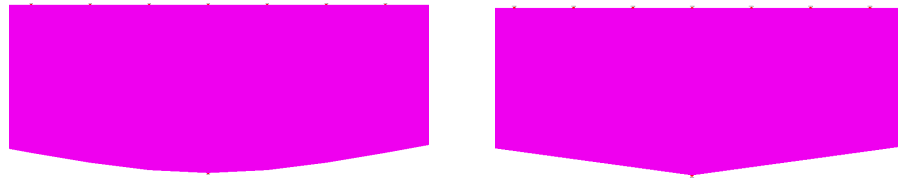


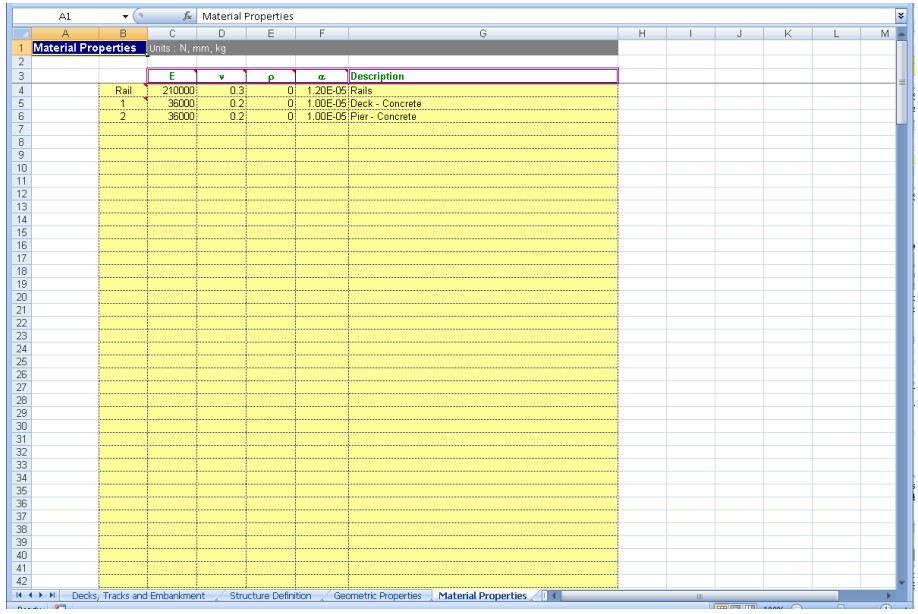
Figure 32: Model after Assignment of Multiple Varying Sections with Two Reference Paths



(a) **(b)**

Figure 33: Zoomed Plot of Pier Location between Spans of Deck 1 Showing (a) Smoothed Section for a Multiple Varying Sections with One Reference Path per Deck and (b) Correct Unsmoothed Section for a Multiple Varying Sections with One Reference Path per Span

Worksheet 4: Material Properties



Material Properties	Units : N, mm, kg				
	E	ν	ρ	α	Description
Rail	210000	0.3	0	1.20E-05	Rails
1	36000	0.2	0	1.00E-05	Deck - Concrete
2	36000	0.2	0	1.00E-05	Pier - Concrete

Figure 34: Material Properties Table for Structure

The material properties worksheet should list all of the material properties required for the modelling of the structure and the unique ID numbers must include all of the material properties that have been assigned in the ***Structure Definition*** worksheet. The elastic properties are all standard LUSAS values which should be entered in Newtons, millimetres and kilograms. The mass density (ρ) is not used in the analysis but is provided to allow the model to be solved with self-weight loading and for it to be combined with the thermal/train loading effects covered in these analyses.

Note. The number of entries can be increased by adding data to the bottom of the table. Data input will terminate on the first blank ID number in column B.

Worksheet 5: Interaction and Expansion Joint Properties

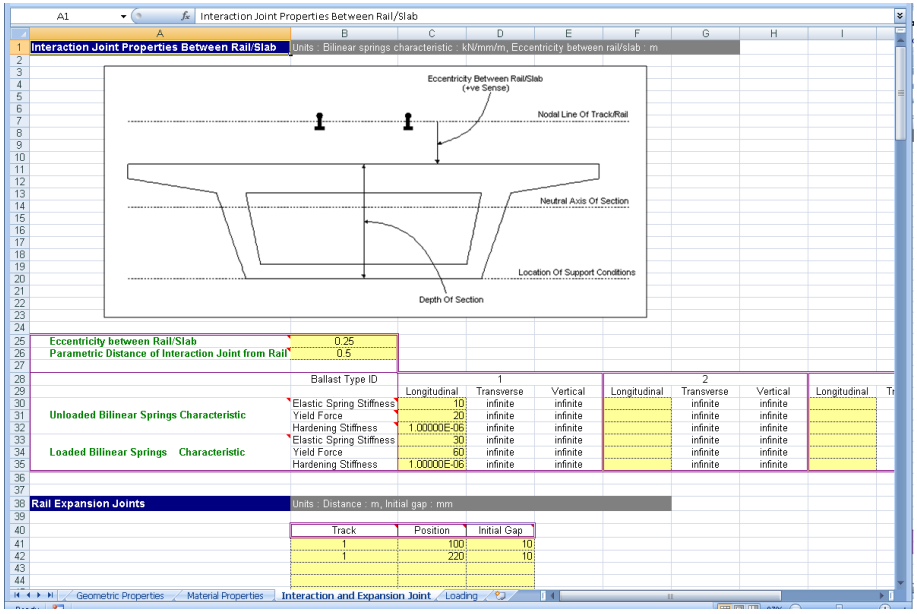


Figure 35: Interaction Properties Between the Track/Bridge and Expansion Joint Definition

The main bilinear interaction effects for the track/bridge interaction are defined in this worksheet along with additional properties associated with the rail/track. These include the eccentricity between the rail/slab (see Figure 11 and the ***Geometric Properties*** section) and the presence of any rail expansion joints.

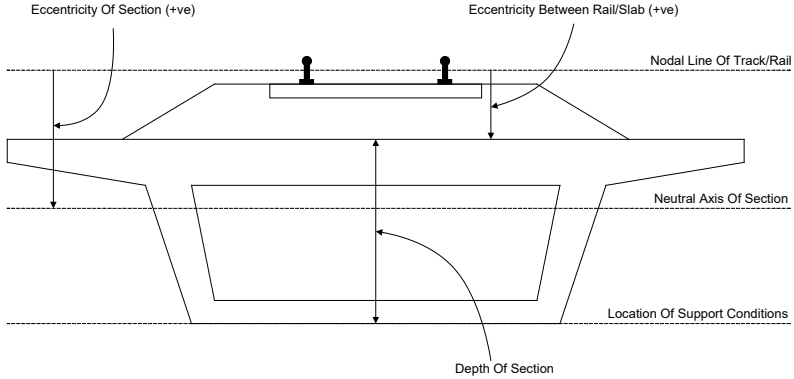
Eccentricity Between Rail/Slab

The eccentricity between the rail/slab is used to define the distance between the nodal line of the rail/track and the top of the bridge slab/deck as indicated in Figure 11. In general, all eccentricities will be positive in the modelling unless the neutral axis of the structure section is above the level of the rails. This only happens for certain types of structures and the definitions of eccentricity should generally follow the sign conventions defined in the following figure.

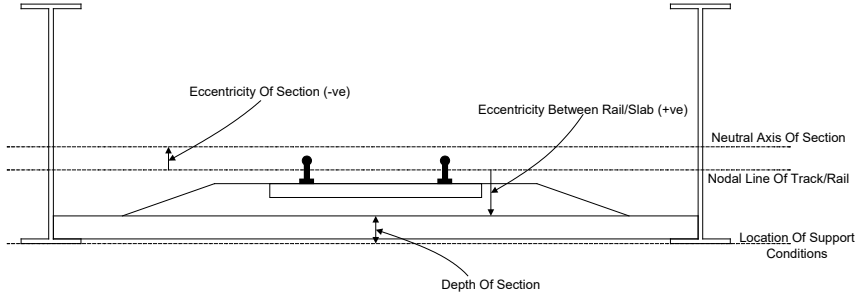
Parametric Distance of Interaction Joint from Rail

The position of the interaction joint from the rail is controlled by this entry. When the eccentricity between the rail/track and the top of the bridge slab/deck is small the eccentricity can be modelled using eccentricity in the elements representing the components of the model. For larger eccentricities the positioning of the rail/track relative to the bridge slab/deck should be modelled using rigid offsets and the positioning of the interaction joints can be set to be at the elevation of the rail/track by

setting this entry to 0, at the elevation of the bridge slab/deck by setting this entry to 1, or at any position in between by setting a value between 0 and 1. A value of 0.5 should normally be used to place the interaction joints midway between the rail/track and the bridge slab/deck. If the "Eccentricity Between Rail/Slab" entry is small then this value will not be used (as already stated).



Eccentricity Definitions (Section Neutral Axis Below Rail Level, Support At Base)



Eccentricity Definitions (Section Neutral Axis Above Rail Level, Support At Base)

Figure 36: Sign Conventions for Eccentricity Definition

Bilinear Interaction Properties

The bilinear interaction properties are derived from the bilinear curves defined in the UIC774-3 Code of Practice and it is possible to define up to five separate sets of properties by default. Properties are entered for both the unloaded state where just temperature loads are applied in the model to the track and the loaded state where both temperature and trainset loads are applied to the track. For each state of loading the elastic spring stiffness is defined in kN/mm per metre length of track, the yield force (onset of plastic yield) is defined in kN per metre length and the hardening stiffness

defined as a small value so there is no stiffness once plastic yielding has started. The values in Figure 35 are for unballasted track where the displacement between the elastic and plastic zones and the associated resistance in the plastic zone are (see the earlier discussion on the bilinear relationship):

$$u_0 = 0.5 \text{ mm}$$
$$k = 40 \text{ kN/m (Unloaded)}$$
$$k = 60 \text{ kN/m (Loaded)}$$

The elastic spring stiffness is calculated directly from:

$$\text{Elastic Spring Stiffness} = \frac{k}{u_0}$$

giving 80 kN / mm per m of track for the unloaded and 120 kN / mm per m of track for the loaded interaction elastic spring stiffness values.

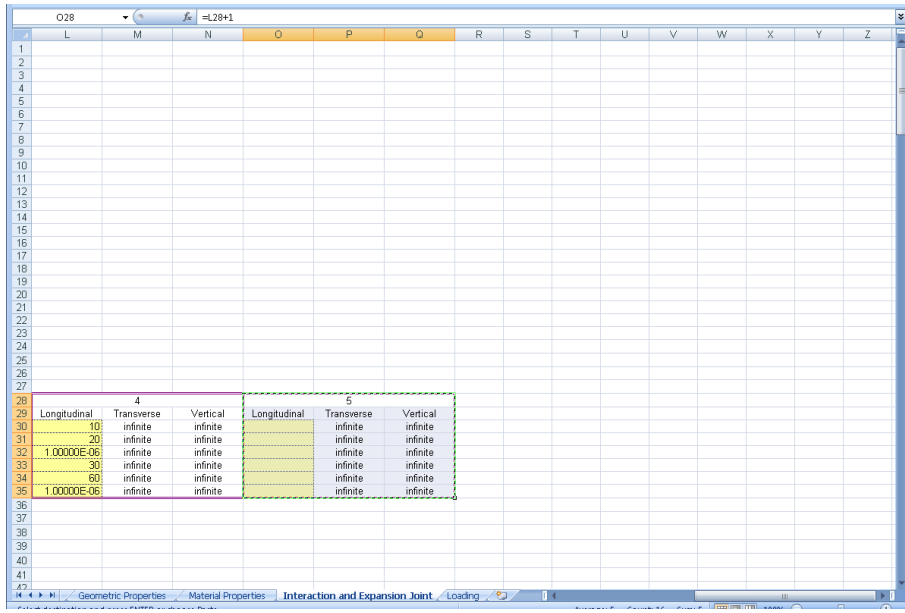
Note. If a zero or small yield force is used in the interaction characteristics the default settings for the nonlinear convergence scheme used in the solution may not result in a converged solution. These convergence parameters may need to be adjusted and the model resolved if this occurs.

Increasing the number of bilinear interaction properties

The input spreadsheet allows the input of five different ballast types by default for the model which can be specified in the ***Decks, Tracks and Embankment*** and ***Structure Definition*** worksheets for the modelling. If more than five ballast definitions are required to fully define the variation of ballast properties characterising the track-structure-interaction then the number of definitions can be increased by copying and pasting the last bilinear definition section as many times as required as demonstrated below.

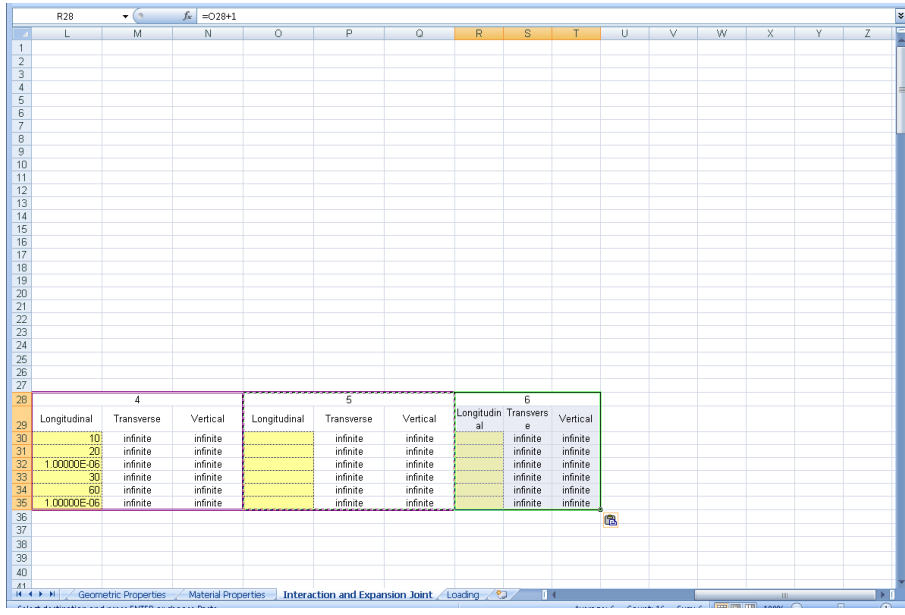
Note. This may require the worksheet to be unprotected first. This worksheet protection should be turned back on immediately after the extra entries for additional interaction properties have been inserted into the worksheet to avoid accidental changes to other parts of the worksheet that could cause errors when the spreadsheet is imported into the Rail Track Analysis tool.

In the example below we have defined four bilinear interaction properties but we need to define a total of seven. Using the fifth and final definition in the worksheet we will create the input sections for the additional two definitions required and adjust the column widths to match the rest of the worksheet.



	4			5	
Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical
10	infinite	infinite		infinite	infinite
20	infinite	infinite		infinite	infinite
1.00000E-06	infinite	infinite		infinite	infinite
30	infinite	infinite		infinite	infinite
60	infinite	infinite		infinite	infinite
1.00000E-06	infinite	infinite		infinite	infinite

Figure 37: Select the Fifth Bilinear Definition Section



	4			5			6	
Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical
10	infinite	infinite		infinite	infinite		infinite	infinite
20	infinite	infinite		infinite	infinite		infinite	infinite
1.00000E-06	infinite	infinite		infinite	infinite		infinite	infinite
30	infinite	infinite		infinite	infinite		infinite	infinite
60	infinite	infinite		infinite	infinite		infinite	infinite
1.00000E-06	infinite	infinite		infinite	infinite		infinite	infinite

Figure 38: Paste the Bilinear Definition Section to Create the Sixth Definition

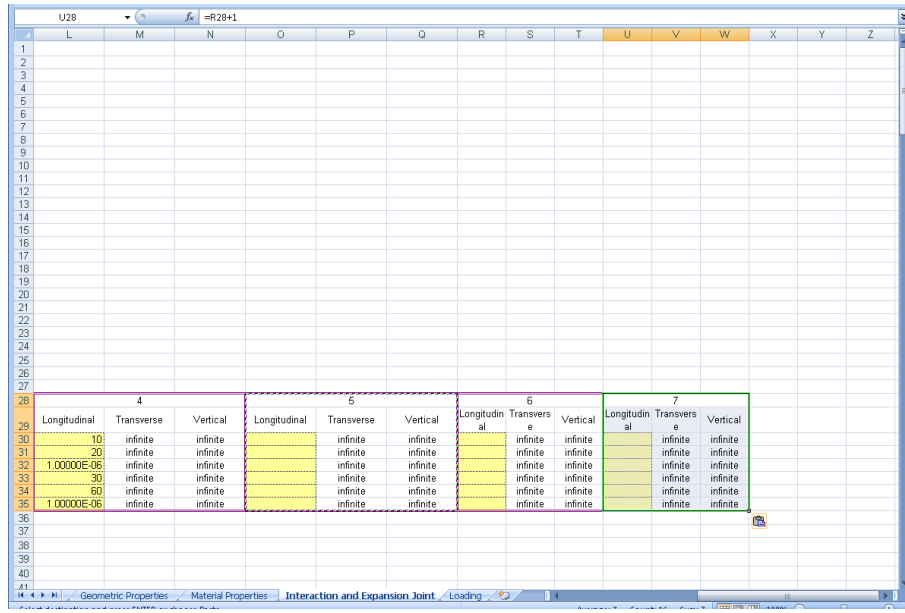


Figure 39: Paste the Bilinear Definition Section to Create the Seventh Definition

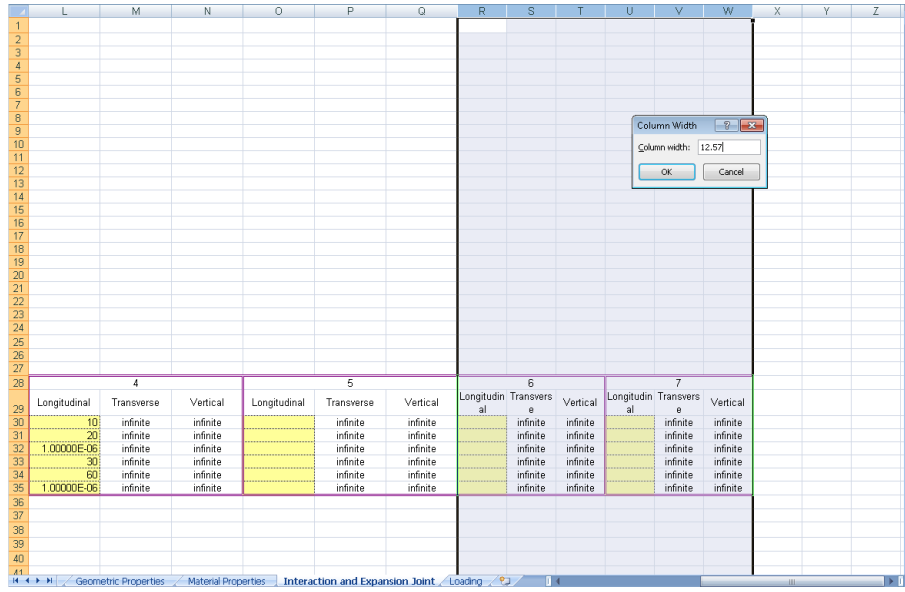
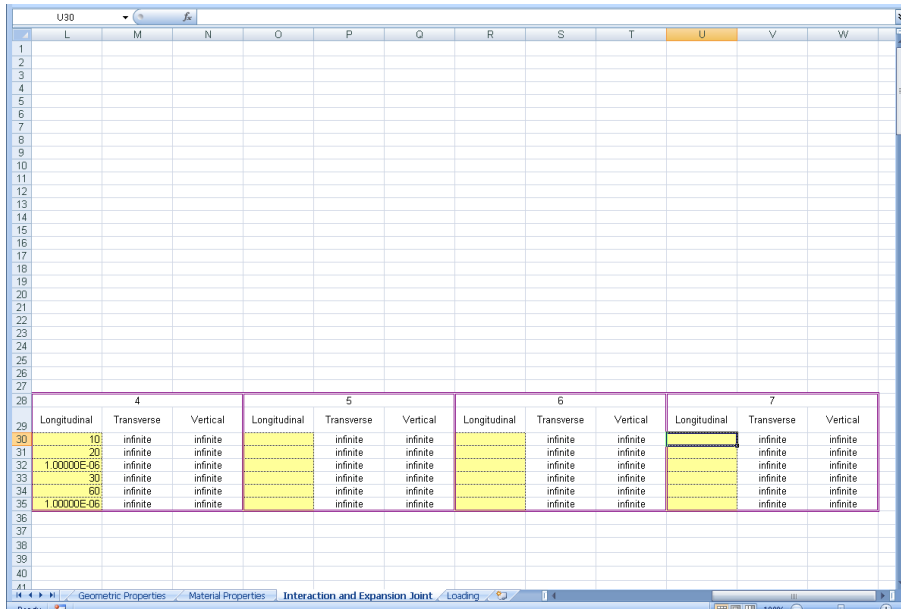


Figure 40: Select the Columns to Adjust the Column Width to Match Other Columns



4			5			6			7		
Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical
10	infinite	infinite		infinite	infinite		infinite	infinite		infinite	infinite
20	infinite	infinite		infinite	infinite		infinite	infinite		infinite	infinite
1.00000E-06	infinite	infinite		infinite	infinite		infinite	infinite		infinite	infinite
30	infinite	infinite		infinite	infinite		infinite	infinite		infinite	infinite
60	infinite	infinite		infinite	infinite		infinite	infinite		infinite	infinite
1.00000E-06	infinite	infinite		infinite	infinite		infinite	infinite		infinite	infinite

Figure 41: Completed Bilinear Definitions Ready for Input

Any number of bilinear interaction definitions can be added to the worksheet up to the limit of the number of columns in the spreadsheet. The only restriction for the Rail Track Analysis tool is that the formatting / layout of the columns must be identical to the existing bilinear interaction definitions in the worksheet. When the new bilinear interaction definition section is copied and pasted into the worksheet it will automatically take the next integer ID above the previous definition.

Note. It is possible to manually edit the bilinear interaction definition integer IDs at the top of the sections and even change their order but this is not recommended. If these definition IDs are edited then the onus is entirely on the user to ensure that they are valid integer IDs and IDs are not repeated otherwise data input errors will occur.

Including Zero and/or Reduced Longitudinal Resistance Interaction Modelling

Zero Longitudinal Resistance (ZLR) and Reduced Longitudinal Resistance (RLR) interaction modelling cannot be included directly in the input spreadsheet. The inclusion of ZLR and/or RLR rail fastener modelling is usually dependent on the inspection axial stress and displacements in the rail track and these having exceeded acceptable levels. For this reason a rail track analysis must have been built and analysed (and post-processed) before the ZLR and/or RLR can be included into the modelling and is covered in detail in the section on ***Performing a ZLR/RLR Rail Track Analysis***.

Defining Rail Expansion Joints

If rail expansion joints/devices are present in the bridge then the information for these can be entered into the worksheet for each track. The data input takes the form of a unique track ID number, the position and initial gap. For each track ID number the expansion joint is defined by entering the position in metres from the start of the left-hand embankment and initial gap in millimetres. The expansion joint data will be read from the spreadsheet until a blank track ID entry is detected. The expansion joints can be specified in any order.

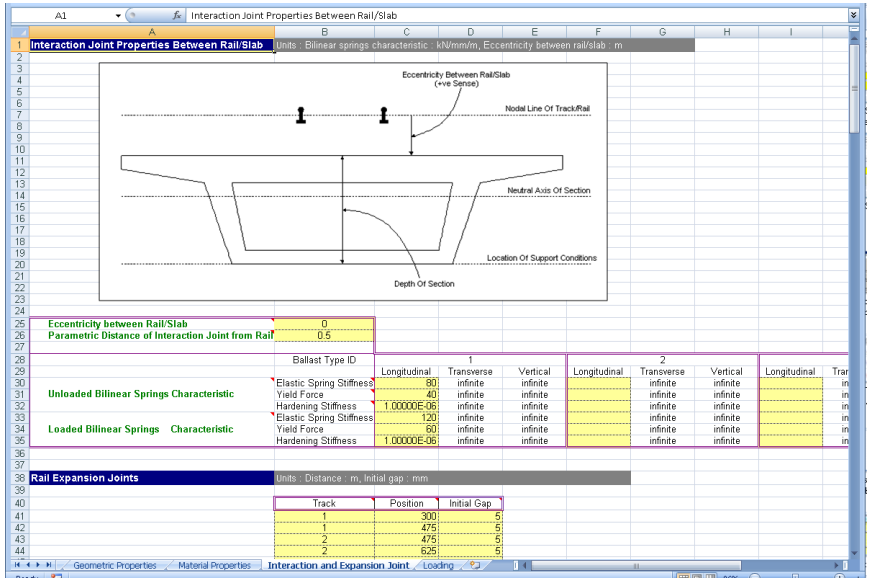
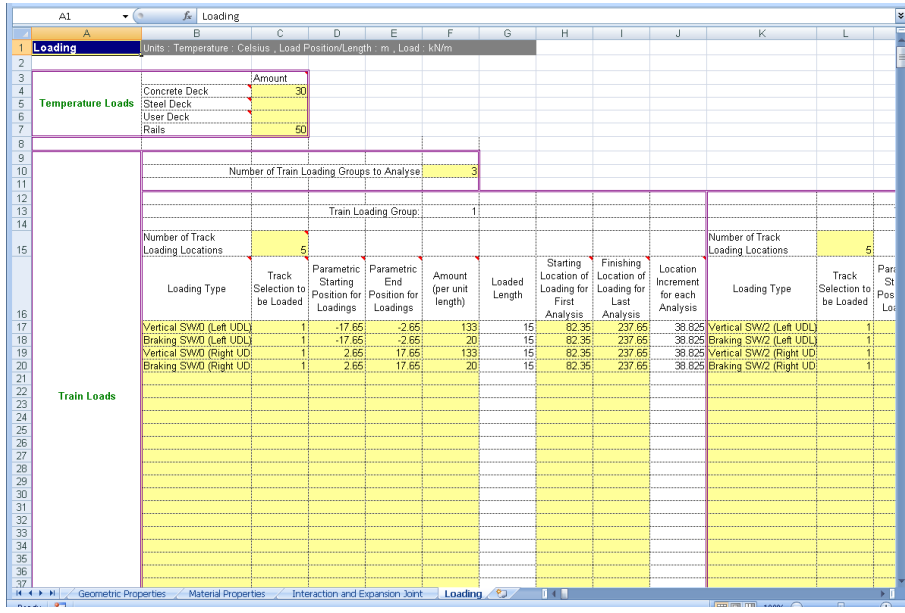


Figure 42: Sample Expansion Joint Definitions

Worksheet 6: Thermal and Train Loading



Loading

Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m

Temperature Loads

	Amount
Concrete Deck	30
Steel Deck	
User Deck	
Rails	50

Train Loads

Number of Train Loading Groups to Analyse: 3

Train Loading Group: 1

Number of Track Loading Locations	5								Number of Track Loading Locations	5	
Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis	Loading Type	Track Selection to be Loaded	Para St Pos Lo
Vertical SW/0 (Left UDL)	1	-17.65	-2.65	133	15	82.35	237.65	38.825	Vertical SW/2 (Left UDL)	1	
Braking SW/0 (Left UDL)	1	-17.65	-2.65	20	15	82.35	237.65	38.825	Braking SW/2 (Left UDL)	1	
Vertical SW/0 (Right UD	1	2.65	17.65	133	15	82.35	237.65	38.825	Vertical SW/2 (Right UD	1	
Braking SW/0 (Right UD	1	2.65	17.65	20	15	82.35	237.65	38.825	Braking SW/2 (Right UD	1	

Geometric Properties | Material Properties | Interaction and Expansion Joint | Loading

Figure 43: Definition of Thermal and Train Loading for Structure

The loading worksheet allows the input of the temperature and trainset loading characteristics that are to be considered for the structure. This includes the capability of defining multiple trainset configurations and locations using the Train Loading Groups and parametric loading facilities which are described below.

Temperature Loading

The temperature effects in the rails for a continuously welded rail (CWR) track do not cause a displacement of the track and do not need to be considered (UIC774-3 Clause 1.4.2), only changes in temperature of the bridge deck relative to the reference temperature need to be considered for CWR track.

For all other tracks the change in temperature of the bridge deck and rails relative to the reference temperature of the deck when the rail was fixed needs to be considered in accordance to the Code of Practice and design specifications.

The temperature loads for both the slab/deck and the rail should be entered (zero if not required) in Celsius (degrees centigrade) where temperature rises are entered as positive values and temperature drops are entered as negative values.

Within the ***Geometric Properties*** worksheet the assignment of the geometric attributes to the decks and spans of the structure allowed the selection of whether the structural components were constructed from concrete, steel or from a user-defined fabrication

type. Within the temperature loading definitions different temperature changes from the reference temperature can be defined in the ***Loading*** worksheet for each of these types as shown in Figure 43. Where a deck type does not exist in the model the temperature change can be left blank or set to zero.

Note. For an analysis where more than one temperature loading may need to be entered for the same deck type either the user-defined type can used or the model should be defined with a single deck type temperature and then a temperature only model built. This temperature only model can then have its temperature loading for the appropriate decks adjusted before the **Apply Rail Loads** dialog is then used to include the trainset loading to the rail tracks. It should however be noted that it is the responsibility of the user to ensure that such an analysis with multiple temperatures for the same deck type adheres to the appropriate Codes of Practice.

Trainset Loading to Rails of Tracks

The Rail Track Analysis tool allows the analysis of the positioning / movement of multiple trainset configurations within the same overall Rail Track Analysis. This is done through the Train Loading Groups and parametric positioning of the trainsets within each of these Train Loading Groups. This can be used for either the global passage of multiple different trainset configurations across the whole structure (such as an analysis containing SW/0, SW/2 and HSLM-A trainset configurations / loadings to assess the overall behaviour to each of these) or the targeted and / or more detailed placement of a single (or more) trainset configuration(s) at critical positions indicated by a prior global analysis or by engineering judgement.

For each of the Train Loading Groups the trainset loading is defined in terms of the type, track to load, position and magnitude. The loading allows for multiple trainset loading positions to be defined in each Train Loading Group and all of these positions will be analysed in one model by the Rail Track Analysis tool.

Since trainset configurations can be longer than the approach embankment recommendations of UIC774-3 (and in some cases could be significantly longer than the approach embankment and structure) the Rail Track Analysis tool allows the trainset loading to fall outside the extents of the model.

Currently the ***Loading*** worksheet of the input spreadsheet allows up to 10 Train Loading Groups (each with formatted input of 125 rows of loading definitions to describe the longitudinal and vertical loading pattern) to be defined within the formatting.

As many rail/train loads that are required can be defined in the spreadsheet with data input terminating when blank data is detected in the loading type column. This allows more complex loading patterns to be defined such as those illustrated in Figure 44 and “Appendix B: Definition of Complex Trainset Configurations”. To extend the bottom of the table beyond the 125 loading definitions extra rows can be inserted (making sure to copy the formulae in columns G and J for Train Loading Group 1 and similarly for others) or the last rows copied and pasted as many times as required.

Similarly, should the number of Train Loading Groups need to be increased from the 10 provided in the template this can be done by selecting the whole of the region defining the tenth Train Loading Group (as indicated in Figure 45) and pasting it as many times to the right of the existing Train Loading Groups (as indicated in Figure 46).

Note. This may require the worksheet to be unprotected first. This worksheet protection should be turned back on immediately after the extra entries for additional loads have been inserted into the worksheet to avoid accidental changes to other parts of the worksheet that could cause errors when the spreadsheet is imported into the Rail Track Analysis tool.

The inputs to the worksheet are:

Number of train loading groups to analyse

This defines the number of Train Loading Groups to include in the analysis. If only a single trainset configuration is to be considered then this should be set to 1. To analyse more than one Train Loading Group the number should be set to a positive integer equal to (or less than) the number of Train Loading Groups that have been defined in the worksheet. No breaks / gaps are permitted in the definition of the Train Loading Groups.

Then, for each of the Train Loading Groups the inputs are:

Number of track loading locations

This defines the number of parametric locations for the placement of the trainset loading carried out in the analysis of this Train Loading Group. If only a single position of the trainset loading is to be considered then this should be set to 1. To analyse more than one location the number should be set to a positive integer.

Loading type

This defines the loading type that will be assigned to the selected track. The first character governs the loading type with valid options being **A**cceleration or **T**raction, **B**raking and **V**ertical. A more descriptive definition of the loading type may be entered if required as illustrated in “Appendix B: Definition of Complex Trainset Configurations” so long as the first character in the description is set to either A, B, T or V.

Track selection to be loaded

This defines the track that the loading will be assigned to for the current Train Loading Group and can be any of the tracks within the model.

For structures supporting two or more tracks the UIC774-3 Code of Practice (Clause 1.4.3) and “Eurocode 1: Actions on Structures – Part 2: Traffic loads on bridges (EN 1991-2:2003)” state that the braking forces on one track shall be considered with the acceleration/traction forces on one other track. In addition, “Eurocode 1: Actions on

Structures – Part 2: Traffic loads on bridges (EN 1991-2:2003)" states that where two or more tracks have the same permitted direction of travel either traction on two tracks or braking on two tracks shall be taken into account. Other codes of practice may have different conditions that need to be considered.

Parametric starting position for loadings

This defines the starting parametric position of the loading of the trainset for the current Train Loading Group. For the trainset the starting position is the left-most position of the load when considering the trainset alone (i.e. independent of the structure). The reference parametric position used for the combination of the trainset loading and the current position on the structure is at a value of zero so positions that are negative will place the defined loading to the left of the reference position defined using the entries in columns H and I and positions that are positive will place the loading to the right.

Parametric end position for loadings

This defines the ending parametric position of the loading of the trainset for the current Train Loading Group. For the trainset the ending position is the right-most position of the load when considering the trainset alone (i.e. independent of the structure). These are relative to the reference position as described for the parametric starting position above.

Amount (per unit length)

This defines the magnitude of the trainset loading in units of kN per metre length for the current Train Loading Group. For longitudinal loads such as acceleration, traction and braking loads a positive value will cause the loading to act towards the right embankment, a negative value will cause the loading to act towards the left embankment. For vertical loads a positive value will cause the loading to act downwards onto the track and structure.

Loaded length

The loaded length is automatically calculated from the parametric starting and end position for the loading and provides a check that these values have been entered correctly. Negative or zero loaded lengths are not permitted in the modelling.

Figure 44 illustrates some trainset loading configurations and their input into the worksheet. Examples (d) and (e) in this figure are equivalent and both definition methods are equally valid in the worksheet. Further examples are illustrated in "Appendix B: Definition of Complex Trainset Configurations".

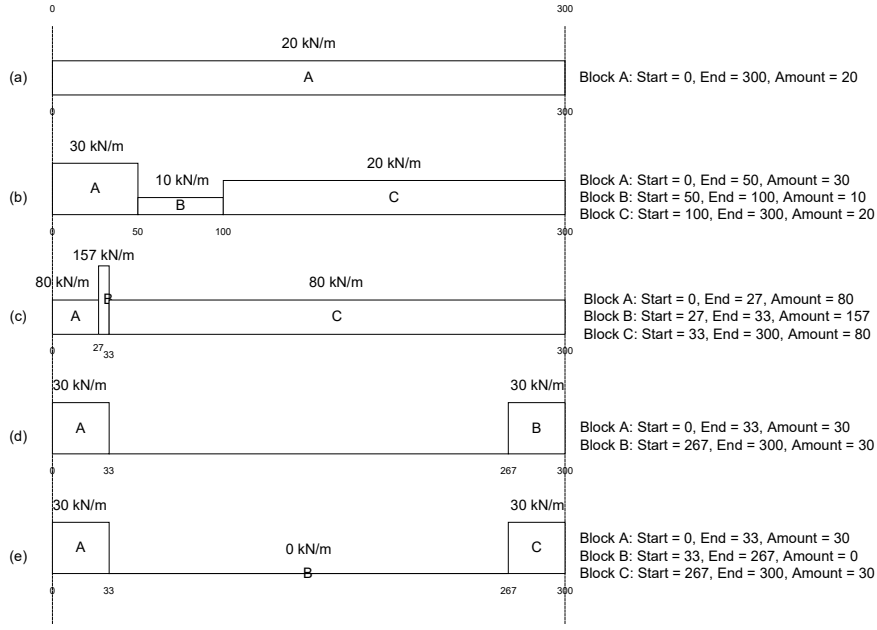


Figure 44: Sample Trainset Loading Position Definitions

Note. It is possible to approximate concentrated loads in trainset loading configurations through the use of UDLs over small contact lengths. Due to the scale of the modelling, with elements typically 1 to 2m in length, the use of a small contact length (such as 5 to 10% of the element length or smaller) allows the concentrated load to be modelled. The procedure for modelling concentrated loads within the Rail Track Analysis tool is covered in “Appendix B: Definition of Complex Trainset Configurations”.

Starting location of loading for first analysis

This defines the starting location of the reference position of the parametric trainset loading on the track for the first analysis for the current Train Loading Group. The location should be defined from the left-most end of the left-hand embankment which is at a location of 0.0m.

The starting position can be defined outside the limits of the rail track. A negative value will place the reference position of the trainset before the left-most end of the left-hand embankment and a value greater than the total track length (available from the Decks, Tracks and Embankment worksheet of the input spreadsheet) will place it after the right-most end of the right-hand embankment.

Any trainset loading outside of the model extents (embankment lengths) will be excluded from the track-structure-interaction analysis.

Finishing location of loading for last analysis

This defines the finishing location of the reference position of the parametric trainset loading on the track for the last analysis for the current Train Loading Group. The location should be defined from the left-most end of the left-hand embankment which is at a location of 0.0m.

The finishing position can be defined in a similar manner to the starting position described above. Any trainset loading outside the model extents (embankment lengths) will be excluded from the track-structure-interaction analysis.

Location increment for each analysis

The location increment for the loading for each analysis is automatically calculated from the starting and finishing locations of the loading and the defined number of track loading locations. All of the loading for a given track should have the same increment to ensure that each component of the loading moves as a group. Generally the starting and finishing locations for the reference position of the loading for a given track should be identical for that track. Different location increments are possible between tracks when more than one track is analysed with positive location increments indicating that the trainset is moving from left to right and negative location increments indicating that the trainset is moving from right to left.

For a single track structure the trainset loading may be stationary (location increment = 0.0m) but for this condition the number of track loading locations <u>must</u> be set to 1. For a two or more track structure, one of the trainsets on one of the tracks may be stationary but an error will result if all trainset loading the tracks are stationary if the number of track loading locations is greater than 1. To analyse multiple stationary trainsets on a two or more track structure the number of track loading locations <u>must</u> be set to 1.

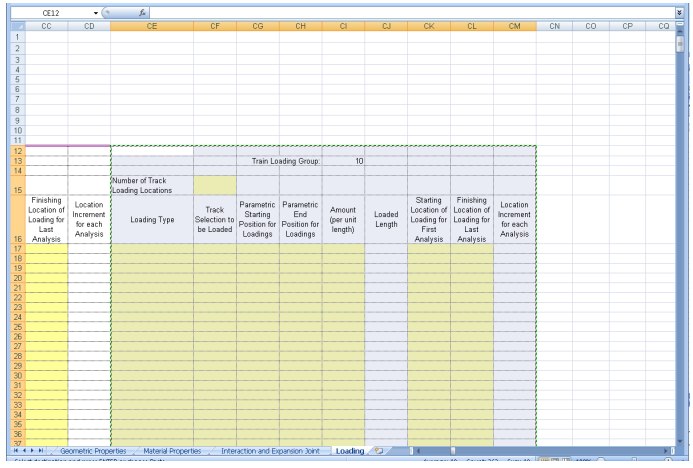


Figure 45: Adding Extra Train Loading Groups (Copy)

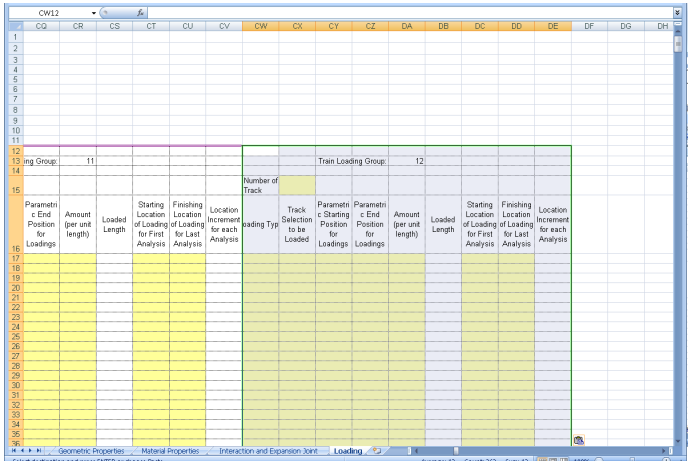


Figure 46: Adding Extra Train Loading Groups (Paste)

Rail Track Analysis Menu Options

The Rail Track Analysis option is accessed through the Bridge menu by selecting the Rail Track Analysis entry. This menu entry provides the following five options:

- **Build UIC774-3 Model…**
- **Apply Rail Loads…**
- **Extract Results to Excel…**
- **Define ZLR/RLR Properties…**
- **Define ZLR/RLR Regions…**

Build UIC774-3 Model Dialog

Model units are specified on the 'Decks, Tracks and Embankments' worksheet and can be specified as either 'N,m,kg,s,C' or 'kip,ft,kslug,s,F'. The first row of each worksheet states the units in use. Note that, by design, changing the model unit units in use (on the 'Decks, Tracks and Embankments' worksheet) does not convert the values in the spreadsheet.

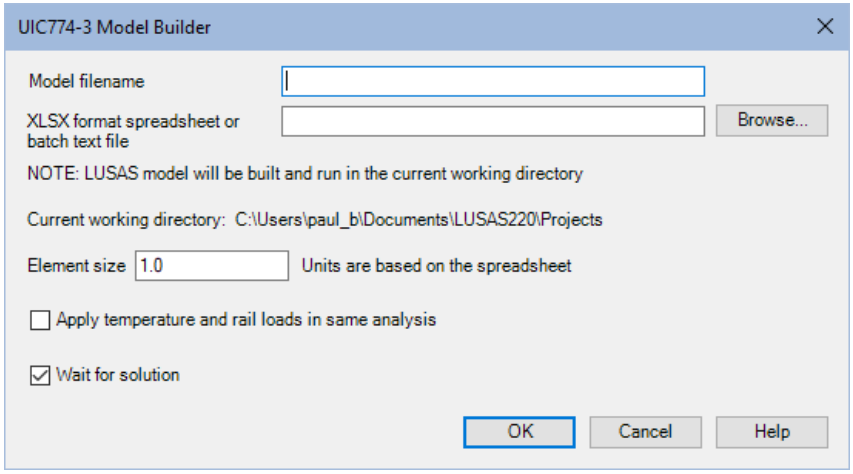


Figure 47: UIC774-3 Model Builder Dialog

- **Model filename** The model filename for the analysis should be entered into the box if batch processing is not being used (see below). The file should not contain any folder specification as all models created will be placed in the current working folder indicated on the dialog.

- **XLSX format spreadsheet or batch text file** If batch processing is not being used and a single model is being created, the filename of the spreadsheet that will be used to define the analysis must be entered into the box (including file extension). If no folder structure is specified, the spreadsheet should be located in the current working folder. Alternatively, the Browse… button may be used to locate the spreadsheet.

  If batch processing of multiple models is being performed, then a batch text file listing the spreadsheets to use for defining the models should be entered into the box (must have a *.txt file extension). The batch text file can be entered explicitly into the dialog or located using the Browse… button and selecting "Batch text file (*.txt)" as the file type.

  For batch processing, the batch can contain spreadsheets with different units.

The format of the batch text file is indicated below and simply contains a TAB delimited list of the spreadsheet files to build the models from and an optional LUSAS model name (if no model name is supplied the basename of the Excel or compatible XLSX spreadsheet will be used) with one model entry per line. If no folder structure is defined for the spreadsheet files then the current working folder will be assumed to contain them, otherwise they may exist at any folder level on the computer system. If a spreadsheet file cannot be found or contains invalid data it will be skipped in the batch processing and an error reported in the "UIC774-3_BuildModel.log" file created in the

current working folder. Blank lines are ignored and batch processing will terminate at the end of the batch text file. The number of analyses in the batch process is unlimited.

In the example below the first model built from the Bridge1.xlsx spreadsheet will be called LUSAS_Bridge1.mdl, the second model will take its basename from the spreadsheet and will be called Bridge2.mdl and the third model will be called RTA_Bridge3.mdl .

```
Bridge1.xlsx      LUSAS_Bridge1
..\SomeFolder\Bridge2.xlsx
D:\Project\Spreadsheet\Bridge3.xlsx   RTA_Bridge3
```

Figure 48: Example Batch Text File With Three Bridges To Build

- **Element Size** The element size to use in the finite element mesh should be specified in this box. According to the UIC774-3 Code of Practice, the maximum element size that is permitted in an analysis is 2.0m (Clause 1.7.3). The dialog therefore generally allows element sizes of 0 < Element Size ≤ 2.0m (or 0 < Element Size ≤ 6.56168ft in the case of US units) for the building of the models. Larger element sizes can be used (up to the length of the smallest bridge deck span) but a warning will be issued about non-compliance with the UIC774-3 Code of Practice. In the case of a batch text file input for multiple input spreadsheets, the units shown in the dialog will be based upon the first indicated spreadsheet.

Note. For large bridges and/or embankments the use of small element sizes can generate excessively large models which take significant time to manipulate / solve. Use of element sizes below 1.0m should be used with caution.

- **Apply temperature and rail loads in same analysis** Two analysis types are available from the model building dialog. These are:

  - The solution of the combined temperature and rail loading effects (option turned on)
  - The solution of just the temperature effects (option turned off)

If only a single rail loading configuration is going to be analysed for a particular model then this option should be switched on.

If, on the other hand, a range of rail loading configurations needs to be applied to a model (for different train positions with varying braking / accelerating loading configurations) then this option should be turned off to allow the rail loads to be applied separately by the **Apply Rail Loads** dialog described below.

Building a model to solve only temperature effects also allows the structural model to be updated prior to applying the rail loading. A situation where this may be needed is

the case where full representation of piers has been included in the track-structure-interaction model rather than the simplified longitudinal equivalent spring approach and the support conditions need be modified for pier foundations to change them from full fixity to a rotational stiffness (see the discussion of the ***Structure Definition*** section of the Excel or compatible XLSX spreadsheet). Other situations may be the need to incorporate varying cross-sections to the decks and spans of the structure (see section "***Varying Section Geometric Properties***") or the addition of girder modelling or additional detailing to the basic deck modelling provided by the Rail Track Analysis tool which couldn't be included within the spreadsheet input (although such additional modelling must be carried out with caution). All of these are possible when a "temperature effects only" model is built in the Rail Track Analysis tool.

Caution. Models created from the original spreadsheet data contain named groups that are used in the creation of results worksheets. Care should be taken to avoid making changes to these groups, the definition/layout of the track-structure-interaction between the tracks and the decks and the loadcases themselves otherwise the application of the rail loading and post-processing may fail. It is also advisable to keep backups of the models and, unless you have extensive experience of modifying Rail Track Analysis models, regularly test the modifications that are made to the model to ensure at minimum that a single trainset loading can still be applied to the rails and post-processed (this will avoid spending a lot of time making modifications to the model only to ultimately find that you have invalidated the track-structure-interaction model for the Rail Track Analysis tool).

- **Wait for solution** If the option to wait for the solution is selected then all of the analyses will be run from Modeller and nothing can be carried out in the current Modeller window until the solution has finished. For relatively small structures or analyses with a limited set of parametric trainset loading locations this is may be fine. If a large number of parametric trainset loading locations are included in an analysis and/or a large number of models are being built using the batch processing, then waiting for the solution can take a considerable amount of time. Under this situation the wait for solution option can be turned off which will cause the analyses to be built and run but the Modeller application will be free for additional tasks.

Caution. You should not attempt to run another rail track analysis in the same folder as an existing analysis is being built or solved. Attempting to do this will corrupt the current analysis that is being built or solved. If sufficient LUSAS / rail track analysis licenses are available on the machine that is being used, then additional rail track analyses can be performed so long as each analysis is performed in a different folder.

Apply Rail Loads Dialog

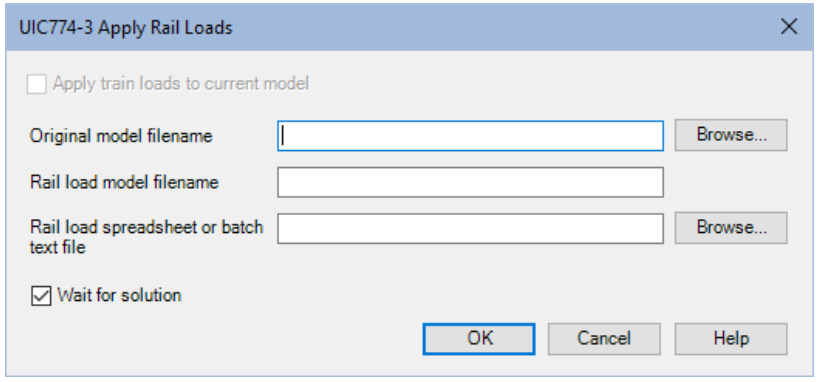


Figure 49: UIC774-3 Apply Rail Loads Dialog

If the bridge model was built and solved with only the temperature loads (**Apply temperature and rail loads in same analysis** turned off in model building dialog) then this model can subsequently be used for applying rail load configurations using this dialog. The dialog should not be used for models that have been built with both the temperature and rail loading applied and will report an error if attempted.

- **Apply train loads to current model** If the current model loaded was generated from the **Build Model...** dialog with the **Apply temperature and rail loads in same analysis** option turned off then this option can be selected. If this option is not selected then the **Original model filename** entry is available for manual selection of the original model containing only temperature loads.

- **Original model filename** If a single rail load configuration is to be analysed and the currently loaded model is not being used, the original model filename should be entered into the box. Alternatively, the Browse… button can be used to locate the original model file containing only the temperature loading. For batch processing the original model filename is ignored.

- **Rail load model filename** If a single rail load configuration is to be analysed the new filename for the model incorporating the temperature and rail loads should be entered into the box. This filename can contain the path name for the model location (folder must exist) but should generally only have the filename defined which will then be saved in the current working folder. This filename can be the same as the original model filename but should generally be different to allow the temperature loading model to be reused for another rail load configuration. For batch processing the new rail load model filename is ignored.

- **Rail load spreadsheet or batch text file** If a single rail load configuration is to be analysed for the specified bridge model the filename of the Excel or compatible XLSX format spreadsheet containing the required loading should be

entered into the box. Alternatively the Browse… button can be used to locate the file. Once the spreadsheet has been specified the OK button can be clicked to carry out the modification of the original bridge model to include the combined effects of the temperature and rail loading. The units in the selected XLSX format spreadsheet must match the units the Rail Track Analysis model was built with.

If multiple models and/or multiple rail load configurations are to be analysed, then only the batch text file (which must have a *.txt file extension) listing the information required by the software should be entered into this box. Alternatively, the Browse… button can be used, selecting "Batch text file (*.txt)" as the file type.

For each model/rail configuration analysis the batch text file should contain a separate line of data. Each line should specify the original temperature model, the new combined loading model to create, and the XLSX format spreadsheet that contains the rail configuration definition. Each item on a line should be TAB delimited to allow spaces to be used in the filenames. An example batch text file is shown below.

```
Bridge1.mdl    Bridge1_RailConfig1.mdl     Bridge1_RailConfig1.xlsx
Bridge1.mdl    Bridge1_RailConfig2.mdl     Bridge1_RailConfig2.xlsx
Bridge1.mdl    Bridge1_RailConfig3.mdl     Bridge1_RailConfig3.xlsx
Bridge1.mdl    Bridge1_RailConfig4.mdl     Bridge1_RailConfig4.xlsx
Bridge2.mdl    Bridge2_RailConfig1.mdl     Bridge2_RailConfig1.xlsx
Bridge2.mdl    Bridge2_RailConfig2.mdl     Bridge2_RailConfig2.xlsx
Bridge3.mdl    Bridge3_RailConfig1.mdl     Bridge3_RailConfig1.xlsx
```

Figure 50: Sample Rail Loading Batch Text File

In the above example, three different bridge deck temperature models have been selected and four rail load configurations analysed for the first, two rail load configurations for the second and one rail load configuration for the third. The number of entries in the batch text file is unlimited and batch processing will terminate once the end of the file is reached. If any analysis fails due to missing or invalid files an error will be reported to the "UIC774-3_RailLoads.log" file in the current working folder.

Note. If the batch text file method is being used the **Apply train loads to current model** option will be ignored since the list of temperature only models to use for the applying of the rail loads for each of the analyses is contained within the batch text file.

- **Wait for solution** If the option to wait for the solution is selected then all of the analyses will be run from Modeller and nothing can be carried out in the current Modeller window until the solution has finished. For relatively small structures or analyses with a limited set of parametric trainset loading locations this is may be fine. If a large number of parametric trainset loading locations are included in an analysis and/or a large number of models are being built using the batch

processing then waiting for the solution can take a considerable amount of time. Under this situation the wait for solution option can be turned off which will cause the analyses to be built and run but the Modeller application will be free for additional tasks.

Caution. You should not attempt to run another rail track analysis in the same folder as the one where an existing analysis is being built or solved. Attempting to do this will corrupt the current analysis that is being built or solved. If sufficient LUSAS / rail track analysis licenses are available on the computer that is being used, then additional rail track analyses can be performed so long as each analysis is performed in a different folder.

Extract Results to Excel Dialog

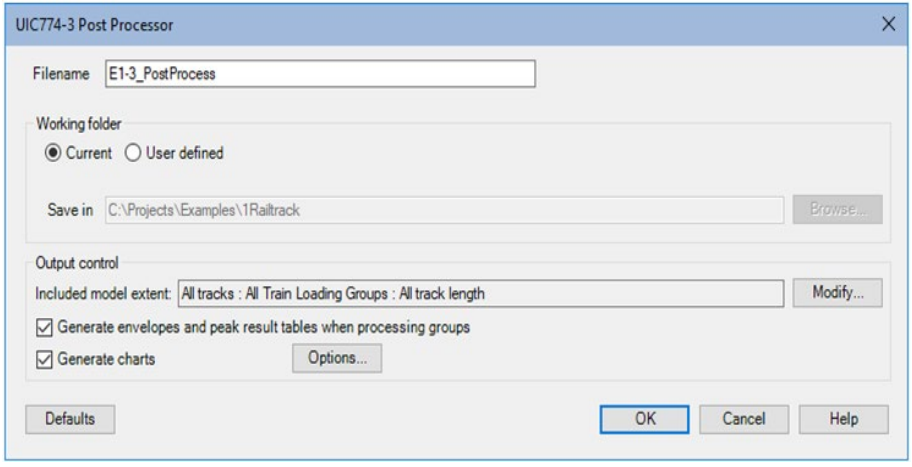


Figure 51: UIC774-3 Post Processor Dialog

A dedicated post-processing dialog is provided that allows the automatic extraction of the results from the track/bridge interaction analysis to an XLSX format spreadsheet. On start-up, if nothing is selected in Modeller, the dialog will inspect the active model to ensure that there are results present and also detect whether the UIC774-3 groups defined during the model building process are present in the Groups Treeview. For this reason any manual editing of the model should be kept to a minimum and the track groups (for example “Track 1”, “Track 2”), deck group (“Decks”) and interaction joint groups (for example “Interaction Springs - Track 1”) should not be modified or renamed.

- **Filename** The filename for the XLSX format spreadsheet that will be created should be entered into this box. The filename must not have any folder structure specified as the file will be placed in the folder selected below.

- **Working folder / Save In** If the spreadsheet is to be saved in a folder other than the current working folder then the User defined option can be selected and the required folder entered into the box or browsed for using the … button.

- **Output control** The output from the post-processor can be customised. By default all output for all tracks and all Train Loading Groups/positions in the analyses are output to the spreadsheet with charts. For very large analyses this can not only take time, but it can also exceed the memory limits. The **Included model extent** allows the selection of the tracks / Train Loading Groups / track extent to be controlled for the post-processing. Further options are also included to control the generation of the envelopes / peak result tables and the generation of individual charts within the post-processing.

- After clicking **OK** the software will perform the requested post-processing and generate a XLSX format spreadsheet in the chosen output folder.

Output Control

The automatic post-processor allows the output extracted from the track-structure-interaction analysis to be customised. This is particularly useful for very large models that may include long structures where specific decks need to be interrogated or where only specific train loading configurations of a larger parametric study need to be considered. Within the **Output control** input of the post-processor the options to perform enveloping/peak summary tables and charting may also be adjusted.

Included model extent

By default all tracks, all Train Loading Groups and the whole track length will be included in any post-processing, and this will be reported in the **Included model extent** textbox when the post-processor is run for the first time on a model as indicated in Figure 51. To change the selected output extent click on the **Modify…** button to display the **Modify Output Control** dialog shown in Figure 52. In this dialog the tracks, Train Loading Groups and track extent to be post-processed can all be selected as illustrated in Figure 53. On clicking the **OK** button in the **Modify Output Control** dialog the main post-processing dialog will mirror the selection in the **Included model extent** textbox (Figure 54).

These settings will be saved with the model and will be available the next time model is loaded, and the post-processing dialog is started to post-process a different track / Train Loading Group / extent of track.

The default settings of outputting all tracks, all Train Loading Groups and the whole rail track length can be reset by clicking the **Defaults** button in the **Modify Output Control** dialog.

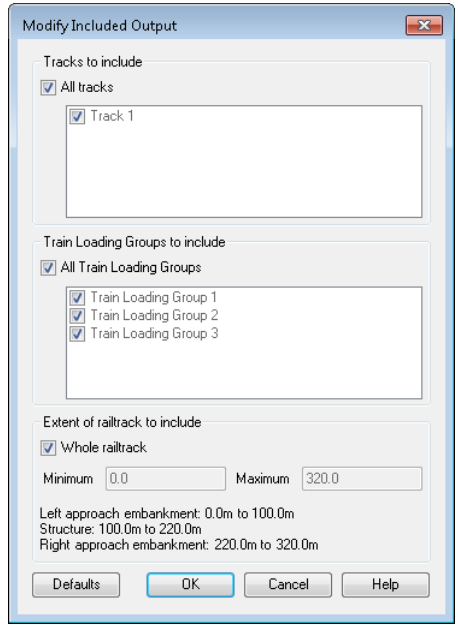


Figure 52: Modify Included Output Dialog

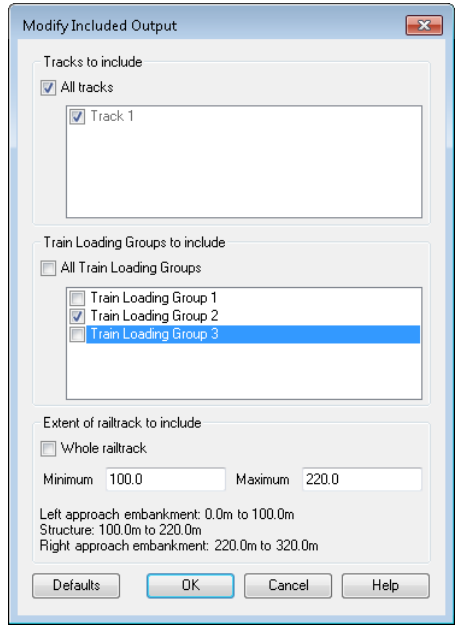


Figure 53: Train Loading Group 2 and Structure Selected Only

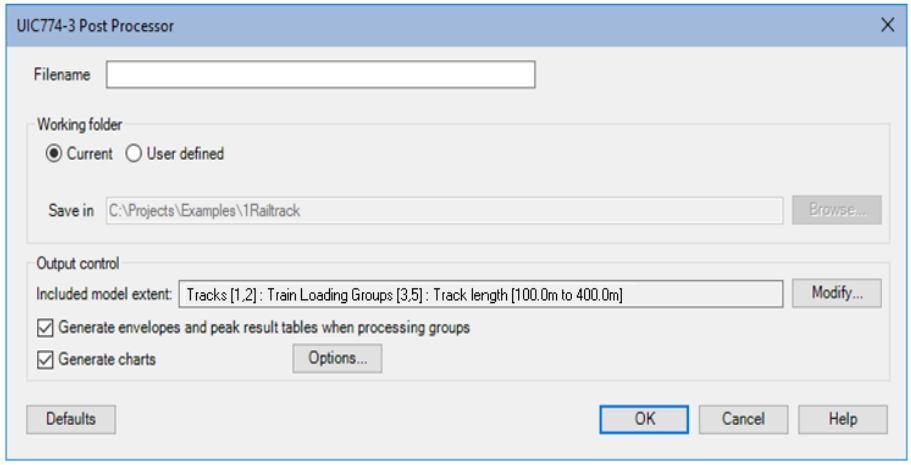


Figure 54: Revised Main Post Processor Dialog

Generate envelopes and peak result tables when processing groups

This option allows the post-processor to perform enveloping prior to outputting the results of these (including charts) to the final XLSX spreadsheet itself. The key advantage of this is that the quantities output can also include derived quantities such as the longitudinal relative railbed displacement (displacement of the track relative to the bridge deck / embankment).

As part of this enveloping operation the post-processor also generates peak result tables for quantities such as the longitudinal relative railbed displacement, displacements between the ends of bridge decks, longitudinal reactions and track axial stresses to allow comparison of the peak observations for each Train Loading Group / trainset position considered with the Code of Practice limits (see section "***Additional Results from Enveloping***" for more information).

Generate charts

By default the post-processing will create charts for all of the key quantities in the output XLSX spreadsheet generated for all of the tracks, Train Loading Groups and track extent selected. Clicking on the ***Modify…*** button will allow the included charts to be adjusted from the defaults shown in Figure 55.

The track charts available for output are:

- ***Railbed / track / deck*** Plots the longitudinal displacements of the track and the structure along with the longitudinal relative railbed (displacement of the track relative to the deck) on a single chart.
- ***Axial rail stress (single track)*** Plots the axial stress for the track that is currently being post-processed.

- ***Axial rail stress (multiple tracks)*** Plots the axial stresses for the current track being post-processed and all other tracks being post-processed. The chart has two further display options to control the legibility of the chart when the number of tracks plotted on the same chart increases.

  Limit for all curves to have peaks labelled controls the maximum number of curves (tracks) allowed in the chart for all of them to still have the peak value labels included. If the number of tracks plotted exceeds this value, then no track plots will have the peaks labelled.

  Limit on total number of curves in chart controls the maximum number of curves (tracks) allowed in the chart. If the number of tracks to be plotted exceeds this value, then the multiple track axial rail stress chart will be excluded from the post-processing spreadsheet.

The deck charts available for output are:

- ***Longitudinal displacement*** Plots the longitudinal displacement of the deck of the structure where the track-structure-interaction occurs between the structure and the ballast. This is generally the "top of the slab" for most decks. These displacements are at the nodal line in the Finite Element model (the geometric sections are modelled eccentric to this with rigid offsets to ensure correct support locations) and they are not the displacements at the neutral axis or the displacements at the bearings.

- ***Vertical displacement*** Plots the vertical displacement of the deck of the structure where the track-structure-interaction occurs.

- ***Rotational displacement*** Plots the rotation of the deck of the structure where the track-structure-interaction occurs.

- ***Axial force*** Plots the axial force in the deck of the structure.

- ***Shear force*** Plots the vertical shear force in the deck of the structure.

- ***Bending moment*** Plots the vertical bending moment in the deck of the structure.

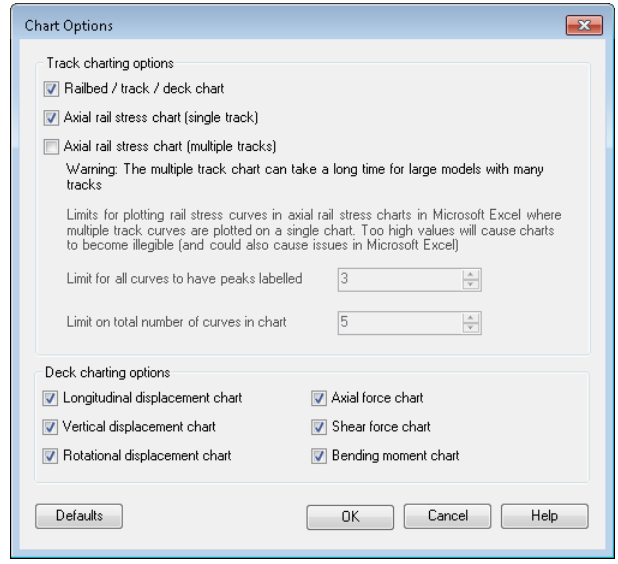


Figure 55: Chart Options Dialog

Define ZLR/RLR Properties Dialog

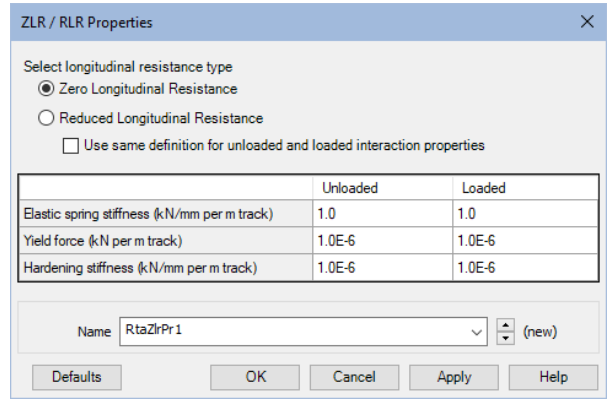


Figure 56: ZLR/RLR Property Definition Dialog

If Zero Longitudinal Resistance (ZLR) and/or Reduced Longitudinal Resistance (RLR) regions are to be included in the track-structure-interaction modelling, then the definitions of the ZLR and/or RLR properties need to be created using the **ZLR/RLR Properties** dialog.

- **Zero Longitudinal Resistance** For a rail fastener connection which provides effectively frictionless movement of the rail in the longitudinal direction. The default properties can be modified if minor resistance is observed or if the rail fastener is able to resist some longitudinal load when the train loading is present (under the "Loaded" condition).

- **Reduced Longitudinal Resistance** For a rail fastener connection/ballast system that provides reduced resistance in the longitudinal direction compared to the original system modelled in the track-structure-interaction model. See below for defaults.

- **Use same definition for unloaded and loaded interaction properties** If selected, only a single set of bilinear interaction properties needs to be defined which applies to both the Unloaded (temperature only) and the Loaded (temperature and train loading) conditions. If the option is not selected (the default), then separate bilinear interaction properties are defined for the two conditions.

- **Name** Enter a unique attribute name for the ZLR/RLR property. The ZLR/RLR property definition will appear under the "Rail Track Analysis>ZLR/RLR Properties" entry in the Utilities Treeview.

The input for the ZLR and RLR property definitions is the same as the input for the original Excel or compatible XLSX format spreadsheet described in the ***Bilinear Interaction Properties*** sub-section under the ***Worksheet 5: Interaction and Expansion Joint Properties*** section.

For a RLR resistance type the default properties for a model that has a single ballast type will be the original properties that were input into the spreadsheet that was used to build the Rail Track Analysis model. This makes it easy to define the reduced resistance attribute as these values can then be modified using standard formulae such as 0.5*Val where Val is the default number that has been placed into the dialog. Clicking the "Defaults" button for a model with a single ballast type will populate the RLR properties with these original spreadsheet values again.

For a RLR resistance type for a model with multiple ballast types there will be no default properties and clicking the "Defaults" button will clear the dialog for this type of model. When a Rail Track Analysis model has multiple ballast types, the dialog is unable to determine which ballast type the default should be returned for.

Note. The hardening stiffness for all resistance types is normally set to a very small number, default = 1.0E-6 kN/mm per m track, to ensure perfectly plastic yielding without numerical issues. Setting a larger hardening stiffness will cause plastic hardening after yielding and usually incorrect results from the Rail Track Analysis.

Define ZLR/RLR Regions Dialog

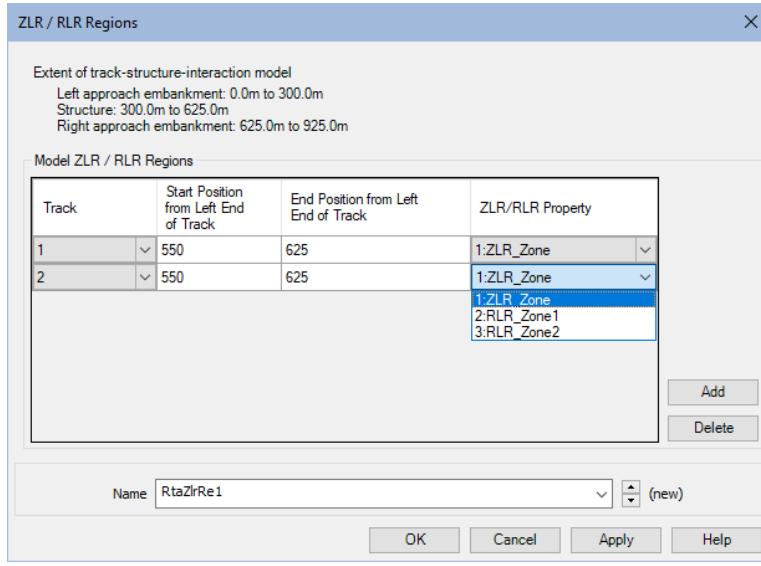


Figure 57: ZLR/RLR Region Definition Dialog

Any ZLR and/or RLR regions are defined using the **ZLR/RLR Regions** dialog. A region contains all of the zones of different longitudinal resistances (ZLR and/or RLR) that define the entire changes to the original bilinear track-structure-interaction definitions that were created from the original input spreadsheet used to build the Rail Track Analysis model. If it is selected for the Rail Track Analysis, a ZLR/RLR Region definition will overwrite the original track-structure-interaction definitions over the zones that have been specified in the region definition.

Each region definition includes one or more of the following entries to define a zone within the region:

- **Track** The rail track that the current ZLR/RLR zone applies to.
- **Start Position from Left End of Track** The start (left end) of the current ZLR/RLR zone relative to the far left end of the track / start of the left-hand approach embankment.
- **End Position from Left End of Track** The end (right end) of the current ZLR/RLR zone relative to the far left end of the track / start of the left-hand approach embankment.
- **ZLR/RLR Property** Name of the ZLR/RLR property to use for the current zone.

The final input for the region definition is:

- **Name** Enter a unique attribute name for the ZLR/RLR region. The ZLR/RLR region definition will appear under the "Rail Track Analysis>ZLR/RLR Regions" entry in the Utilities Treeview.

To add a new ZLR/RLR zone click the **Add** button. Select the required rail track for the new zone from the list and enter the required start and end positions then select the required ZLR/RLR property from the available list. To delete zones from the region definition, select cells in the rows of the grid that you wish to delete and click the **Delete** button.

The start and end of the modified longitudinal resistance zones for each rail track are defined relative to the left end of the rail track (relative to the start of the left approach embankment). This allows zones of ZLR or RLR to be placed anywhere within the length of the model. To assist with the placing of the zones a summary of the key model geometry is provided above the main input table in the dialog.

The ZLR/RLR property is selected from the properties that have been previously defined in the **ZLR / RLR Property** definition dialog.

If a ZLR/RLR zone is specified later in the region definition that overlaps a previous ZLR/RLR zone for the same rail track, the new ZLR/RLR zone will overwrite the previous zone where the overlap occurs in the definition for that rail track.

A ZLR / RLR region will not affect the behaviour of the track-structure-interaction model until it is set active. Only a single ZLR / RLR region can be active in the model.

Within a single model it is possible to define more than one region should a master model be needed for a sensitivity study – this will be discussed more in the section below on how to use ZLR/RLR modelling.

Exporting/Importing ZLR/RLR Data from Models

Where a set of ZLR/RLR property and potentially ZLR/RLR region definitions need to be shared across multiple models the data export/import tools within Modeller can be used to store the definitions within a library. All or just part of the data within the library can then be transferred from one model to the other via the library. The tools are accessed from the **File > Import/Export Model Data**... menu entry.

Figure 58 shows an example of the exporting of the full definition of a combined ZLR/RLR region with its associated ZLR and RLR property definitions from a model. For a different rail track analysis model Figure 59 shows that the library has been selected for importing. For this model only the ZLR and RLR properties are going to be imported though and not the region.

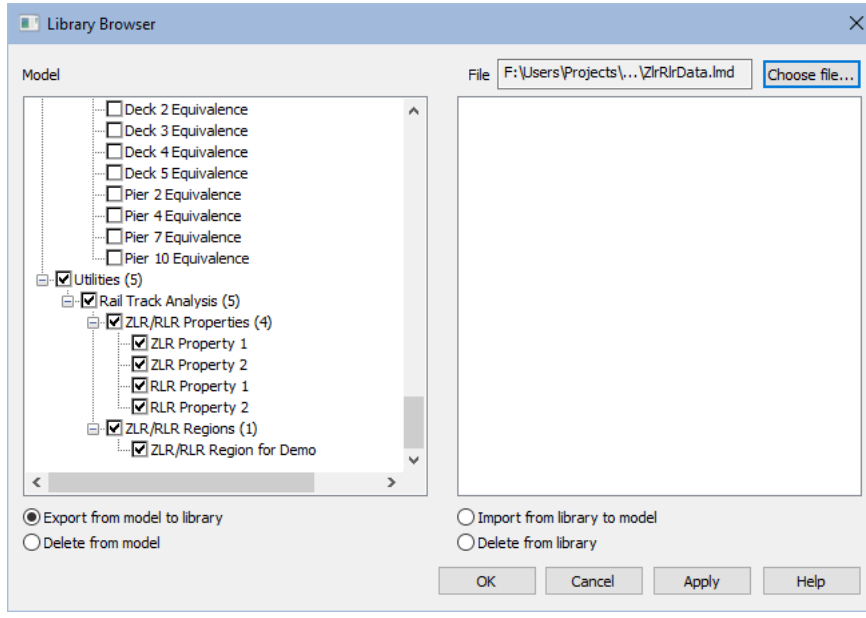


Figure 58: Exporting the ZLR and RLR Properties and Region

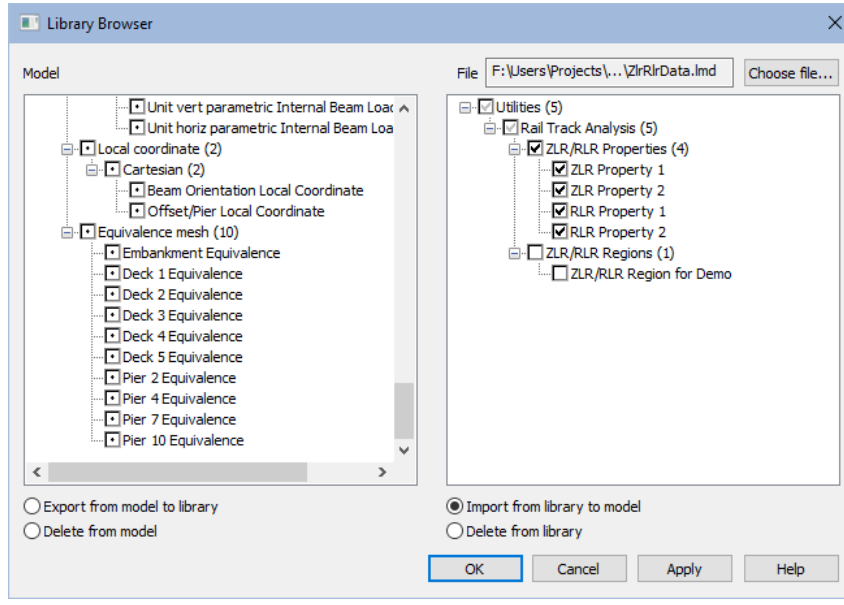


Figure 59: Importing the ZLR and RLR Properties Only

Note. Care should be taken when importing both RLR properties and ZLR/RLR regions from libraries. RLR properties may be specific to the track-structure-interaction parameters of the models that they were originally defined for. Similarly, the zones / lengths of zones defined in the ZLR/RLR regions in a library may specifically relate to a particular structure that was analysed and from which the library was created.

Only the export/import of ZLR/RLR properties should be attempted using this tool. Attempting to export/import any other aspects of the rail track analysis modelling is likely to invalidate the rail track analysis and could stop an analysis from being performed successfully.

Performing a ZLR/RLR Rail Track Analysis

A Rail Track Analysis model must have been built from the input Excel or compatible XLSX spreadsheet before any ZLR/RLR properties or regions can be defined in a model. It is also usual that the results of the Rail Track Analysis would have been inspected (either manually or using the automatic post-processing facilities provided by the Rail Track Analysis tool) to determine where the regions of ZLR/RLR should be placed to relieve regions of high axial stress in the tracks.

The ZLR/RLR properties and regions can then be defined in the model using the dialogs that are described above. Once a fully qualified ZLR/RLR region has been defined the region needs to be set active in Modeller before it will affect the Rail Track Analysis. A region is set active by right-clicking on it in the Utilities Treeview and selecting the “Set Active” option. More than one ZLR/RLR region can be defined in the model but only one ZLR/RLR region can be set active within the model at any time. The definition of the regions (in terms of the ZLR/RLR zones within the region) may be as complex as necessary though to define the model.

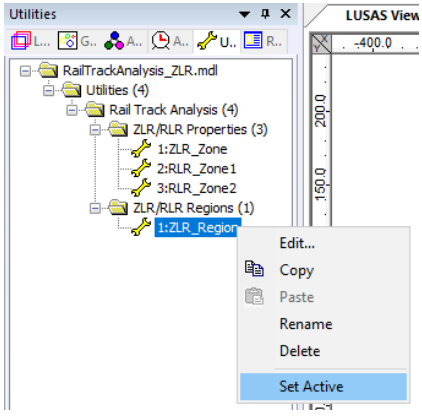


Figure 60: Setting a ZLR/RLR Region Active

Note. It is also possible to set all regions inactive (by right-clicking on the active region and deselecting the "Set Active") to return the track-structure-interaction model to the state it was before any ZLR / RLR regions were defined.

There are two ways that the ZLR / RLR modelling can be used in the Rail Track Analysis tool, iteratively or through a sensitivity study using a master model that has a variety of ZLR/RLR configurations defined within it.

Method 1: Iteratively

The iterative approach will generally be the more common approach to find a configuration that meets the design criteria. For this an initial track-structure-interaction analysis will have been carried out and the response obtained.

1) Where excessive rail axial stresses have been observed in particular regions, the interaction is modified to include ZLR and/or RLR at strategic locations,

2) The model is saved (often as a new filename to preserve the original model), resolved and post-processed again to assess the effect of the configuration of ZLR and/or RLR,

3) The performance of the current design is assessed: If the performance is unacceptable then the arrangement of ZLR and/or RLR is modified and we return to 2); if the performance is acceptable then exit the iteration process.

Method 2: Sensitivity

The sensitivity approach is based more on engineering judgement and past experience since it generally requires some knowledge of the types of layouts of ZLR and/or RLR that would be needed to meet the design criteria for reducing the excessive rail axial stresses. It could also be used if specific layouts to be considered were specified from the start of a project. An initial track-structure-interaction analysis will have been carried out and the response obtained.

1) Excessive rail axial stresses are observed in particular regions indicating where it may be beneficial to include ZLR and/or RLR,

2) Based on engineering judgement and past experience multiple configurations of ZLR and/or RLR are 'designed' and input into a 'master' model but are left deactivated, so they have no effect on the track-structure-interaction analysis. This master model is saved (often as a new filename to preserve the original model) to be used for the creation of all subsequent sensitivity models,

3) For each ZLR and/or RLR region in the master model:

    a. Load the master model,

b. Set the appropriate ZLR/RLR region active,

c. Save the model as a new filename, solve and post-process the analysis to allow the assessment of the effect of the configuration of ZLR and/or RLR,

d. The performance of the current design is assessed: If the performance is unacceptable then the next arrangement of ZLR and/or RLR in the master model will be considered and we return to 3); if the performance is acceptable then

   i. Either accept the current design and exit the study, or

   ii. Return to 3) to continue with the sensitivity study to see if another of the ZLR and/or RLR configurations gives a better performance.

Rail Track Analysis Results Spreadsheet

The results spreadsheet contains worksheets of results for specific areas of interest. The number of worksheets created will depend upon the number of tracks and decks modelled and whether enveloping of results was selected.

When using the Rail Track Analysis post-processor dialog the post-processing carried out is dependent upon whether any selections have been made in LUSAS Modeller. The Rail Track analysis post-processor can carry out:

- **Post-processing of automatically defined groups** (when no selections have been made in Modeller)
- **Post-processing of selected track / rail nodes**
- **Post-processing of selected lines if groups are missing** (if they are meshed with beam elements)

Results Worksheets Created

The spreadsheet created will contain worksheets that typically include results for:

- **Track 1, 2 etc**
- **Deck 1, 2, 3 etc**
- **Envelope, Track 1, 2 etc**
- **Envelope, Deck 1, 2, 3 etc**
- **Railbed Check**
- **Longitudinal Reactions Check**

- **Rail Stresses Check**

and, if more than one deck is defined in the model, additional results for:

- **Deck End Longitudinal Displacements (axial, end rotations and total)**
- **Deck End Vertical Displacements**

plus, if ZLR/RLR modelling is included:

- **ZLR-RLR Summary**

Note. Results shown in this version of the manual were captured in previous versions of the software. Colours used for charting will differ in the latest version owing to updates made by LUSAS and changes made by Microsoft to the default colour scheme in Excel, from which they were captured.

Post-processing of Automatically Defined Groups

If nothing is selected in the Modeller window and all of the UIC774-3 groups are present in the Groups Treeview then separate results worksheets are generated for the tracks/rails and decks. If more than one results file is loaded, no combinations or envelopes are defined in the LUSAS model and enveloping has been selected then additional envelope results output is generated in separate results worksheets.

If basic combinations or envelopes were defined in the LUSAS model the results from these are output to the tracks/rails and decks worksheets in addition to the temperature only and combined temperature and train loading results. If enveloping has been selected, then an additional envelope will be generated for the basic combinations included in the model (and these results will be included in the overall envelope of all results).

Note. Basic combinations that contain only pure loadcases can be post-processed but basic combinations that contain envelopes or smart combinations cannot be post-processed. Envelopes cannot be post-processed if they contain smart combinations. It should, however, be noted that the creation of combinations of nonlinear results (such as those from the Rail Track Analysis tool) is not strictly valid and results should be used with caution.

ZLR/RLR Summary

If a Rail Track Analysis that includes ZLR and/or RLR modelling has been performed, then the first worksheet in the results spreadsheet will contain a summary of the zone and associated property definitions used within the active region for the analysis.

A sample summary for a Rail Track Analysis with a simple ZLR region is shown in Figure 61. The summary shows that the Rail Track Analysis has an active ZLR/RLR region consisting of matching ZLR zones for the two tracks that use a single ZLR property definition.

Summary of Zero Longitudinal Resistance / Reduced Longitudinal Resistance Definitions

Job Title: UIC 774-3 Model: Esveld-TempAndTGV
Analysis Filename: EsveldZLR_TempAndTGV~Analysis 1
Model Directory: F:\Users\Projects\RailTrackAnalysis
Analysis Date: 12/08/2022
Model Units: N,m,kg,s,C

ZLR / RLR Region Definition **Region Name:** Deck 6: 75m ZLR Region

Track	Start Position from Left End of Track (m)	End Position from Left End of Track (m)	ZLR/RLR Property
1	610	685	ZLR Properties
2	610	685	ZLR Properties

NOTE: Finite Element mesh discretisation for track-structure-interaction joint modelling means that some minor differences may occur

ZLR / RLR Property Definitions

ZLR/RLR Property	Property Type	Unloaded			Loaded		
		Elastic spring stiffness (kN/mm per m track)	Yield force (kN per m track)	Hardening stiffness (kN/mm per m track)	Elastic spring stiffness (kN/mm per m track)	Yield force (kN per m track)	Hardening stiffness (kN/mm per m track)
ZLR Properties	ZLR	1	0.000001	0.000001	1	0.000001	0.000001

ZLR-RLR Summary | Track 1 | Track 2 | Decks

Figure 61: ZLR/RLR Properties and Active Region Summary

The ZLR/RLR region definition can consist of a simple zone as illustrated in Figure 61 or it could consist of multiple zones with different properties – the number of ZLR/RLR properties that can be defined and assigned to a ZLR/RLR region is unlimited. When the zones of ZLR/RLR are defined in the ZLR/RLR region dialog, if positions within the definitions of the zones of a rail track overlap the last zone defined in the table for a particular rail track will overwrite the previous definitions for that rail track. Messages will have been issued when the original region was defined and these will be repeated in the summary as illustrated in the example shown in Figure 62 below.

Summary of Zero Longitudinal Resistance / Reduced Longitudinal Resistance Definitions

Job Title: UIC 774-3 Model: Esveld-TempAndTGV
Analysis Filename: EsveldMultiZLRandRLR_TempAndTGV~Analysis 1
Model Directory: F:\Users\Projects\RailTrackAnalysis
Analysis Date: 12/08/2022
Model Units: N,m,kg,s,C

ZLR / RLR Region Definition **Region Name:** Unrealistic ZLR/RLR Region for Demo

Track	Start Position from Left End of Track (m)	End Position from Left End of Track (m)	ZLR/RLR Property	
1	0	1038	RLR Property 1	
1	300	738	RLR Property 2	Overlaps a previous region in the ZLR / RLR definition
1	610	685	ZLR Property 1	Overlaps a previous region in the ZLR / RLR definition
1	713	763	ZLR Property 2	Overlaps a previous region in the ZLR / RLR definition
2	0	1038	RLR Property 1	
2	300	738	RLR Property 2	Overlaps a previous region in the ZLR / RLR definition
2	610	685	ZLR Property 1	Overlaps a previous region in the ZLR / RLR definition
2	713	763	ZLR Property 2	Overlaps a previous region in the ZLR / RLR definition

NOTE: Finite Element mesh discretisation for track-structure-interaction joint modelling means that some minor differences may occur

ZLR / RLR Property Definitions

ZLR/RLR Property	Property Type	Unloaded			Loaded		
		Elastic spring stiffness (kN/mm per m track)	Yield force (kN per m track)	Hardening stiffness (kN/mm per m track)	Elastic spring stiffness (kN/mm per m track)	Yield force (kN per m track)	Hardening stiffness (kN/mm per m track)
RLR Property 1	RLR	8.75	17.5	0.000001	8.75	17.5	0.000001
RLR Property 2	RLR	7.5	15	0.000001	7.5	15	0.000001
ZLR Property 1	ZLR	1	0.000001	0.000001	1	0.000001	0.000001
ZLR Property 2	ZLR	1	0.000001	0.000001	1	0.000001	0.000001

ZLR-RLR Summary | Track 1 | Track 2 | Decks

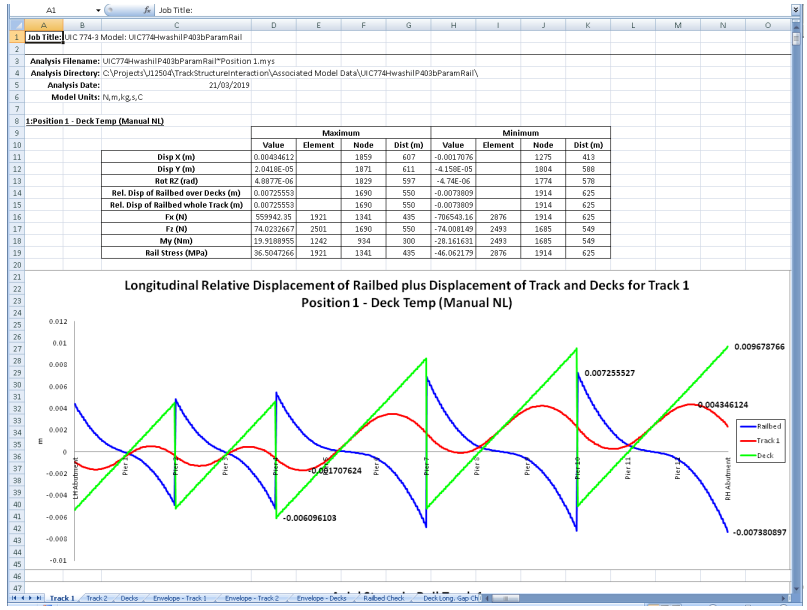
Figure 62: Region Summary with Multiple Zones and Properties (including overlaps)

Rail Track Results

A separate results worksheet is created for each track in the model. In this worksheet the displacement (including railbed relative displacement), forces / moments and axial stresses in the track rails are reported for all of the results files. If only temperature results exist in a results file the post-processing will only generate the output for these (Increment 1 of the nonlinear analysis), Figure 63 to Figure 65. If trainset loading is also present in the analyses then for each results file the results for the temperature only (Increment 1 of the nonlinear analysis) and the combined temperature and trainset loading (Increment 2 of the nonlinear analysis) are output for each results file, Figure 66 to Figure 68.

Figure 69 shows a zoomed out version of the worksheet showing the output for multiple results files. In this figure the temperature only and combined results for two results files are illustrated with the analyses incrementing from left to right and for each, the first column of results and graphs are for the temperature only case and the second column are for the combined case for each analysis.

Note. When only a single Train Loading Group is analysed the results and charts will report results / chart titles as “Position ? – Deck Temp (Manual NL)” or “Position ? – Train Loads”. For analyses where multiple Train Loading Groups are included then each of the results / chart titles will reflect the Train Loading Group and position with text such as “Train Loading Group ? – Position ? – Train Loads” to identify the results and charts within the post-processing spreadsheet (and provide fully titled charts should these be copied and pasted from the spreadsheet).



Job Title: UIC 774-3 Model: UIC774HwashIIP403bParamRail

Analysis Filename: UIC774HwashIIP403bParamRail~Position 1.mys
Analysis Directory: C:\Projects\J12504\TrackStructureInteraction\Associated Model Data\UIC774HwashIIP403bParamRail\
Analysis Date: 21/03/2019
Model Units: N,m,kg,s,C

1:Position 1 - Deck Temp (Manual NL)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00434612		1859	607	-0.0017076		1275	413
Disp Y (m)	2.0416E-05		1871	611	-4.158E-05		1804	588
Rot RZ (rad)	4.8877E-06		1829	597	-4.74E-06		1774	578
Rel. Disp of Railbed over Decks (m)	0.00725553		1690	550	-0.0073809		1914	625
Rel. Disp of Railbed whole Track (m)	0.00725553		1690	550	-0.0073809		1914	625
Fx (N)	559942.35	1921	1341	435	-706543.16	2876	1914	625
Fz (N)	74.0232667	2501	1690	550	-74.008149	2493	1685	549
My (Nm)	19.9188955	1242	934	300	-28.161631	2493	1685	549
Rail Stress (MPa)	36.5047266	1921	1341	435	-46.062179	2876	1914	625

Figure 63: Track Worksheet Summary and Railbed Graph for Temperature Only Results of Analysis, Increment 1 (1 of 3)

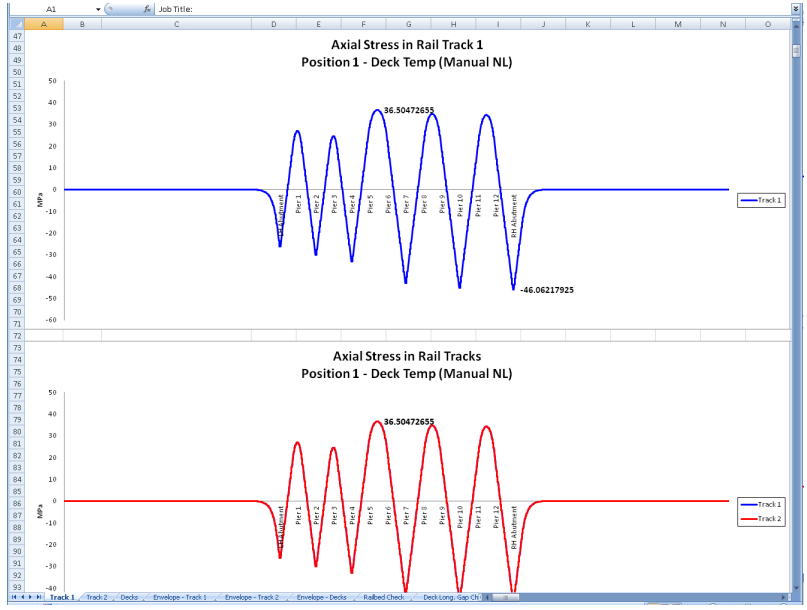


Figure 64: Track Worksheet Rail Stress Graphs for Temperature Only Results of Analysis, Increment 1 (2 of 3)

A1 Job Title:

	Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Rel. Disp of Railbed (m)	Fx (N)	Fz (N)	My (Nm)	Rail Stress (MPa)
99															
100	39	33		0	-300	0	0	0	0	0	0	-3.034E-15	1.212E-209	2.086E-210	-1.978E-19
101	39	38		1	-299	0	0	-9.42E-25	9.172E-219	1.113E-216	-9.42E-25	-3.034E-15	1.212E-209	2.086E-210	-1.978E-19
102	44	38		1	-299	0	0	-9.42E-25	9.172E-219	1.113E-216	-9.42E-25	-3.11E-15	-4.49E-209	-1.35E-209	-2.027E-19
103	44	39		2	-298	0	0	-1.907E-24	-2.43E-218	-4.63E-216	-1.907E-24	-3.11E-15	-4.49E-209	-1.35E-209	-2.027E-19
104	48	39		2	-298	0	0	-1.907E-24	-2.43E-218	-4.63E-216	-1.907E-24	-3.262E-15	1.76E-208	5.203E-209	-2.127E-19
105	48	43		3	-297	0	0	-2.92E-24	9.113E-218	1.81E-215	-2.92E-24	-3.262E-15	1.76E-208	5.203E-209	-2.127E-19
106	51	43		3	-297	0	0	-2.92E-24	9.113E-218	1.81E-215	-2.92E-24	-3.496E-15	-6.85E-208	-2.03E-208	-2.279E-19
107	51	46		4	-296	0	0	-4.005E-24	-3.55E-217	-7.05E-215	-4.005E-24	-3.496E-15	-6.85E-208	-2.03E-208	-2.279E-19
108	56	46		4	-296	0	0	-4.005E-24	-3.55E-217	-7.05E-215	-4.005E-24	-3.816E-15	2.669E-207	7.892E-208	-2.480E-19
109	56	49		5	-295	0	0	-5.19E-24	1.381E-216	2.746E-214	-5.19E-24	-3.816E-15	2.669E-207	7.892E-208	-2.480E-19
110	59	49		5	-295	0	0	-5.19E-24	1.381E-216	2.746E-214	-5.19E-24	-4.232E-15	-1.04E-206	-3.07E-207	-2.759E-19
111	59	52		6	-294	0	0	-6.504E-24	-5.38E-216	-1.07E-213	-6.504E-24	-4.232E-15	-1.04E-206	-3.07E-207	-2.759E-19
112	63	52		6	-294	0	0	-6.504E-24	-5.38E-216	-1.07E-213	-6.504E-24	-4.752E-15	4.048E-206	1.197E-206	-3.098E-19
113	63	55		7	-293	0	0	-7.979E-24	2.094E-215	4.165E-213	-7.979E-24	-4.752E-15	4.048E-206	1.197E-206	-3.098E-19
114	67	55		7	-293	0	0	-7.979E-24	2.094E-215	4.165E-213	-7.979E-24	-5.39E-15	-1.58E-205	-4.66E-206	-3.514E-19
115	67	58		8	-292	0	0	-9.653E-24	-8.16E-215	-1.62E-212	-9.653E-24	-5.39E-15	-1.58E-205	-4.66E-206	-3.514E-19
116	71	58		8	-292	0	0	-9.653E-24	-8.16E-215	-1.62E-212	-9.653E-24	-6.162E-15	6.14E-205	1.816E-205	-4.018E-19
117	71	62		9	-291	0	0	-1.157E-23	3.177E-214	6.318E-212	-1.157E-23	-6.162E-15	6.14E-205	1.816E-205	-4.018E-19
118	76	62		9	-291	0	0	-1.157E-23	3.177E-214	6.318E-212	-1.157E-23	-7.088E-15	-2.39E-204	-7.07E-205	-4.621E-19
119	76	65		10	-290	0	0	-1.377E-23	-1.24E-213	-2.46E-211	-1.377E-23	-7.088E-15	-2.39E-204	-7.07E-205	-4.621E-19
120	79	65		10	-290	0	0	-1.377E-23	-1.24E-213	-2.46E-211	-1.377E-23	-8.189E-15	9.313E-204	2.754E-204	-5.339E-19
121	79	66		11	-289	0	0	-1.631E-23	4.819E-213	9.583E-211	-1.631E-23	-8.189E-15	9.313E-204	2.754E-204	-5.339E-19
122	83	66		11	-289	0	0	-1.631E-23	4.819E-213	9.583E-211	-1.631E-23	-9.494E-15	-3.63E-203	-1.07E-203	-6.189E-19
123	83	71		12	-288	0	0	-1.926E-23	-1.88E-212	-3.73E-210	-1.926E-23	-9.494E-15	-3.63E-203	-1.07E-203	-6.189E-19
124	87	71		12	-288	0	0	-1.926E-23	-1.88E-212	-3.73E-210	-1.926E-23	-1.103E-14	1.413E-202	4.177E-203	-7.193E-19
125	87	72		13	-287	0	0	-2.268E-23	7.309E-212	1.454E-209	-2.268E-23	-1.103E-14	1.413E-202	4.177E-203	-7.193E-19
126	91	72		13	-287	0	0	-2.268E-23	7.309E-212	1.454E-209	-2.268E-23	-1.285E-14	-5.5E-202	-1.63E-202	-8.376E-19
127	91	77		14	-286	0	0	-2.667E-23	-2.85E-211	-5.66E-209	-2.667E-23	-1.285E-14	-5.5E-202	-1.63E-202	-8.376E-19
128	95	77		14	-286	0	0	-2.667E-23	-2.85E-211	-5.66E-209	-2.667E-23	-1.498E-14	2.143E-201	6.336E-202	-9.767E-19
129	95	79		15	-285	0	0	-3.132E-23	1.109E-210	2.205E-208	-3.132E-23	-1.498E-14	2.143E-201	6.336E-202	-9.767E-19
130	99	79		15	-285	0	0	-3.132E-23	1.109E-210	2.205E-208	-3.132E-23	-1.749E-14	-8.34E-201	-2.47E-201	-1.14E-18
131	99	83		16	-284	0	0	-3.675E-23	-4.32E-210	-8.59E-208	-3.675E-23	-1.749E-14	-8.34E-201	-2.47E-201	-1.14E-18
132	104	83		16	-284	0	0	-3.675E-23	-4.32E-210	-8.59E-208	-3.675E-23	-2.043E-14	3.25E-200	9.61E-201	-1.332E-18
133	104	84		17	-283	0	0	-4.309E-23	1.682E-209	3.344E-207	-4.309E-23	-2.043E-14	3.25E-200	9.61E-201	-1.332E-18
134	107	84		17	-283	0	0	-4.309E-23	1.682E-209	3.344E-207	-4.309E-23	-2.388E-14	-1.27E-199	-3.74E-200	-1.557E-18
135	107	87		18	-282	0	0	-5.05E-23	-6.55E-209	-1.3E-206	-5.05E-23	-2.388E-14	-1.27E-199	-3.74E-200	-1.557E-18
136	112	87		18	-282	0	0	-5.05E-23	-6.55E-209	-1.3E-206	-5.05E-23	-2.792E-14	4.93E-199	1.458E-199	-1.82E-18
137	112	91		19	-281	0	0	-5.917E-23	2.551E-208	5.072E-206	-5.917E-23	-2.792E-14	4.93E-199	1.458E-199	-1.82E-18
138	116	91		19	-281	0	0	-5.917E-23	2.551E-208	5.072E-206	-5.917E-23	-3.265E-14	-1.92E-198	-5.68E-199	-2.129E-18
139	116	94		20	-280	0	0	-6.931E-23	-9.93E-208	-1.98E-205	-6.931E-23	-3.265E-14	-1.92E-198	-5.68E-199	-2.129E-18
140	119	94		20	-280	0	0	-6.931E-23	-9.93E-208	-1.98E-205	-6.931E-23	-3.819E-14	7.477E-198	2.211E-198	-2.49E-18
141	119	96		21	-279	0	0	-8.116E-23	3.869E-207	7.694E-205	-8.116E-23	-3.819E-14	7.477E-198	2.211E-198	-2.49E-18
142	123	96		21	-279	0	0	-8.116E-23	3.869E-207	7.694E-205	-8.116E-23	-4.469E-14	-2.91E-197	-8.61E-198	-2.913E-18
143	123	99		22	-278	0	0	-9.504E-23	-1.51E-206	-3E-204	-9.504E-23	-4.469E-14	-2.91E-197	-8.61E-198	-2.913E-18

Track 1 | Track 2 | Decks | Envelope - Track 1 | Envelope - Track 2 | Envelope - Decks | Railbed Check | Deck Long - Gap Ch

Figure 65: Track Worksheet Tabulated Output for Temperature Only Results of Analysis, Increment 1 (3 of 3)

A1 Job Title:

8: Position 4 - Train Loads

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00943460		1632	531	0		33	0
Disp Y (m)	1.6738E-05		1833	598	-0.0011922		1656	539
Rot RZ (rad)	0.00017484		1685	549	-0.0001154		1628	530
Rel. Disp of Railbed over Decks (m)	0.00994426		1690	550	-0.0082287		1914	625
Rel. Disp of Railbed whole Track (m)	0.00994426		1690	550	-0.0082287		1914	625
Fx (N)	56485.835	1921	1341	435	-347734.03	2493	1685	549
Fz (N)	4681.62541	2493	1685	549	-4658.7747	2501	1690	550
My (Nm)	1765.79837	2501	1690	550	-686.86805	2457	1665	542
Rail Stress (MPa)	36.824403	1921	1341	435	-61.78631	2493	1685	549

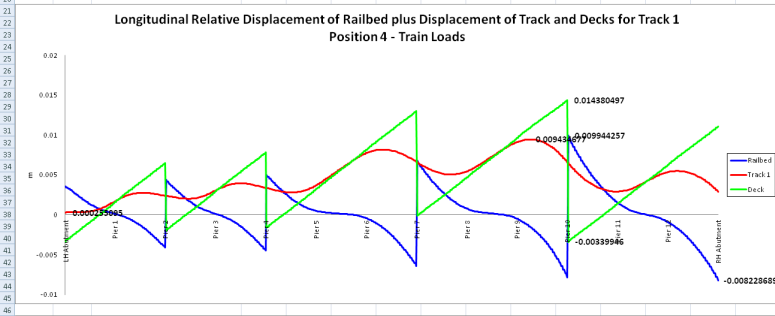


Figure 66: Track Worksheet Summary and Railbed Graph for Temperature and Trainset Results of Analysis, Increment 2 (1 of 3)

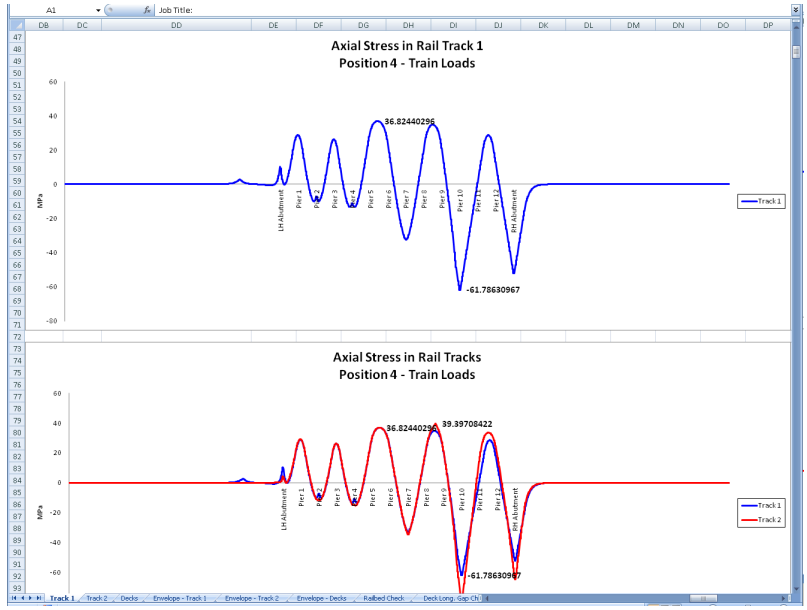
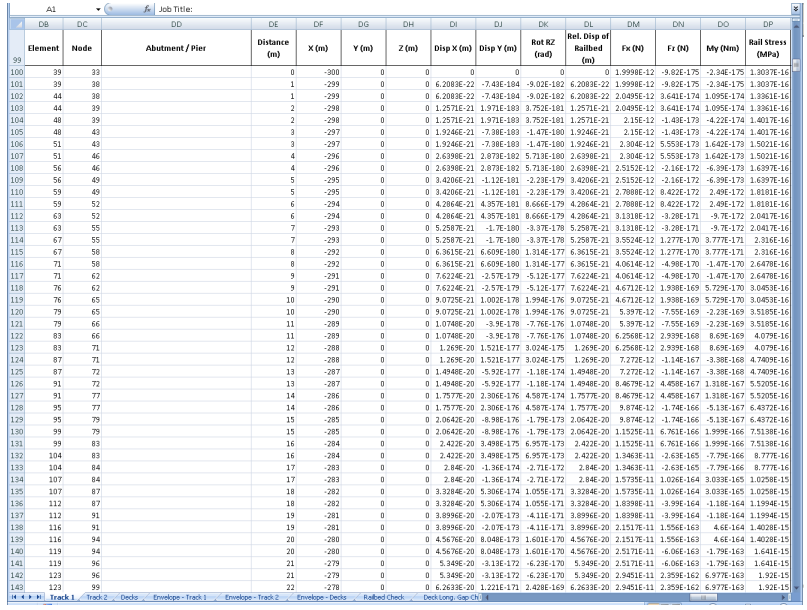


Figure 67: Track Worksheet Rail Stress Graphs for Temperature and Trainset Results of Analysis, Increment 2 (2 of 3)



	Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Rel. Disp of Railbed (m)	Fx (N)	Fz (N)	My (Nm)	Rail Stress (MPa)
100	39	33		0	-300	0	0	0	0	0	0	1.9998E-12	-9.82E-175	-2.34E-175	1.3037E-16
101	39	38		1	-299	0	0	6.2083E-22	-7.43E-184	-9.02E-182	6.2083E-22	1.9998E-12	-9.82E-175	-2.34E-175	1.3037E-16
102	44	38		1	-299	0	0	6.2083E-22	-7.43E-184	-9.02E-182	6.2083E-22	2.0495E-12	3.641E-174	1.095E-174	1.3361E-16
103	44	39		2	-298	0	0	1.2571E-21	1.971E-183	3.752E-181	1.2571E-21	2.0495E-12	3.641E-174	1.095E-174	1.3361E-16
104	48	39		2	-298	0	0	1.2571E-21	1.971E-183	3.752E-181	1.2571E-21	2.15E-12	-1.43E-173	-4.22E-174	1.4017E-16
105	48	43		3	-297	0	0	1.9246E-21	-7.38E-183	-1.47E-180	1.9246E-21	2.15E-12	-1.43E-173	-4.22E-174	1.4017E-16
106	51	43		3	-297	0	0	1.9246E-21	-7.38E-183	-1.47E-180	1.9246E-21	2.304E-12	5.553E-173	1.642E-173	1.5021E-16
107	51	46		4	-296	0	0	2.6398E-21	2.873E-182	5.713E-180	2.6398E-21	2.304E-12	5.553E-173	1.642E-173	1.5021E-16
108	56	46		4	-296	0	0	2.6398E-21	2.873E-182	5.713E-180	2.6398E-21	2.5152E-12	-2.16E-172	-6.39E-173	1.6397E-16
109	56	49		5	-295	0	0	3.4206E-21	-1.12E-181	-2.23E-179	3.4206E-21	2.5152E-12	-2.16E-172	-6.39E-173	1.6397E-16
110	59	49		5	-295	0	0	3.4206E-21	-1.12E-181	-2.23E-179	3.4206E-21	2.7888E-12	8.422E-172	2.49E-172	1.8101E-16
111	59	52		6	-294	0	0	4.2864E-21	4.357E-181	8.666E-179	4.2864E-21	2.7888E-12	8.422E-172	2.49E-172	1.8101E-16
112	63	52		6	-294	0	0	4.2864E-21	4.357E-181	8.666E-179	4.2864E-21	3.1318E-12	-3.28E-171	-9.7E-172	2.0417E-16
113	63	55		7	-293	0	0	5.2587E-21	-1.7E-180	-3.37E-178	5.2587E-21	3.1318E-12	-3.28E-171	-9.7E-172	2.0417E-16
114	67	55		7	-293	0	0	5.2587E-21	-1.7E-180	-3.37E-178	5.2587E-21	3.5524E-12	1.277E-170	3.777E-171	2.316E-16
115	67	58		8	-292	0	0	6.3615E-21	6.609E-180	1.314E-177	6.3615E-21	3.5524E-12	1.277E-170	3.777E-171	2.316E-16
116	71	58		8	-292	0	0	6.3615E-21	6.609E-180	1.314E-177	6.3615E-21	4.0614E-12	-4.98E-170	-1.47E-170	2.6478E-16
117	71	62		9	-291	0	0	7.6224E-21	-2.57E-179	-5.12E-177	7.6224E-21	4.0614E-12	-4.98E-170	-1.47E-170	2.6478E-16
118	76	62		9	-291	0	0	7.6224E-21	-2.57E-179	-5.12E-177	7.6224E-21	4.6712E-12	1.938E-169	5.729E-170	3.0453E-16
119	76	65		10	-290	0	0	9.0725E-21	1.002E-178	1.994E-176	9.0725E-21	4.6712E-12	1.938E-169	5.729E-170	3.0453E-16
120	79	65		10	-290	0	0	9.0725E-21	1.002E-178	1.994E-176	9.0725E-21	5.397E-12	-7.55E-169	-2.23E-169	3.5185E-16
121	79	66		11	-289	0	0	1.0748E-20	-3.9E-178	-7.76E-176	1.0748E-20	5.397E-12	-7.55E-169	-2.23E-169	3.5185E-16
122	83	66		11	-289	0	0	1.0748E-20	-3.9E-178	-7.76E-176	1.0748E-20	6.2568E-12	2.939E-168	8.69E-169	4.079E-16
123	83	71		12	-288	0	0	1.269E-20	1.521E-177	3.024E-175	1.269E-20	6.2568E-12	2.939E-168	8.69E-169	4.079E-16
124	87	71		12	-288	0	0	1.269E-20	1.521E-177	3.024E-175	1.269E-20	7.272E-12	-1.14E-167	-3.38E-168	4.7409E-16
125	87	72		13	-287	0	0	1.4948E-20	-5.92E-177	-1.18E-174	1.4948E-20	7.272E-12	-1.14E-167	-3.38E-168	4.7409E-16
126	91	72		13	-287	0	0	1.4948E-20	-5.92E-177	-1.18E-174	1.4948E-20	8.4679E-12	4.458E-167	1.318E-167	5.5205E-16
127	91	77		14	-286	0	0	1.7577E-20	2.306E-176	4.587E-174	1.7577E-20	8.4679E-12	4.458E-167	1.318E-167	5.5205E-16
128	95	77		14	-286	0	0	1.7577E-20	2.306E-176	4.587E-174	1.7577E-20	9.874E-12	-1.74E-166	-5.13E-167	6.4372E-16
129	95	79		15	-285	0	0	2.0642E-20	-8.98E-176	-1.79E-173	2.0642E-20	9.874E-12	-1.74E-166	-5.13E-167	6.4372E-16
130	99	79		15	-285	0	0	2.0642E-20	-8.98E-176	-1.79E-173	2.0642E-20	1.1525E-11	6.761E-166	1.999E-166	7.5138E-16
131	99	83		16	-284	0	0	2.422E-20	3.498E-175	6.957E-173	2.422E-20	1.1525E-11	6.761E-166	1.999E-166	7.5138E-16
132	104	83		16	-284	0	0	2.422E-20	3.498E-175	6.957E-173	2.422E-20	1.3463E-11	-2.63E-165	-7.79E-166	8.777E-16
133	104	84		17	-283	0	0	2.84E-20	-1.36E-174	-2.71E-172	2.84E-20	1.3463E-11	-2.63E-165	-7.79E-166	8.777E-16
134	107	84		17	-283	0	0	2.84E-20	-1.36E-174	-2.71E-172	2.84E-20	1.5735E-11	1.026E-164	3.033E-165	1.0258E-15
135	107	87		18	-282	0	0	3.3284E-20	5.306E-174	1.055E-171	3.3284E-20	1.5735E-11	1.026E-164	3.033E-165	1.0258E-15
136	112	87		18	-282	0	0	3.3284E-20	5.306E-174	1.055E-171	3.3284E-20	1.8398E-11	-3.99E-164	-1.18E-164	1.1994E-15
137	112	91		19	-281	0	0	3.8996E-20	-2.07E-173	-4.11E-171	3.8996E-20	1.8398E-11	-3.99E-164	-1.18E-164	1.1994E-15
138	116	91		19	-281	0	0	3.8996E-20	-2.07E-173	-4.11E-171	3.8996E-20	2.1517E-11	1.556E-163	4.6E-164	1.4028E-15
139	116	94		20	-280	0	0	4.5676E-20	8.048E-173	1.601E-170	4.5676E-20	2.1517E-11	1.556E-163	4.6E-164	1.4028E-15
140	119	94		20	-280	0	0	4.5676E-20	8.048E-173	1.601E-170	4.5676E-20	2.5171E-11	-6.06E-163	-1.79E-163	1.641E-15
141	119	96		21	-279	0	0	5.349E-20	-3.13E-172	-6.23E-170	5.349E-20	2.5171E-11	-6.06E-163	-1.79E-163	1.641E-15
142	123	96		21	-279	0	0	5.349E-20	-3.13E-172	-6.23E-170	5.349E-20	2.9451E-11	2.359E-162	6.977E-163	1.92E-15
143	123	99		22	-278	0	0	6.2633E-20	1.221E-171	2.428E-169	6.2633E-20	2.9451E-11	2.359E-162	6.977E-163	1.92E-15

Figure 68: Track Worksheet Tabulated Output for Temperature and Trainset Results of Analysis, Increment 2 (3 of 3)

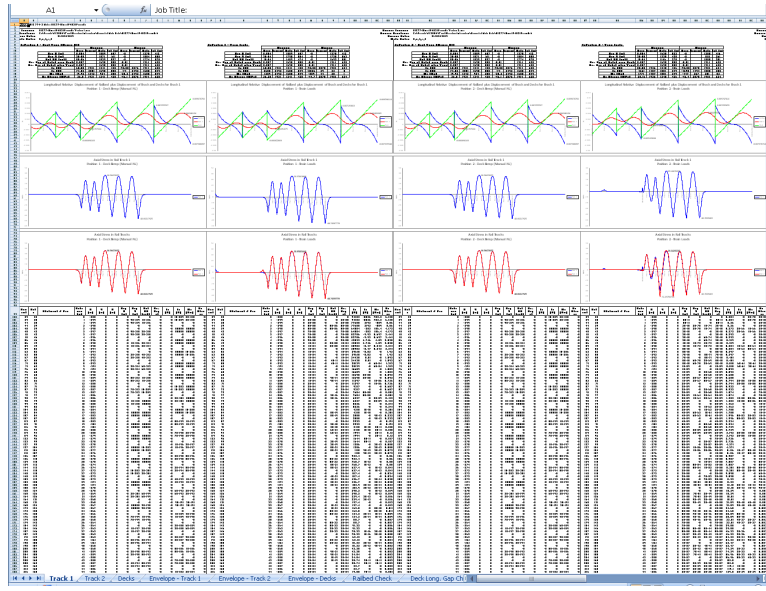
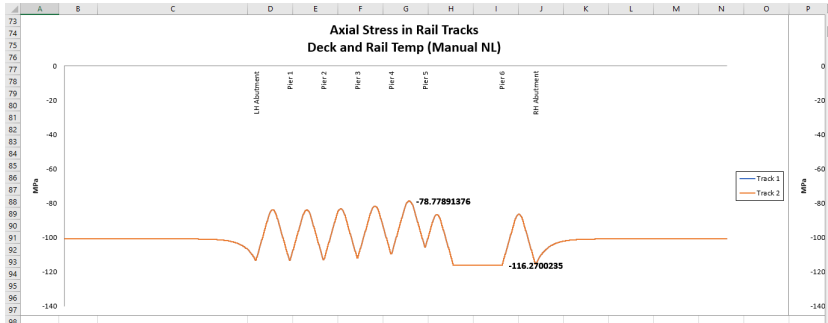


Figure 69: Track Worksheet for Multiple Results Files

If ZLR and/or RLR modelling has been included in the Rail Track Analysis, then an additional legend is included above the “Rail Stress” column of the tabular output in the track worksheets as shown in Figure 70. Within the tabular results the rail stress cells that correspond to regions of track that are within zones of ZLR track will be coloured with the pale blue shading and the regions of track that are within zones of RLR track will be coloured with the pale orange shading.

For the structure that has been modelled in Figure 70 it is possible to visualise where the ZLR track is present in the rail stress chart itself as it is indicated by the constant rail stress of -116.27 MPa stretching from within Deck 6 to Pier 6. The extent of the region of ZLR is indicated within the tabulated results in Figure 71 and Figure 72 which shows that the zone stretches over a range of 310 to 385 m from the start of the left-hand abutment to Pier 6 (610 to 685 m from the start of the track including the left-hand abutment).



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 (rad)	Rel. Disp of Railbed (m)	Fx (N)	Fz (N)	My (Nm)	Rail Stress (MPa)	Element
102	32	23		0	-300	0	0	0	0	0	0	-1549497.6	6.9018E-26	-2.441E-25	-100.8	32
103	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
104	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

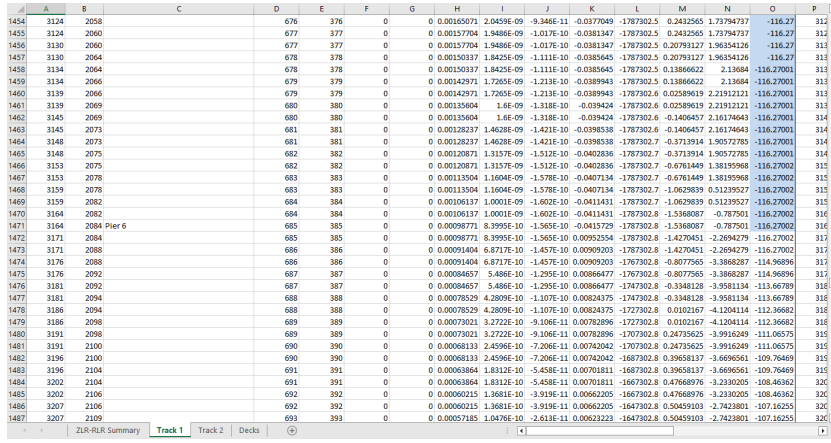
ZLR-RLR Summary | Track 1 | Track 2 | Decks

Figure 70: Track Results – Top of Tabular Results for ZLR/RLR Modelling

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1307	2755	1840		603	303	0	0	0.00689824	3.7133E-09	6.1916E-11	-0.0064639	-1647300.8	-0.0076117	0.68699168	-107.16242	275
1308	2758	1840		603	303	0	0	0.00689824	3.7133E-09	6.1916E-11	-0.0064639	-1667300.8	-0.0072649	0.67955338	-108.46349	275
1309	2758	1843		604	304	0	0	0.00686175	3.7736E-09	5.868E-11	-0.0068558	-1667300.8	-0.0072649	0.67955338	-108.46349	275
1310	2764	1843		604	304	0	0	0.00686175	3.7736E-09	5.868E-11	-0.0068558	-1687300.8	-0.0070944	0.67237375	-109.76456	276
1311	2764	1846		605	305	0	0	0.00681906	3.8306E-09	5.5478E-11	-0.007254	-1687300.8	-0.0070944	0.67237375	-109.76456	276
1312	2768	1846		605	305	0	0	0.00681906	3.8306E-09	5.5478E-11	-0.007254	-1707300.8	-0.0070552	0.66529895	-111.06563	276
1313	2768	1847		606	306	0	0	0.00677018	3.8845E-09	5.231E-11	-0.0076586	-1707300.8	-0.0070552	0.66529895	-111.06563	276
1314	2774	1847		606	306	0	0	0.00677018	3.8845E-09	5.231E-11	-0.0076586	-1727300.8	-0.0071087	0.65821698	-112.36669	277
1315	2774	1852		607	307	0	0	0.0067151	3.9352E-09	4.9176E-11	-0.0080694	-1727300.8	-0.0071087	0.65821698	-112.36669	277
1316	2778	1852		607	307	0	0	0.0067151	3.9352E-09	4.9176E-11	-0.0080694	-1747300.8	-0.0072231	0.65105107	-113.66776	277
1317	2778	1855		608	308	0	0	0.00665382	3.9829E-09	4.6075E-11	-0.0084866	-1747300.8	-0.0072231	0.65105107	-113.66776	277
1318	2783	1855		608	308	0	0	0.00665382	3.9829E-09	4.6075E-11	-0.0084866	-1767300.8	-0.0073728	0.64375313	-114.96883	278
1319	2783	1858		609	309	0	0	0.00658635	4.0274E-09	4.301E-11	-0.00891	-1767300.8	-0.0073728	0.64375313	-114.96883	278
1320	2789	1858		609	309	0	0	0.00658635	4.0274E-09	4.301E-11	-0.00891	-1787300.8	-0.0075384	0.63629753	-116.26989	278
1321	2789	1861		610	310	0	0	0.00651269	4.0689E-09	3.998E-11	-0.0093398	-1787300.8	-0.0075384	0.63629753	-116.26989	278
1322	2794	1861		610	310	0	0	0.00651269	4.0689E-09	3.998E-11	-0.0093398	-1787300.8	-0.0077054	0.62867562	-116.2699	279
1323	2794	1862		611	311	0	0	0.00643902	4.1074E-09	3.6986E-11	-0.0097696	-1787300.8	-0.0077054	0.62867562	-116.2699	279
1324	2800	1862		611	311	0	0	0.00643902	4.1074E-09	3.6986E-11	-0.0097696	-1787300.8	-0.007864	0.62089088	-116.2699	280
1325	2800	1865		612	312	0	0	0.00636536	4.1429E-09	3.403E-11	-0.0101994	-1787300.8	-0.007864	0.62089088	-116.2699	280
1326	2804	1865		612	312	0	0	0.00636536	4.1429E-09	3.403E-11	-0.0101994	-1787300.8	-0.0080078	0.61295497	-116.2699	280
1327	2804	1870		613	313	0	0	0.00629169	4.1754E-09	3.1111E-11	-0.0106291	-1787300.8	-0.0080078	0.61295497	-116.2699	280
1328	2808	1870		613	313	0	0	0.00629169	4.1754E-09	3.1111E-11	-0.0106291	-1787300.9	-0.0081332	0.60488445	-116.2699	280
1329	2808	1872		614	314	0	0	0.00621802	4.2051E-09	2.823E-11	-0.0110589	-1787300.9	-0.0081332	0.60488445	-116.2699	280
1330	2813	1872		614	314	0	0	0.00621802	4.2051E-09	2.823E-11	-0.0110589	-1787300.9	-0.008239	0.59669834	-116.2699	281
1331	2813	1874		615	315	0	0	0.00614436	4.2319E-09	2.5389E-11	-0.0114887	-1787300.9	-0.008239	0.59669834	-116.2699	281
1332	2819	1874		615	315	0	0	0.00614436	4.2319E-09	2.5389E-11	-0.0114887	-1787300.9	-0.0083253	0.5884162	-116.2699	281
1333	2819	1878		616	316	0	0	0.00607069	4.2559E-09	2.2587E-11	-0.0119185	-1787300.9	-0.0083253	0.5884162	-116.2699	281
1334	2824	1878		616	316	0	0	0.00607069	4.2559E-09	2.2587E-11	-0.0119185	-1787300.9	-0.0083934	0.58005685	-116.2699	282
1335	2824	1882		617	317	0	0	0.00599702	4.2771E-09	1.9825E-11	-0.0123482	-1787300.9	-0.0083934	0.58005685	-116.2699	282
1336	2830	1882		617	317	0	0	0.00599702	4.2771E-09	1.9825E-11	-0.0123482	-1787300.9	-0.0084453	0.57163751	-116.2699	283
1337	2830	1883		618	318	0	0	0.00592336	4.2955E-09	1.7103E-11	-0.012778	-1787300.9	-0.0084453	0.57163751	-116.2699	283
1338	2833	1883		618	318	0	0	0.00592336	4.2955E-09	1.7103E-11	-0.012778	-1787300.9	-0.0084831	0.5631733	-116.2699	283
1339	2833	1888		619	319	0	0	0.00584969	4.3113E-09	1.4421E-11	-0.0132078	-1787300.9	-0.0084831	0.5631733	-116.2699	283
1340	2840	1888		619	319	0	0	0.00584969	4.3113E-09	1.4421E-11	-0.0132078	-1787300.9	-0.0085093	0.55467706	-116.2699	284

ZLR-RLR Summary | Track 1 | Track 2 | Decks

Figure 71: Track Results – Visualisation of Extents of ZLR Track (1 of 2)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1454	3124	2058		676	376	0	0	0.00165071	2.0459E-09	-9.346E-11	-0.0377049	-1787302.5	0.2432565	1.73794737	-116.27	312
1455	3124	2060		677	377	0	0	0.00157704	1.9486E-09	-1.017E-10	-0.0381347	-1787302.5	0.2432565	1.73794737	-116.27	312
1456	3130	2060		677	377	0	0	0.00157704	1.9486E-09	-1.017E-10	-0.0381347	-1787302.5	0.20793127	1.96354126	-116.27	313
1457	3130	2064		678	378	0	0	0.00150337	1.8425E-09	-1.111E-10	-0.0385645	-1787302.5	0.20793127	1.96354126	-116.27	313
1458	3134	2064		678	378	0	0	0.00150337	1.8425E-09	-1.111E-10	-0.0385645	-1787302.5	0.13866622	2.13684	-116.27001	313
1459	3134	2066		679	379	0	0	0.00142971	1.7265E-09	-1.213E-10	-0.0389943	-1787302.5	0.13866622	2.13684	-116.27001	313
1460	3139	2066		679	379	0	0	0.00142971	1.7265E-09	-1.213E-10	-0.0389943	-1787302.6	0.02589619	2.21912121	-116.27001	313
1461	3139	2069		680	380	0	0	0.00135604	1.6E-09	-1.318E-10	-0.039424	-1787302.6	0.02589619	2.21912121	-116.27001	313
1462	3145	2069		680	380	0	0	0.00135604	1.6E-09	-1.318E-10	-0.039424	-1787302.6	-0.1406457	2.16174643	-116.27001	314
1463	3145	2073		681	381	0	0	0.00128237	1.4628E-09	-1.421E-10	-0.0398538	-1787302.6	-0.1406457	2.16174643	-116.27001	314
1464	3148	2073		681	381	0	0	0.00128237	1.4628E-09	-1.421E-10	-0.0398538	-1787302.7	-0.3713914	1.90572785	-116.27001	314
1465	3148	2075		682	382	0	0	0.00120871	1.3157E-09	-1.512E-10	-0.0402836	-1787302.7	-0.3713914	1.90572785	-116.27001	314
1466	3153	2075		682	382	0	0	0.00120871	1.3157E-09	-1.512E-10	-0.0402836	-1787302.7	-0.6761449	1.38195968	-116.27002	315
1467	3153	2078		683	383	0	0	0.00113504	1.1604E-09	-1.578E-10	-0.0407134	-1787302.7	-0.6761449	1.38195968	-116.27002	315
1468	3159	2078		683	383	0	0	0.00113504	1.1604E-09	-1.578E-10	-0.0407134	-1787302.7	-1.0629839	0.51239527	-116.27002	315
1469	3159	2082		684	384	0	0	0.00106137	1.0001E-09	-1.602E-10	-0.0411431	-1787302.7	-1.0629839	0.51239527	-116.27002	315
1470	3164	2082		684	384	0	0	0.00106137	1.0001E-09	-1.602E-10	-0.0411431	-1787302.8	-1.5368087	-0.787501	-116.27002	316
1471	3164	2084	Pier 6	685	385	0	0	0.00098771	8.3995E-10	-1.565E-10	-0.0415729	-1787302.8	-1.5368087	-0.787501	-116.27002	316
1472	3171	2084		685	385	0	0	0.00098771	8.3995E-10	-1.565E-10	0.00952554	-1787302.8	-1.4270451	-2.2694279	-116.27002	317
1473	3171	2088		686	386	0	0	0.00091404	6.8717E-10	-1.457E-10	0.00909203	-1787302.8	-1.4270451	-2.2694279	-116.27002	317
1474	3176	2088		686	386	0	0	0.00091404	6.8717E-10	-1.457E-10	0.00909203	-1767302.8	-0.8077565	-3.3868287	-114.96896	317
1475	3176	2092		687	387	0	0	0.00084657	5.4866E-10	-1.295E-10	0.00866477	-1767302.8	-0.8077565	-3.3868287	-114.96896	317
1476	3181	2092		687	387	0	0	0.00084657	5.4866E-10	-1.295E-10	0.00866477	-1747302.8	-0.3348128	-3.9581134	-113.66789	318
1477	3181	2094		688	388	0	0	0.00078529	4.2809E-10	-1.107E-10	0.00824375	-1747302.8	-0.3348128	-3.9581134	-113.66789	318
1478	3186	2094		688	388	0	0	0.00078529	4.2809E-10	-1.107E-10	0.00824375	-1727302.8	0.0102167	-4.1204114	-112.36682	318
1479	3186	2098		689	389	0	0	0.00073021	3.2722E-10	-9.106E-11	0.00782896	-1727302.8	0.0102167	-4.1204114	-112.36682	318
1480	3191	2098		689	389	0	0	0.00073021	3.2722E-10	-9.106E-11	0.00782896	-1707302.8	0.24735625	-3.9916249	-111.06575	319
1481	3191	2100		690	390	0	0	0.00068133	2.4596E-10	-7.206E-11	0.00742042	-1707302.8	0.24735625	-3.9916249	-111.06575	319
1482	3196	2100		690	390	0	0	0.00068133	2.4596E-10	-7.206E-11	0.00742042	-1687302.8	0.39658137	-3.6696561	-109.76469	319
1483	3196	2104		691	391	0	0	0.00063864	1.8312E-10	-5.458E-11	0.00701811	-1687302.8	0.39658137	-3.6696561	-109.76469	319
1484	3202	2104		691	391	0	0	0.00063864	1.8312E-10	-5.458E-11	0.00701811	-1667302.8	0.47668976	-3.2330205	-108.46362	320
1485	3202	2106		692	392	0	0	0.00060215	1.3681E-10	-3.919E-11	0.00662205	-1667302.8	0.47668976	-3.2330205	-108.46362	320
1486	3207	2106		692	392	0	0	0.00060215	1.3681E-10	-3.919E-11	0.00662205	-1647302.8	0.50459103	-2.7423801	-107.16255	320
1487	3207	2109		693	393	0	0	0.00057185	1.0476E-10	-2.613E-11	0.00623223	-1647302.8	0.50459103	-2.7423801	-107.16255	320

ZLR-RLR Summary | Track 1 | Track 2 | Decks

Figure 72: Track Results – Visualisation of Extents of ZLR Track (2 of 2)

If valid basic combinations or envelopes that match the criteria described in "***Post-processing of automatically defined groups***" (page 63) are present in the model then additional results for these will be tabulated into the XLSX worksheets for the tracks. For basic combinations a warning will be added at the top of the extracted results indicating that basic combinations of nonlinear results are not strictly valid. For LUSAS envelopes all quantities other than the longitudinal relative railbed displacements will be extracted for the tracks and the results from LUSAS envelopes will also be excluded from any enveloping carried out.

Note. Longitudinal relative railbed displacements cannot be calculated within the LUSAS envelopes directly because this is a quantity derived from two separate disconnected nodes in the model and requires a knowledge of the geometry of the model. The calculation of the longitudinal relative railbed displacements can only be carried out by the Rail Track Analysis specific post-processing.

Deck Results

A separate worksheet is created for the deck in the model. In this worksheet the displacement and forces / moments in the deck are reported for all of the results files. If only temperature results exist in a results file the post-processing will only generate the output for these (Increment 1 of the nonlinear analysis). If trainset loading is also present in the analyses then for each results file the results for the temperature only (Increment 1 of the nonlinear analysis) and the combined temperature and trainset loading (Increment 2 of the nonlinear analysis) are output for each results file. Figure 73 to Figure 76 show the tabulated and graph output generated for the deck for all of the loading conditions included in the analyses. Figure 77 shows a zoomed out version of the worksheet showing the output for multiple results files. In this figure the temperature only and combined results for more than two results files are illustrated

with the analyses incrementing from left to right and for each, the first column of results and graphs are for the temperature only case and the second column are for the combined case for each analysis.

Note. The tabulated and graphed nodal displacements for the deck are the displacements associated with the top of the slab / the surface where the interaction occurs between the structure and the track, not the displacements at the neutral axis or at the bearings, since this is the nodal line of the main deck mesh to ensure correct longitudinal relative railbed displacement calculations. It is possible to calculate the displacements at these locations if needed – see "*Appendix C: Calculation of Deck Displacements at Alternative Locations to Top of Slab / Deck*".

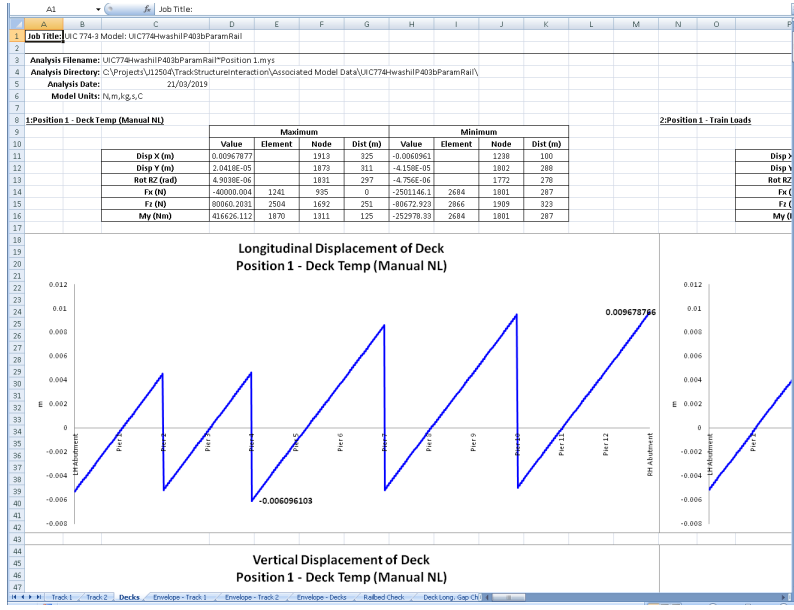


Figure 73: Deck Worksheet Summary and Longitudinal Displacement Graph for Results of Analysis (1 of 4)

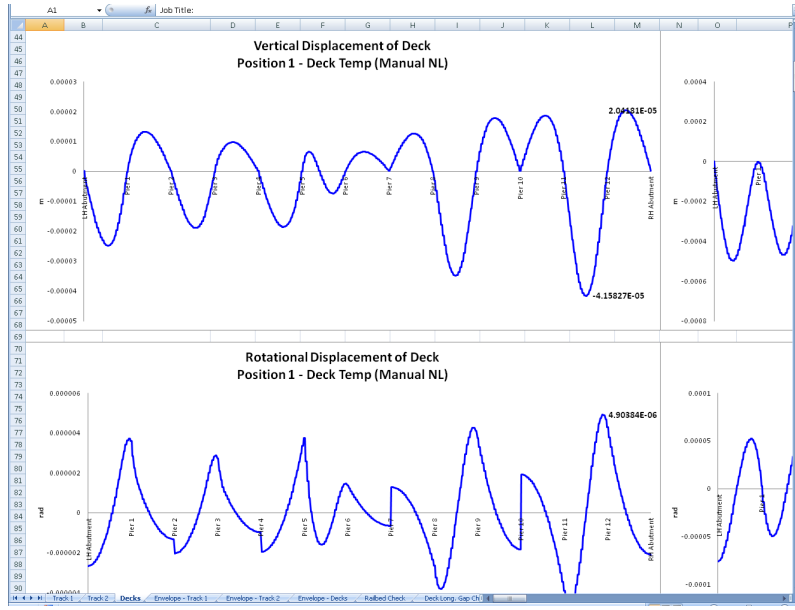


Figure 74: Deck Worksheet Vertical and Rotational Displacement Graphs for Results of Analysis (2 of 4)

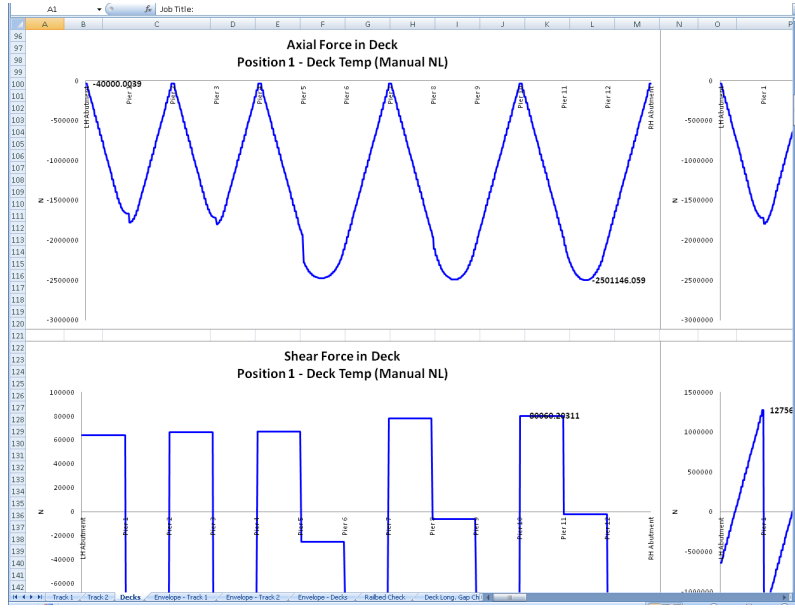
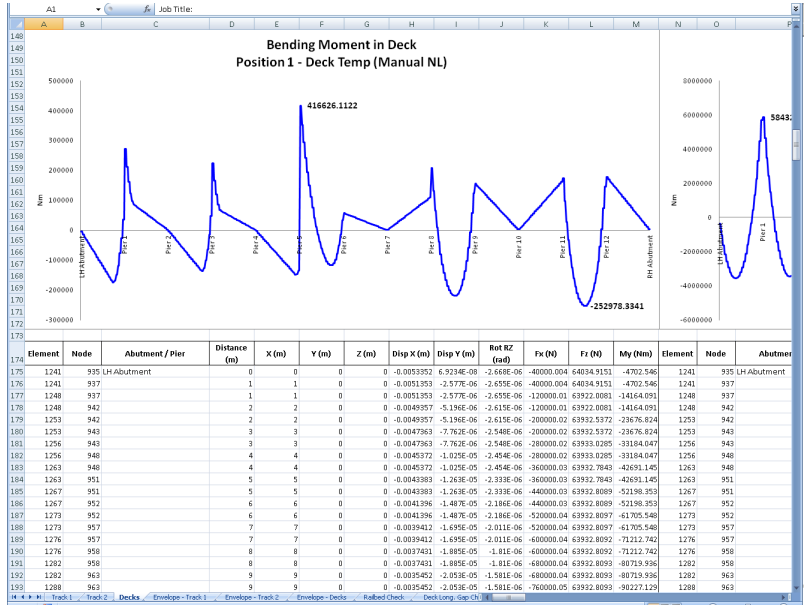


Figure 75: Deck Worksheet Axial and Shear Force Graphs for Results of Analysis (3 of 4)



Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Fx (N)	Fz (N)	My (Nm)	Element	Node	Abutmer
1241	935	LH Abutment	0	0	0	0	-0.0053352	6.9234E-08	-2.668E-06	-40000.004	64034.9151	-4702.546	1241	935	LH Abutment
1241	937		1	1	0	0	-0.0051353	-2.577E-06	-2.655E-06	-40000.004	64034.9151	-4702.546	1241	937	
1248	937		1	1	0	0	-0.0051353	-2.577E-06	-2.655E-06	-120000.01	63922.0081	-14164.091	1248	937	
1248	942		2	2	0	0	-0.0049357	-5.196E-06	-2.615E-06	-120000.01	63922.0081	-14164.091	1248	942	
1253	942		2	2	0	0	-0.0049357	-5.196E-06	-2.615E-06	-200000.02	63932.5372	-23676.824	1253	942	
1253	943		3	3	0	0	-0.0047363	-7.762E-06	-2.548E-06	-200000.02	63932.5372	-23676.824	1253	943	
1256	943		3	3	0	0	-0.0047363	-7.762E-06	-2.548E-06	-280000.02	63933.0285	-33184.047	1256	943	
1256	948		4	4	0	0	-0.0045372	-1.025E-05	-2.454E-06	-280000.02	63933.0285	-33184.047	1256	948	
1263	948		4	4	0	0	-0.0045372	-1.025E-05	-2.454E-06	-360000.03	63932.7843	-42691.145	1263	948	
1263	951		5	5	0	0	-0.0043383	-1.263E-05	-2.333E-06	-360000.03	63932.7843	-42691.145	1263	951	
1267	951		5	5	0	0	-0.0043383	-1.263E-05	-2.333E-06	-440000.03	63932.8089	-52198.353	1267	951	
1267	952		6	6	0	0	-0.0041396	-1.487E-05	-2.186E-06	-440000.03	63932.8089	-52198.353	1267	952	
1273	952		6	6	0	0	-0.0041396	-1.487E-05	-2.186E-06	-520000.04	63932.8097	-61705.548	1273	952	
1273	957		7	7	0	0	-0.0039412	-1.695E-05	-2.011E-06	-520000.04	63932.8097	-61705.548	1273	957	
1276	957		7	7	0	0	-0.0039412	-1.695E-05	-2.011E-06	-600000.04	63932.8092	-71212.742	1276	957	
1276	958		8	8	0	0	-0.0037431	-1.885E-05	-1.81E-06	-600000.04	63932.8092	-71212.742	1276	958	
1282	958		8	8	0	0	-0.0037431	-1.885E-05	-1.81E-06	-680000.04	63932.8093	-80719.936	1282	958	
1282	963		9	9	0	0	-0.0035452	-2.053E-05	-1.581E-06	-680000.04	63932.8093	-80719.936	1282	963	
1288	963		9	9	0	0	-0.0035452	-2.053E-05	-1.581E-06	-760000.05	63932.8093	-90227.129	1288	963	

Figure 76: Deck Worksheet Bending Moment Graph and Tabulated Output for Results of Analysis (4 of 4)

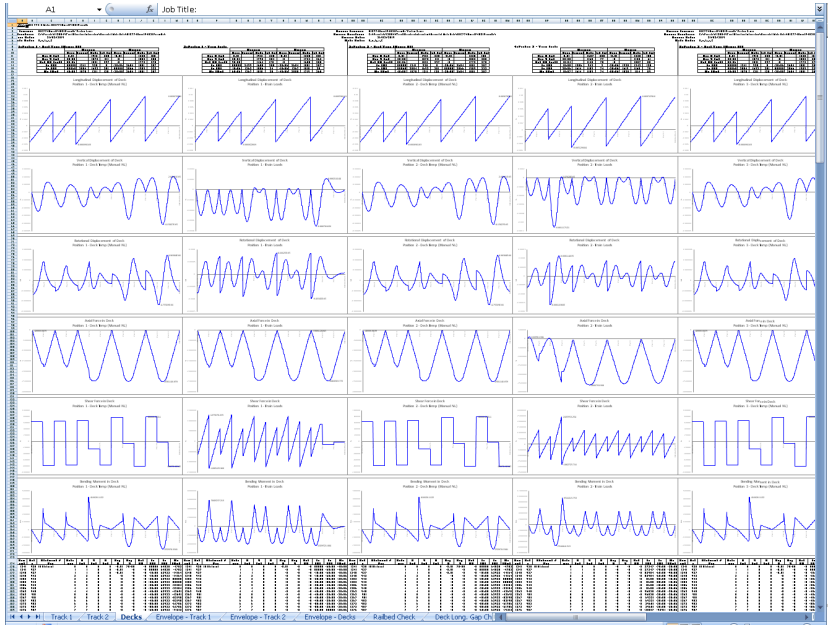


Figure 77: Deck Worksheet for Multiple Results Files

If valid basic combinations or envelopes that match the criteria described in "***Post-processing of automatically defined groups***" (page 63) are present in the model then additional results for these will be tabulated into the XLSX worksheets for the decks. For basic combinations a warning will be added at the top of the extracted results indicating that basic combinations of nonlinear results are not strictly valid.

Additional Results from Enveloping

If more than one results file is loaded, basic combinations are defined in the model that may be post-processed (see the restrictions under the "***Post-processing of automatically defined groups***" section on page 63) and enveloping has been selected then additional envelope results output can be generated by the post-processor in separate worksheets in the XLSX format spreadsheet. These additional worksheets include envelopes of the raw results and summary tables for key results that are required for checking against the UIC774-3 code. The track and deck envelopes produce the same summary tables, graphs and results highlighted in the previous two sections for the following envelopes:

- **Maximum and minimum envelopes for temperature loading only**
- **Maximum and minimum envelopes for temperature and trainset rail loading**
- **Maximum and minimum envelopes for all of the basic combinations defined in the model (if valid basic combinations are present)**
- **Maximum and minimum envelopes for all configurations (an envelope of all of the above results – temperature only, temperature and trainset, basic combinations)**

The additional UIC774-3 summary tables output by the post-processor are dependent upon the configuration of the model (the number of tracks and the number of decks in the structure) but will include some or all of the following tables:

- **Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)**
- **Longitudinal Relative Displacement between Ends of Decks (Axial)**
- **Longitudinal Relative Displacement between Ends of Decks (End Rotations)**
- **Longitudinal Relative Displacement between Ends of Decks (Total Effects)**
- **Vertical Relative Displacement between Ends of Decks**
- **Longitudinal Reactions**
- **Axial Rail Stress**

Note. The ‘total effect’ longitudinal relative displacement between the ends of the decks is the sum of the axial movement of the deck support position and the movement of the top of the deck from the rotation of the deck about this support position.

Sample tables are shown in the following figures which provide the peak values, the track that the peak is occurring in (if appropriate), the distance from the left end of the structure of the peak and also a description of where the peak is occurring. In all of the worksheets the worst effects are highlighted in bold and blue text to allow the quick determination of which analysis is causing the worst effects for each of the checks that need to be performed.

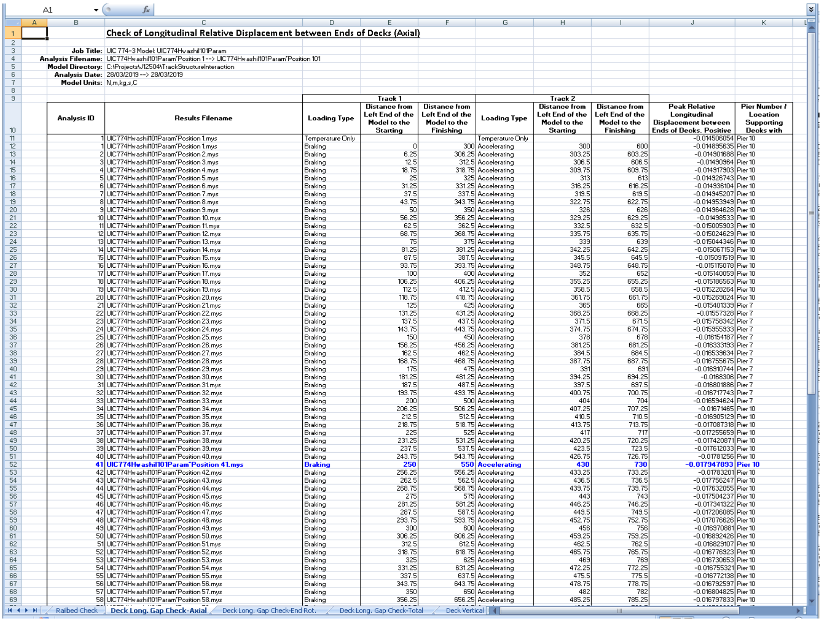
Check of Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)

Job Title: UIC 774-3 Model: UIC774Hwashil101Param
Analysis Filename: UIC774Hwashil101Param~Position 1 --> UIC774Hwashil101Param~Position 101
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

		Track 1			Track 2						
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Peak Relative Longitudinal Displacement between Rail and Slab (m)	Track Number with Peak Displacement	Distance from Left End of Structure for Peak Displacement	Description of peak location
1	UIC774Hwashil101Param~Position 1.mys	Temperature Only			Temperature Only			0.007380897	1	325	RH Abutment
1	UIC774Hwashil101Param~Position 1.mys	Braking	0	300	Accelerating	300	600	0.007375343	2	325	RH Abutment
2	UIC774Hwashil101Param~Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	0.007375286	2	325	RH Abutment
3	UIC774Hwashil101Param~Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	0.007371726	2	325	RH Abutment
4	UIC774Hwashil101Param~Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	0.007366432	1	325	RH Abutment
5	UIC774Hwashil101Param~Position 5.mys	Braking	25	325	Accelerating	313	613	0.007359531	1	325	RH Abutment
6	UIC774Hwashil101Param~Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	0.007351955	1	325	RH Abutment
7	UIC774Hwashil101Param~Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	0.007344906	1	325	RH Abutment
8	UIC774Hwashil101Param~Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	0.007341198	1	325	RH Abutment
9	UIC774Hwashil101Param~Position 9.mys	Braking	50	350	Accelerating	326	626	0.007343822	1	325	RH Abutment
10	UIC774Hwashil101Param~Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	0.007351003	1	325	RH Abutment
11	UIC774Hwashil101Param~Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	0.007357474	1	325	RH Abutment
12	UIC774Hwashil101Param~Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	0.007361759	1	325	RH Abutment
13	UIC774Hwashil101Param~Position 13.mys	Braking	75	375	Accelerating	339	639	0.007364832	1	325	RH Abutment
14	UIC774Hwashil101Param~Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	0.007369301	2	325	RH Abutment
15	UIC774Hwashil101Param~Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	0.007375626	2	325	RH Abutment
16	UIC774Hwashil101Param~Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	0.00738173	2	325	RH Abutment
17	UIC774Hwashil101Param~Position 17.mys	Braking	100	400	Accelerating	352	652	0.007388264	2	325	RH Abutment
18	UIC774Hwashil101Param~Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	0.007401499	2	325	RH Abutment
19	UIC774Hwashil101Param~Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	0.007413397	2	325	RH Abutment
20	UIC774Hwashil101Param~Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	0.007427382	1	325	RH Abutment
21	UIC774Hwashil101Param~Position 21.mys	Braking	125	425	Accelerating	365	665	0.007448419	1	175	Pier 7
22	UIC774Hwashil101Param~Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	0.007539783	1	175	Pier 7
23	UIC774Hwashil101Param~Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	0.007647694	1	175	Pier 7
24	UIC774Hwashil101Param~Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	0.007784441	1	175	Pier 7
25	UIC774Hwashil101Param~Position 25.mys	Braking	150	450	Accelerating	378	678	0.007976226	1	175	Pier 7
26	UIC774Hwashil101Param~Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	0.008227912	1	175	Pier 7
27	UIC774Hwashil101Param~Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	0.008511118	1	175	Pier 7
28	UIC774Hwashil101Param~Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	0.008814177	1	175	Pier 7
29	UIC774Hwashil101Param~Position 29.mys	Braking	175	475	Accelerating	391	691	0.00913004	1	175	Pier 7
30	UIC774Hwashil101Param~Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	0.009004875	1	175	Pier 7
31	UIC774Hwashil101Param~Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	0.008877371	1	175	Pier 7
32	UIC774Hwashil101Param~Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	0.008714173	1	175	Pier 7
33	UIC774Hwashil101Param~Position 33.mys	Braking	200	500	Accelerating	404	704	0.008590034	1	175	Pier 7
34	UIC774Hwashil101Param~Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	0.008468225	1	175	Pier 7
35	UIC774Hwashil101Param~Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	0.008349209	1	175	Pier 7
36	UIC774Hwashil101Param~Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	0.008371439	1	250	Pier 10
37	UIC774Hwashil101Param~Position 37.mys	Braking	225	525	Accelerating	417	717	0.008562548	1	250	Pier 10
38	UIC774Hwashil101Param~Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	0.008827527	1	250	Pier 10
39	UIC774Hwashil101Param~Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	0.009126661	1	250	Pier 10
40	UIC774Hwashil101Param~Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	0.009452668	1	250	Pier 10
41	**UIC774Hwashil101Param~Position 41.mys**	**Braking**	**250**	**550**	**Accelerating**	**430**	**730**	**0.009782891**	**1**	**250**	**Pier 10**
42	UIC774Hwashil101Param~Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	0.009625799	1	250	Pier 10
43	UIC774Hwashil101Param~Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	0.009455666	1	250	Pier 10
44	UIC774Hwashil101Param~Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	0.009255804	1	250	Pier 10
45	UIC774Hwashil101Param~Position 45.mys	Braking	275	575	Accelerating	443	743	0.009125299	1	250	Pier 10
46	UIC774Hwashil101Param~Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	0.009007622	1	250	Pier 10
47	UIC774Hwashil101Param~Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	0.008982503	1	325	RH Abutment
48	UIC774Hwashil101Param~Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	0.009122915	1	325	RH Abutment
49	UIC774Hwashil101Param~Position 49.mys	Braking	300	600	Accelerating	456	756	0.009148895	1	325	RH Abutment
50	UIC774Hwashil101Param~Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	0.009041033	2	325	RH Abutment
51	UIC774Hwashil101Param~Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	0.009098869	2	325	RH Abutment
52	UIC774Hwashil101Param~Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	0.009139484	2	325	RH Abutment
53	UIC774Hwashil101Param~Position 53.mys	Braking	325	625	Accelerating	469	769	0.009192716	2	325	RH Abutment
54	UIC774Hwashil101Param~Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	0.009208688	2	325	RH Abutment
55	UIC774Hwashil101Param~Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	0.009223563	2	325	RH Abutment
56	UIC774Hwashil101Param~Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	0.009224284	2	325	RH Abutment
57	UIC774Hwashil101Param~Position 57.mys	Braking	350	650	Accelerating	482	782	0.009230925	2	325	RH Abutment
58	UIC774Hwashil101Param~Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	0.009236702	2	325	RH Abutment
59	UIC774Hwashil101Param~Position 59.mys	Braking	362.5	662.5	Accelerating	488.5	788.5	0.009237485	2	325	RH Abutment
60	UIC774Hwashil101Param~Position 60.mys	Braking	368.75	668.75	Accelerating	491.75	791.75	0.00923643	2	325	RH Abutment
61	UIC774Hwashil101Param~Position 61.mys	Braking	375	675	Accelerating	495	795	0.009233461	2	325	RH Abutment
62	UIC774Hwashil101Param~Position 62.mys	Braking	381.25	681.25	Accelerating	498.25	798.25	0.009228364	2	325	RH Abutment
63	UIC774Hwashil101Param~Position 63.mys	Braking	387.5	687.5	Accelerating	501.5	801.5	0.009221938	2	325	RH Abutment

Railbed Check | Deck Long. Gap Check-Axial | Deck Long. Gap Check-End Rot. | Deck Long. Gap Check-Total | Deck Vertical

Figure 78: Railbed Displacement Check Worksheet for Multiple Results Files

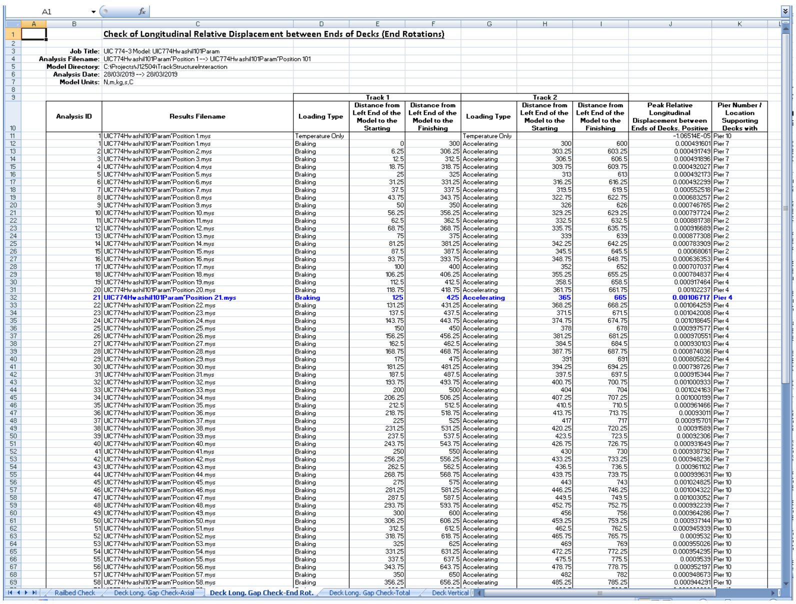


Check of Longitudinal Relative Displacement between Ends of Decks (Axial)

Job Title: UIC 774-3 Model: UIC774Hwashil101Param
Analysis Filename: UIC774Hwashil101Param~Position 1 --> UIC774Hwashil101Param~Position 101
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting	Track 2 Distance from Left End of the Model to the Finishing	Peak Relative Longitudinal Displacement between Ends of Decks. Positive	Pier Number / Location Supporting Decks with
1	UIC774Hwashil101Param~Position 1.mys	Temperature Only			Temperature Only			-0.014506054	Pier 10
1	UIC774Hwashil101Param~Position 1.mys	Braking	0	300	Accelerating	300	600	-0.014895635	Pier 10
2	UIC774Hwashil101Param~Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	-0.014901688	Pier 10
3	UIC774Hwashil101Param~Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	-0.01490964	Pier 10
4	UIC774Hwashil101Param~Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-0.014917903	Pier 10
5	UIC774Hwashil101Param~Position 5.mys	Braking	25	325	Accelerating	313	613	-0.014926743	Pier 10
6	UIC774Hwashil101Param~Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-0.014936104	Pier 10
7	UIC774Hwashil101Param~Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-0.014945207	Pier 10
8	UIC774Hwashil101Param~Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-0.014953949	Pier 10
9	UIC774Hwashil101Param~Position 9.mys	Braking	50	350	Accelerating	326	626	-0.014964628	Pier 10
10	UIC774Hwashil101Param~Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	-0.01498533	Pier 10
11	UIC774Hwashil101Param~Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	-0.015005903	Pier 10
12	UIC774Hwashil101Param~Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	-0.015024629	Pier 10
13	UIC774Hwashil101Param~Position 13.mys	Braking	75	375	Accelerating	339	639	-0.015044346	Pier 10
14	UIC774Hwashil101Param~Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	-0.015067153	Pier 10
15	UIC774Hwashil101Param~Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	-0.015091519	Pier 10
16	UIC774Hwashil101Param~Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	-0.015115078	Pier 10
17	UIC774Hwashil101Param~Position 17.mys	Braking	100	400	Accelerating	352	652	-0.015140059	Pier 10
18	UIC774Hwashil101Param~Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	-0.015186563	Pier 10
19	UIC774Hwashil101Param~Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	-0.015228264	Pier 10
20	UIC774Hwashil101Param~Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	-0.015269024	Pier 10
21	UIC774Hwashil101Param~Position 21.mys	Braking	125	425	Accelerating	365	665	-0.015401339	Pier 7
22	UIC774Hwashil101Param~Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	-0.01557328	Pier 7
23	UIC774Hwashil101Param~Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	-0.015758342	Pier 7
24	UIC774Hwashil101Param~Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	-0.015955933	Pier 7
25	UIC774Hwashil101Param~Position 25.mys	Braking	150	450	Accelerating	378	678	-0.016154187	Pier 7
26	UIC774Hwashil101Param~Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	-0.016333193	Pier 7
27	UIC774Hwashil101Param~Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	-0.016539634	Pier 7
28	UIC774Hwashil101Param~Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	-0.016755675	Pier 7
29	UIC774Hwashil101Param~Position 29.mys	Braking	175	475	Accelerating	391	691	-0.016910744	Pier 7
30	UIC774Hwashil101Param~Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	-0.0168306	Pier 7
31	UIC774Hwashil101Param~Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	-0.016801886	Pier 7
32	UIC774Hwashil101Param~Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	-0.016717743	Pier 7
33	UIC774Hwashil101Param~Position 33.mys	Braking	200	500	Accelerating	404	704	-0.016594624	Pier 7
34	UIC774Hwashil101Param~Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	-0.01671465	Pier 10
35	UIC774Hwashil101Param~Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	-0.016905129	Pier 10
36	UIC774Hwashil101Param~Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	-0.017087318	Pier 10
37	UIC774Hwashil101Param~Position 37.mys	Braking	225	525	Accelerating	417	717	-0.017255659	Pier 10
38	UIC774Hwashil101Param~Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	-0.017420871	Pier 10
39	UIC774Hwashil101Param~Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	-0.017612033	Pier 10
40	UIC774Hwashil101Param~Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	-0.01781256	Pier 10
41	**UIC774Hwashil101Param~Position 41.mys**	**Braking**	**250**	**550**	**Accelerating**	**430**	**730**	**-0.017947893**	**Pier 10**
42	UIC774Hwashil101Param~Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	-0.01783201	Pier 10
43	UIC774Hwashil101Param~Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	-0.017756247	Pier 10
44	UIC774Hwashil101Param~Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	-0.017632055	Pier 10
45	UIC774Hwashil101Param~Position 45.mys	Braking	275	575	Accelerating	443	743	-0.017504237	Pier 10
46	UIC774Hwashil101Param~Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	-0.017341322	Pier 10
47	UIC774Hwashil101Param~Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-0.017206085	Pier 10
48	UIC774Hwashil101Param~Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-0.017076626	Pier 10
49	UIC774Hwashil101Param~Position 49.mys	Braking	300	600	Accelerating	456	756	-0.016970881	Pier 10
50	UIC774Hwashil101Param~Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	-0.016892426	Pier 10
51	UIC774Hwashil101Param~Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	-0.016829107	Pier 10
52	UIC774Hwashil101Param~Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	-0.016776923	Pier 10
53	UIC774Hwashil101Param~Position 53.mys	Braking	325	625	Accelerating	469	769	-0.016730653	Pier 10
54	UIC774Hwashil101Param~Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	-0.016755321	Pier 10
55	UIC774Hwashil101Param~Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	-0.016772138	Pier 10
56	UIC774Hwashil101Param~Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	-0.016792597	Pier 10
57	UIC774Hwashil101Param~Position 57.mys	Braking	350	650	Accelerating	482	782	-0.016804825	Pier 10
58	UIC774Hwashil101Param~Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	-0.016797833	Pier 10

Figure 79: Longitudinal Deck End Displacement due to Axial Effects Check Worksheet for Multiple Results Files



Check of Longitudinal Relative Displacement between Ends of Decks (End Rotations)

Job Title: UIC 774-3 Model: UIC774Hwashil101Param
Analysis Filename: UIC774Hwashil101Param~Position 1 --> UIC774Hwashil101Param~Position 101
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting	Track 2 Distance from Left End of the Model to the Finishing	Peak Relative Longitudinal Displacement between Ends of Decks. Positive	Pier Number / Location Supporting Decks with
1	UIC774Hwashil101Param~Position 1.mys	Temperature Only			Temperature Only			-1.06514E-05	Pier 10
1	UIC774Hwashil101Param~Position 1.mys	Braking	0	300	Accelerating	300	600	0.000491601	Pier 7
2	UIC774Hwashil101Param~Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	0.000491749	Pier 7
3	UIC774Hwashil101Param~Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	0.000491896	Pier 7
4	UIC774Hwashil101Param~Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	0.000492027	Pier 7
5	UIC774Hwashil101Param~Position 5.mys	Braking	25	325	Accelerating	313	613	0.000492173	Pier 7
6	UIC774Hwashil101Param~Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	0.000492299	Pier 7
7	UIC774Hwashil101Param~Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	0.000552518	Pier 2
8	UIC774Hwashil101Param~Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	0.000683257	Pier 2
9	UIC774Hwashil101Param~Position 9.mys	Braking	50	350	Accelerating	326	626	0.000746765	Pier 2
10	UIC774Hwashil101Param~Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	0.000797724	Pier 2
11	UIC774Hwashil101Param~Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	0.000881738	Pier 2
12	UIC774Hwashil101Param~Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	0.000916689	Pier 2
13	UIC774Hwashil101Param~Position 13.mys	Braking	75	375	Accelerating	339	639	0.000877308	Pier 2
14	UIC774Hwashil101Param~Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	0.000783909	Pier 2
15	UIC774Hwashil101Param~Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	0.00068061	Pier 2
16	UIC774Hwashil101Param~Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	0.000636353	Pier 4
17	UIC774Hwashil101Param~Position 17.mys	Braking	100	400	Accelerating	352	652	0.000707037	Pier 4
18	UIC774Hwashil101Param~Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	0.000784837	Pier 4
19	UIC774Hwashil101Param~Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	0.000917464	Pier 4
20	UIC774Hwashil101Param~Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	0.00102237	Pier 4
21	**UIC774Hwashil101Param~Position 21.mys**	**Braking**	**125**	**425**	**Accelerating**	**365**	**665**	**0.00106717**	**Pier 4**
22	UIC774Hwashil101Param~Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	0.001064259	Pier 4
23	UIC774Hwashil101Param~Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	0.001042008	Pier 4
24	UIC774Hwashil101Param~Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	0.001018645	Pier 4
25	UIC774Hwashil101Param~Position 25.mys	Braking	150	450	Accelerating	378	678	0.000997577	Pier 4
26	UIC774Hwashil101Param~Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	0.000970551	Pier 4
27	UIC774Hwashil101Param~Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	0.000930103	Pier 4
28	UIC774Hwashil101Param~Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	0.000874036	Pier 4
29	UIC774Hwashil101Param~Position 29.mys	Braking	175	475	Accelerating	391	691	0.000805822	Pier 4
30	UIC774Hwashil101Param~Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	0.000798726	Pier 7
31	UIC774Hwashil101Param~Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	0.000915344	Pier 7
32	UIC774Hwashil101Param~Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	0.001000933	Pier 7
33	UIC774Hwashil101Param~Position 33.mys	Braking	200	500	Accelerating	404	704	0.001024163	Pier 7
34	UIC774Hwashil101Param~Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	0.001000199	Pier 7
35	UIC774Hwashil101Param~Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	0.000961466	Pier 7
36	UIC774Hwashil101Param~Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	0.00093011	Pier 7
37	UIC774Hwashil101Param~Position 37.mys	Braking	225	525	Accelerating	417	717	0.000915701	Pier 7
38	UIC774Hwashil101Param~Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	0.00091589	Pier 7
39	UIC774Hwashil101Param~Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	0.00092306	Pier 7
40	UIC774Hwashil101Param~Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	0.000931649	Pier 7
41	UIC774Hwashil101Param~Position 41.mys	Braking	250	550	Accelerating	430	730	0.000938792	Pier 7
42	UIC774Hwashil101Param~Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	0.000948236	Pier 7
43	UIC774Hwashil101Param~Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	0.000961102	Pier 7
44	UIC774Hwashil101Param~Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	0.000999631	Pier 10
45	UIC774Hwashil101Param~Position 45.mys	Braking	275	575	Accelerating	443	743	0.001024825	Pier 10
46	UIC774Hwashil101Param~Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	0.001004322	Pier 10
47	UIC774Hwashil101Param~Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	0.001003052	Pier 7
48	UIC774Hwashil101Param~Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	0.000992239	Pier 7
49	UIC774Hwashil101Param~Position 49.mys	Braking	300	600	Accelerating	456	756	0.000964286	Pier 7
50	UIC774Hwashil101Param~Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	0.000937144	Pier 10
51	UIC774Hwashil101Param~Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	0.000945939	Pier 10
52	UIC774Hwashil101Param~Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	0.0009532	Pier 10
53	UIC774Hwashil101Param~Position 53.mys	Braking	325	625	Accelerating	469	769	0.000955026	Pier 10
54	UIC774Hwashil101Param~Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	0.000954295	Pier 10
55	UIC774Hwashil101Param~Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	0.0009539	Pier 10
56	UIC774Hwashil101Param~Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	0.000952197	Pier 10
57	UIC774Hwashil101Param~Position 57.mys	Braking	350	650	Accelerating	482	782	0.000948673	Pier 10
58	UIC774Hwashil101Param~Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	0.000944291	Pier 10

Figure 80: Longitudinal Deck End Displacement due to End Rotation Effects Check Worksheet for Multiple Results Files

Check of Longitudinal Relative Displacement between Ends of Decks (Total Effects)

Job Title: UIC 774-3 Model: UIC774Hwashil101Param
Analysis Filename: UIC774Hwashil101Param~Position 1--> UIC774Hwashil101Param~Position 101
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

		Track 1			Track 2				
Analysis ID	**Results Filename**	**Loading Type**	**Distance from Left End of the Model to the Starting**	**Distance from Left End of the Model to the Finishing**	**Loading Type**	**Distance from Left End of the Model to the Starting**	**Distance from Left End of the Model to the Finishing**	**Peak Relative Longitudinal Displacement between Ends of Decks. Positive**	**Pier Number / Location Supporting Decks with**
1	UIC774Hwashil101Param~Position 1.mys	Temperature Only			Temperature Only			-0.014516705	Pier 10
1	UIC774Hwashil101Param~Position 1.mys	Braking	0	300	Accelerating	300	600	-0.01443652	Pier 10
2	UIC774Hwashil101Param~Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	-0.0144409	Pier 10
3	UIC774Hwashil101Param~Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	-0.014444847	Pier 10
4	UIC774Hwashil101Param~Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-0.01444795	Pier 10
5	UIC774Hwashil101Param~Position 5.mys	Braking	25	325	Accelerating	313	613	-0.01445141	Pier 10
6	UIC774Hwashil101Param~Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-0.01445593	Pier 10
7	UIC774Hwashil101Param~Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-0.01446132	Pier 10
8	UIC774Hwashil101Param~Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-0.01446787	Pier 10
9	UIC774Hwashil101Param~Position 9.mys	Braking	50	350	Accelerating	326	626	-0.014477938	Pier 10
10	UIC774Hwashil101Param~Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	-0.014498248	Pier 10
11	UIC774Hwashil101Param~Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	-0.014518457	Pier 10
12	UIC774Hwashil101Param~Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	-0.014537008	Pier 10
13	UIC774Hwashil101Param~Position 13.mys	Braking	75	375	Accelerating	339	639	-0.014556556	Pier 10
14	UIC774Hwashil101Param~Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	-0.014579167	Pier 10
15	UIC774Hwashil101Param~Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	-0.014603325	Pier 10
16	UIC774Hwashil101Param~Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	-0.014626683	Pier 10
17	UIC774Hwashil101Param~Position 17.mys	Braking	100	400	Accelerating	352	652	-0.014651455	Pier 10
18	UIC774Hwashil101Param~Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	-0.014697601	Pier 10
19	UIC774Hwashil101Param~Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	-0.01473899	Pier 10
20	UIC774Hwashil101Param~Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	-0.014779451	Pier 10
21	UIC774Hwashil101Param~Position 21.mys	Braking	125	425	Accelerating	365	665	-0.01488285	Pier 7
22	UIC774Hwashil101Param~Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	-0.0150646	Pier 7
23	UIC774Hwashil101Param~Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	-0.015276157	Pier 7
24	UIC774Hwashil101Param~Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	-0.015507631	Pier 7
25	UIC774Hwashil101Param~Position 25.mys	Braking	150	450	Accelerating	378	678	-0.015724946	Pier 7
26	UIC774Hwashil101Param~Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	-0.015875632	Pier 7
27	UIC774Hwashil101Param~Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	-0.015991812	Pier 7
28	UIC774Hwashil101Param~Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	-0.016089043	Pier 7
29	UIC774Hwashil101Param~Position 29.mys	Braking	175	475	Accelerating	391	691	-0.016179056	Pier 7
30	UIC774Hwashil101Param~Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	-0.016031874	Pier 7
31	UIC774Hwashil101Param~Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	-0.015886542	Pier 7
32	UIC774Hwashil101Param~Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	-0.015824457	Pier 10
33	UIC774Hwashil101Param~Position 33.mys	Braking	200	500	Accelerating	404	704	-0.016007188	Pier 10
34	UIC774Hwashil101Param~Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	-0.016212661	Pier 10
35	UIC774Hwashil101Param~Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	-0.016429718	Pier 10
36	UIC774Hwashil101Param~Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	-0.016645677	Pier 10
37	UIC774Hwashil101Param~Position 37.mys	Braking	225	525	Accelerating	417	717	-0.016832891	Pier 10
38	UIC774Hwashil101Param~Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	-0.016969604	Pier 10
39	UIC774Hwashil101Param~Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	-0.017070087	Pier 10
40	UIC774Hwashil101Param~Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	-0.017150945	Pier 10
41	**UIC774Hwashil101Param~Position 41.mys**	**Braking**	**250**	**550**	**Accelerating**	**430**	**730**	**-0.017220013**	**Pier 10**
42	UIC774Hwashil101Param~Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	-0.017036363	Pier 10
43	UIC774Hwashil101Param~Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	-0.01684313	Pier 10
44	UIC774Hwashil101Param~Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	-0.016632424	Pier 10
45	UIC774Hwashil101Param~Position 45.mys	Braking	275	575	Accelerating	443	743	-0.016479412	Pier 10
46	UIC774Hwashil101Param~Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	-0.016337	Pier 10
47	UIC774Hwashil101Param~Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-0.016236206	Pier 10
48	UIC774Hwashil101Param~Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-0.016133433	Pier 10
49	UIC774Hwashil101Param~Position 49.mys	Braking	300	600	Accelerating	456	756	-0.016037539	Pier 10
50	UIC774Hwashil101Param~Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	-0.015955282	Pier 10
51	UIC774Hwashil101Param~Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	-0.015883168	Pier 10
52	UIC774Hwashil101Param~Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	-0.015823722	Pier 10
53	UIC774Hwashil101Param~Position 53.mys	Braking	325	625	Accelerating	469	769	-0.015775627	Pier 10
54	UIC774Hwashil101Param~Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	-0.015801026	Pier 10
55	UIC774Hwashil101Param~Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	-0.015818238	Pier 10
56	UIC774Hwashil101Param~Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	-0.0158404	Pier 10
57	UIC774Hwashil101Param~Position 57.mys	Braking	350	650	Accelerating	482	782	-0.015856152	Pier 10
58	UIC774Hwashil101Param~Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	-0.015853542	Pier 10

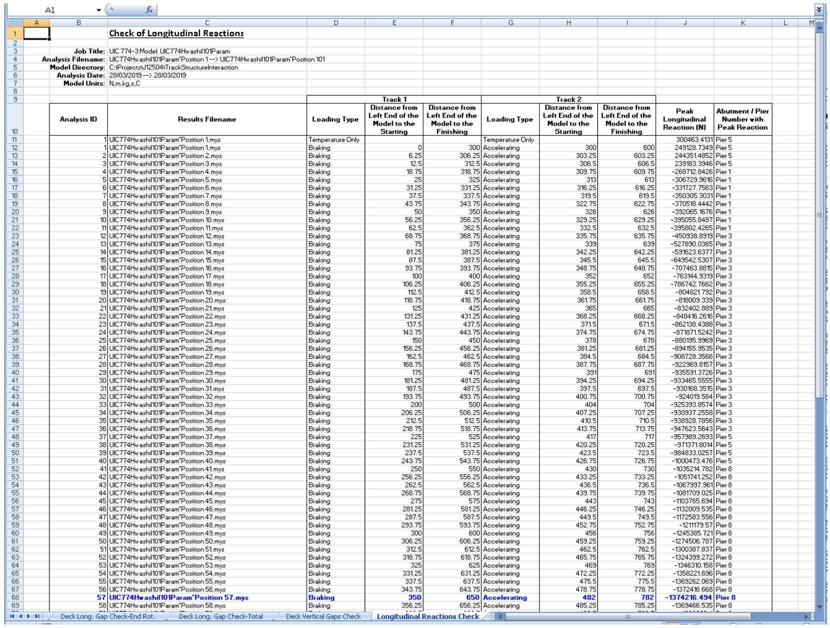
Figure 81: Longitudinal Deck End Displacement due to Total Effects Check Worksheet for Multiple Results Files

Check of Vertical Relative Displacement between Ends of Decks

Job Title: UIC 774-3 Model: UIC774Hwashil101Param
Analysis Filename: UIC774Hwashil101Param~Position 1--> UIC774Hwashil101Param~Position 101
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 08/06/2017 --> 08/06/2017
Model Units: N,m,kg,s,C

		Track 1			Track 2				
Analysis ID	**Results Filename**	**Loading Type**	**Distance from Left End of the Model to the Starting Position of the Loading (m)**	**Distance from Left End of the Model to the Finishing Position of the Loading (m)**	**Loading Type**	**Distance from Left End of the Model to the Starting Position of the Loading (m)**	**Distance from Left End of the Model to the Finishing Position of the Loading (m)**	**Peak Relative Vertical Displacement between Ends of Decks. Positive = Next deck / abutment higher than previous, Negative = Next deck / abutment lower than**	**Pier Number Supporting Decks with Peak Displacement**
1	UIC774Hwashil101Param~Position 1.mys	Temperature Only			Temperature Only			-8.73504E-08	RH Abutment
1	UIC774Hwashil101Param~Position 1.mys	Braking	0	300	Accelerating	300	600	-7.25557E-07	LH Abutment
2	UIC774Hwashil101Param~Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	-9.2416E-07	LH Abutment
3	UIC774Hwashil101Param~Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	-1.00631E-06	LH Abutment
4	UIC774Hwashil101Param~Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-9.9023E-07	LH Abutment
5	UIC774Hwashil101Param~Position 5.mys	Braking	25	325	Accelerating	313	613	-9.06053E-07	LH Abutment
6	UIC774Hwashil101Param~Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-7.93977E-07	LH Abutment
7	UIC774Hwashil101Param~Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-6.92967E-07	LH Abutment
8	UIC774Hwashil101Param~Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-6.2848E-07	LH Abutment
9	UIC774Hwashil101Param~Position 9.mys	Braking	50	350	Accelerating	326	626	9.85809E-07	Pier 2
10	UIC774Hwashil101Param~Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	7.79871E-07	RH Abutment
11	UIC774Hwashil101Param~Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	7.79555E-07	RH Abutment
12	UIC774Hwashil101Param~Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	7.79334E-07	RH Abutment
13	UIC774Hwashil101Param~Position 13.mys	Braking	75	375	Accelerating	339	639	7.79108E-07	RH Abutment
14	UIC774Hwashil101Param~Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	7.78848E-07	RH Abutment
15	UIC774Hwashil101Param~Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	7.78573E-07	RH Abutment
16	UIC774Hwashil101Param~Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	7.78307E-07	RH Abutment
17	UIC774Hwashil101Param~Position 17.mys	Braking	100	400	Accelerating	352	652	7.79438E-07	Pier 4
18	UIC774Hwashil101Param~Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	7.77573E-07	RH Abutment
19	UIC774Hwashil101Param~Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	7.77163E-07	RH Abutment
20	UIC774Hwashil101Param~Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	7.76762E-07	RH Abutment
21	UIC774Hwashil101Param~Position 21.mys	Braking	125	425	Accelerating	365	665	7.76375E-07	RH Abutment
22	UIC774Hwashil101Param~Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	7.75971E-07	RH Abutment
23	UIC774Hwashil101Param~Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	7.75548E-07	RH Abutment
24	UIC774Hwashil101Param~Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	7.75106E-07	RH Abutment
25	UIC774Hwashil101Param~Position 25.mys	Braking	150	450	Accelerating	378	678	7.74649E-07	RH Abutment
26	UIC774Hwashil101Param~Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	7.74203E-07	RH Abutment
27	UIC774Hwashil101Param~Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	7.73742E-07	RH Abutment
28	UIC774Hwashil101Param~Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	7.7327E-07	RH Abutment
29	UIC774Hwashil101Param~Position 29.mys	Braking	175	475	Accelerating	391	691	8.35026E-07	Pier 7
30	UIC774Hwashil101Param~Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	7.71751E-07	RH Abutment
31	UIC774Hwashil101Param~Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	7.70887E-07	RH Abutment
32	UIC774Hwashil101Param~Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	7.70045E-07	RH Abutment
33	UIC774Hwashil101Param~Position 33.mys	Braking	200	500	Accelerating	404	704	7.69293E-07	RH Abutment
34	UIC774Hwashil101Param~Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	7.68525E-07	RH Abutment
35	UIC774Hwashil101Param~Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	7.67773E-07	RH Abutment
36	UIC774Hwashil101Param~Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	7.67023E-07	RH Abutment
37	UIC774Hwashil101Param~Position 37.mys	Braking	225	525	Accelerating	417	717	7.66241E-07	RH Abutment
38	UIC774Hwashil101Param~Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	7.65359E-07	RH Abutment
39	UIC774Hwashil101Param~Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	7.64466E-07	RH Abutment
40	UIC774Hwashil101Param~Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	7.63561E-07	RH Abutment
41	UIC774Hwashil101Param~Position 41.mys	Braking	250	550	Accelerating	430	730	8.30904E-07	Pier 10
42	UIC774Hwashil101Param~Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	7.65606E-07	RH Abutment
43	UIC774Hwashil101Param~Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	7.75582E-07	RH Abutment
44	UIC774Hwashil101Param~Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	7.87265E-07	RH Abutment
45	UIC774Hwashil101Param~Position 45.mys	Braking	275	575	Accelerating	443	743	7.92204E-07	RH Abutment
46	UIC774Hwashil101Param~Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	7.7942E-07	RH Abutment
47	UIC774Hwashil101Param~Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-7.56552E-07	LH Abutment
48	UIC774Hwashil101Param~Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-7.56736E-07	LH Abutment
49	UIC774Hwashil101Param~Position 49.mys	Braking	300	600	Accelerating	456	756	-7.34085E-07	LH Abutment
50	UIC774Hwashil101Param~Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	7.16688E-07	RH Abutment
51	UIC774Hwashil101Param~Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	8.65324E-07	RH Abutment
52	UIC774Hwashil101Param~Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	1.15794E-06	RH Abutment
53	UIC774Hwashil101Param~Position 53.mys	Braking	325	625	Accelerating	469	769	1.59266E-06	RH Abutment
54	UIC774Hwashil101Param~Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	1.61511E-06	RH Abutment
55	UIC774Hwashil101Param~Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	1.615E-06	RH Abutment

Figure 82: Vertical Deck End Displacement Check Worksheet for Multiple Results Files

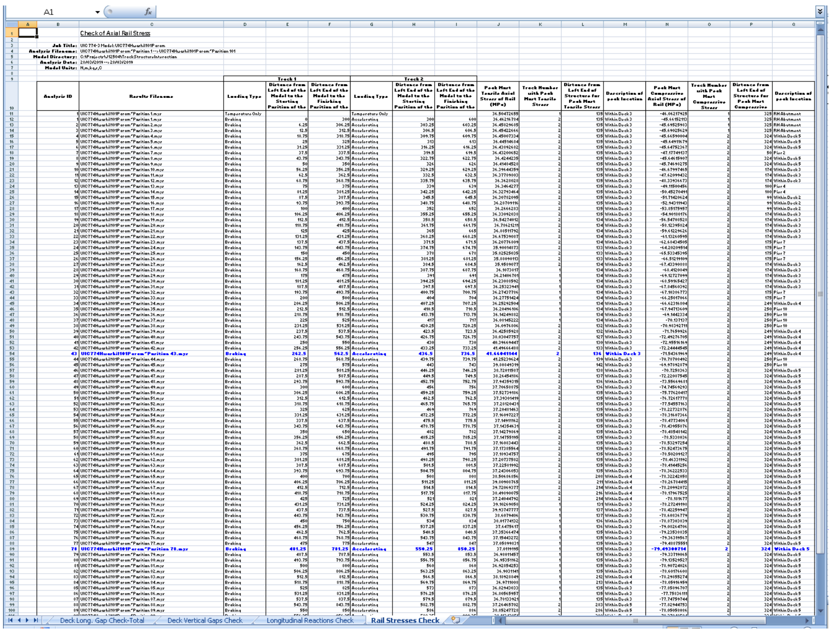


Check of Longitudinal Reactions

Job Title: UIC 774-3 Model: UIC774Hwashil101Param
Analysis Filename: UIC774Hwashil101Param˝Position 1 --> UIC774Hwashil101Param˝Position 101
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

		Track 1			Track 2				
Analysis ID	**Results Filename**	**Loading Type**	**Distance from Left End of the Model to the Starting**	**Distance from Left End of the Model to the Finishing**	**Loading Type**	**Distance from Left End of the Model to the Starting**	**Distance from Left End of the Model to the Finishing**	**Peak Longitudinal Reaction (N)**	**Abutment / Pier Number with Peak Reaction**
1	UIC774Hwashil101Param˝Position 1.mys	Temperature Only			Temperature Only			300463.4131	Pier 5
1	UIC774Hwashil101Param˝Position 1.mys	Braking	0	300	Accelerating	300	600	249128.7349	Pier 5
2	UIC774Hwashil101Param˝Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	244351.4852	Pier 5
3	UIC774Hwashil101Param˝Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	239183.3946	Pier 5
4	UIC774Hwashil101Param˝Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-268712.8426	Pier 1
5	UIC774Hwashil101Param˝Position 5.mys	Braking	25	325	Accelerating	313	613	-306729.9616	Pier 1
6	UIC774Hwashil101Param˝Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-331727.7563	Pier 1
7	UIC774Hwashil101Param˝Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-350305.3031	Pier 1
8	UIC774Hwashil101Param˝Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-370518.4442	Pier 1
9	UIC774Hwashil101Param˝Position 9.mys	Braking	50	350	Accelerating	326	626	-392065.1676	Pier 1
10	UIC774Hwashil101Param˝Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	-395055.8487	Pier 1
11	UIC774Hwashil101Param˝Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	-395802.4265	Pier 1
12	UIC774Hwashil101Param˝Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	-450938.8919	Pier 3
13	UIC774Hwashil101Param˝Position 13.mys	Braking	75	375	Accelerating	339	639	-527890.0365	Pier 3
14	UIC774Hwashil101Param˝Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	-591623.6377	Pier 3
15	UIC774Hwashil101Param˝Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	-649542.5307	Pier 3
16	UIC774Hwashil101Param˝Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	-707463.8815	Pier 3
17	UIC774Hwashil101Param˝Position 17.mys	Braking	100	400	Accelerating	352	652	-763144.9319	Pier 3
18	UIC774Hwashil101Param˝Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	-786742.7662	Pier 3
19	UIC774Hwashil101Param˝Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	-804821.792	Pier 3
20	UIC774Hwashil101Param˝Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	-818009.339	Pier 3
21	UIC774Hwashil101Param˝Position 21.mys	Braking	125	425	Accelerating	365	665	-832402.889	Pier 3
22	UIC774Hwashil101Param˝Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	-848416.2616	Pier 3
23	UIC774Hwashil101Param˝Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	-862138.4388	Pier 3
24	UIC774Hwashil101Param˝Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	-871871.5242	Pier 3
25	UIC774Hwashil101Param˝Position 25.mys	Braking	150	450	Accelerating	378	678	-880195.9969	Pier 3
26	UIC774Hwashil101Param˝Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	-894155.9535	Pier 3
27	UIC774Hwashil101Param˝Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	-908728.3566	Pier 3
28	UIC774Hwashil101Param˝Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	-922969.8157	Pier 3
29	UIC774Hwashil101Param˝Position 29.mys	Braking	175	475	Accelerating	391	691	-935591.3726	Pier 3
30	UIC774Hwashil101Param˝Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	-933465.5555	Pier 3
31	UIC774Hwashil101Param˝Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	-930168.3515	Pier 3
32	UIC774Hwashil101Param˝Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	-924019.564	Pier 3
33	UIC774Hwashil101Param˝Position 33.mys	Braking	200	500	Accelerating	404	704	-925393.8574	Pier 3
34	UIC774Hwashil101Param˝Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	-930937.2558	Pier 3
35	UIC774Hwashil101Param˝Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	-938928.7856	Pier 3
36	UIC774Hwashil101Param˝Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	-947623.5643	Pier 3
37	UIC774Hwashil101Param˝Position 37.mys	Braking	225	525	Accelerating	417	717	-957989.2693	Pier 5
38	UIC774Hwashil101Param˝Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	-971371.8014	Pier 5
39	UIC774Hwashil101Param˝Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	-984833.0257	Pier 5
40	UIC774Hwashil101Param˝Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	-1000473.476	Pier 5
41	UIC774Hwashil101Param˝Position 41.mys	Braking	250	550	Accelerating	430	730	-1035214.782	Pier 8
42	UIC774Hwashil101Param˝Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	-1051741.252	Pier 8
43	UIC774Hwashil101Param˝Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	-1067997.961	Pier 8
44	UIC774Hwashil101Param˝Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	-1081709.025	Pier 8
45	UIC774Hwashil101Param˝Position 45.mys	Braking	275	575	Accelerating	443	743	-1103765.694	Pier 8
46	UIC774Hwashil101Param˝Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	-1132009.535	Pier 8
47	UIC774Hwashil101Param˝Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-1172583.556	Pier 8
48	UIC774Hwashil101Param˝Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-1211179.57	Pier 8
49	UIC774Hwashil101Param˝Position 49.mys	Braking	300	600	Accelerating	456	756	-1245385.721	Pier 8
50	UIC774Hwashil101Param˝Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	-1274506.787	Pier 8
51	UIC774Hwashil101Param˝Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	-1300387.837	Pier 8
52	UIC774Hwashil101Param˝Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	-1324399.272	Pier 8
53	UIC774Hwashil101Param˝Position 53.mys	Braking	325	625	Accelerating	469	769	-1346310.158	Pier 8
54	UIC774Hwashil101Param˝Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	-1358221.696	Pier 8
55	UIC774Hwashil101Param˝Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	-1369262.069	Pier 8
56	UIC774Hwashil101Param˝Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	-1372416.668	Pier 8
57	**UIC774Hwashil101Param˝Position 57.mys**	**Braking**	**350**	**650**	**Accelerating**	**482**	**782**	**-1374216.494**	**Pier 8**
58	UIC774Hwashil101Param˝Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	-1369466.535	Pier 8

Figure 83: Longitudinal Reaction Check Worksheet for Multiple Results Files



Check of Axial Rail Stress

Job Title: UIC 774-3 Model: UIC774Hwashil101Param
Analysis Filename: UIC774Hwashil101Param˝Position 1 --> UIC774Hwashil101Param˝Position 101
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

		Track 1			Track 2										
Analysis ID	**Results Filename**	**Loading Type**	**Distance from Left End of the Model to the Starting Position of the**	**Distance from Left End of the Model to the Finishing Position of the**	**Loading Type**	**Distance from Left End of the Model to the Starting Position of the**	**Distance from Left End of the Model to the Finishing Position of the**	**Peak Most Tensile Axial Stress of Rail (MPa)**	**Track Number with Peak Most Tensile Stress**	**Distance from Left End of Structure for Peak Most Tensile Stress**	**Description of peak location**	**Peak Most Compressive Axial Stress of Rail (MPa)**	**Track Number with Peak Most Compressive Stress**	**Distance from Left End of Structure for Peak Most Compressive**	**Description of peak location**
1	UIC774Hwashil101Param˝Position 1.mys	Temperature Only			Temperature Only			36.50472655	1	135	Within Deck 3	-46.06217925	1	325	RH Abutment
1	UIC774Hwashil101Param˝Position 1.mys	Braking	0	300	Accelerating	300	600	36.46216784	2	135	Within Deck 3	-45.66152113	1	325	RH Abutment
2	UIC774Hwashil101Param˝Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	36.45829685	2	135	Within Deck 3	-45.69525983	1	325	RH Abutment
3	UIC774Hwashil101Param˝Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	36.45422666	2	135	Within Deck 3	-45.69025629	1	325	RH Abutment
4	UIC774Hwashil101Param˝Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	36.45007334	2	135	Within Deck 3	-45.66590004	2	324	Within Deck 5
5	UIC774Hwashil101Param˝Position 5.mys	Braking	25	325	Accelerating	313	613	36.44514684	2	135	Within Deck 3	-45.64911679	2	324	Within Deck 5
6	UIC774Hwashil101Param˝Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	36.43892682	2	135	Within Deck 3	-45.64752367	2	324	Within Deck 5
7	UIC774Hwashil101Param˝Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	36.43200652	2	135	Within Deck 3	-47.17749137	2	50	Pier 2
8	UIC774Hwashil101Param˝Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	36.4244235	2	135	Within Deck 3	-45.64615907	2	324	Within Deck 5
9	UIC774Hwashil101Param˝Position 9.mys	Braking	50	350	Accelerating	326	626	36.41484528	2	135	Within Deck 3	-45.74698275	2	324	Within Deck 5
10	UIC774Hwashil101Param˝Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	36.39644359	2	135	Within Deck 3	-46.67997465	2	174	Within Deck 3
11	UIC774Hwashil101Param˝Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	36.37789803	2	135	Within Deck 3	-47.62099432	2	174	Within Deck 3
12	UIC774Hwashil101Param˝Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	36.3628028	2	135	Within Deck 3	-48.33936673	2	174	Within Deck 3
13	UIC774Hwashil101Param˝Position 13.mys	Braking	75	375	Accelerating	339	639	36.3464277	2	135	Within Deck 3	-49.11500456	2	100	Pier 4
14	UIC774Hwashil101Param˝Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	36.32793464	2	135	Within Deck 3	-50.45270491	2	100	Pier 4
15	UIC774Hwashil101Param˝Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	36.30782095	2	135	Within Deck 3	-51.71420624	2	99	Within Deck 2
16	UIC774Hwashil101Param˝Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	36.28709116	2	135	Within Deck 3	-52.94311943	2	99	Within Deck 2
17	UIC774Hwashil101Param˝Position 17.mys	Braking	100	400	Accelerating	352	652	36.2666283	2	135	Within Deck 3	-53.85175957	2	99	Within Deck 2
18	UIC774Hwashil101Param˝Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	36.33092038	2	135	Within Deck 3	-54.90180176	2	174	Within Deck 3
19	UIC774Hwashil101Param˝Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	36.54274012	2	134	Within Deck 3	-56.54708528	2	174	Within Deck 3
20	UIC774Hwashil101Param˝Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	36.78621211	2	134	Within Deck 3	-58.12395824	2	174	Within Deck 3
21	UIC774Hwashil101Param˝Position 21.mys	Braking	125	425	Accelerating	365	665	36.88511792	2	134	Within Deck 3	-59.61229626	2	174	Within Deck 3
22	UIC774Hwashil101Param˝Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	36.67539087	2	134	Within Deck 3	-61.13260595	2	174	Within Deck 3
23	UIC774Hwashil101Param˝Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	36.20776809	2	134	Within Deck 3	-62.68434505	2	175	Pier 7
24	UIC774Hwashil101Param˝Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	35.90014873	2	133	Within Deck 3	-64.20209514	2	175	Pier 7
25	UIC774Hwashil101Param˝Position 25.mys	Braking	150	450	Accelerating	378	678	35.82525035	2	133	Within Deck 3	-65.53345395	2	175	Pier 7
26	UIC774Hwashil101Param˝Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	35.88090113	2	133	Within Deck 3	-66.51219109	2	175	Pier 7
27	UIC774Hwashil101Param˝Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	35.9589077	2	134	Within Deck 3	-67.43390888	2	174	Within Deck 3
28	UIC774Hwashil101Param˝Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	36.1073817	1	134	Within Deck 3	-68.4120849	2	174	Within Deck 3
29	UIC774Hwashil101Param˝Position 29.mys	Braking	175	475	Accelerating	391	691	36.21406701	1	134	Within Deck 3	-69.12727099	2	174	Within Deck 3
30	UIC774Hwashil101Param˝Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	36.23088592	1	134	Within Deck 3	-68.59165427	2	174	Within Deck 3
31	UIC774Hwashil101Param˝Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	36.25323941	1	134	Within Deck 3	-67.84560392	2	174	Within Deck 3
32	UIC774Hwashil101Param˝Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	36.27437786	1	134	Within Deck 3	-67.10386773	2	175	Pier 7
33	UIC774Hwashil101Param˝Position 33.mys	Braking	200	500	Accelerating	404	704	36.27751424	1	134	Within Deck 3	-66.25017066	2	175	Pier 7
34	UIC774Hwashil101Param˝Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	36.25292504	1	134	Within Deck 3	-66.62316804	2	249	Within Deck 4
35	UIC774Hwashil101Param˝Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	36.20496106	1	134	Within Deck 3	-67.94713609	2	250	Pier 10
36	UIC774Hwashil101Param˝Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	36.14249882	1	134	Within Deck 3	-69.1442334	2	250	Pier 10
37	UIC774Hwashil101Param˝Position 37.mys	Braking	225	525	Accelerating	417	717	36.08145222	1	134	Within Deck 3	-70.137137	2	250	Pier 10
38	UIC774Hwashil101Param˝Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	36.0976806	2	132	Within Deck 3	-70.98392711	2	250	Pier 10
39	UIC774Hwashil101Param˝Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	36.42585928	2	132	Within Deck 3	-71.7659926	2	249	Within Deck 4
40	UIC774Hwashil101Param˝Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	38.03047757	2	127	Within Deck 3	-72.49276705	2	249	Within Deck 4
41	UIC774Hwashil101Param˝Position 41.mys	Braking	250	550	Accelerating	430	730	40.39669447	2	130	Within Deck 3	-72.95516169	2	249	Within Deck 4
42	UIC774Hwashil101Param˝Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	41.49666488	2	133	Within Deck 3	-72.24444545	2	249	Within Deck 4
43	**UIC774Hwashil101Param˝Position 43.mys**	**Braking**	**262.5**	**562.5**	**Accelerating**	**436.5**	**736.5**	**41.66041144**	**2**	**136**	**Within Deck 3**	-71.54361969	2	249	Within Deck 4
44	UIC774Hwashil101Param˝Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	41.25239624	2	139	Within Deck 3	-70.78708492	2	250	Pier 10
45	UIC774Hwashil101Param˝Position 45.mys	Braking	275	575	Accelerating	443	743	39.80849319	2	142	Within Deck 3	-69.97892879	2	250	Pier 10
46	UIC774Hwashil101Param˝Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	38.72011587	2	138	Within Deck 3	-70.7258363	2	324	Within Deck 5
47	UIC774Hwashil101Param˝Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	38.26454186	2	137	Within Deck 3	-72.22087545	2	324	Within Deck 5
48	UIC774Hwashil101Param˝Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	37.94359315	2	136	Within Deck 3	-73.55669681	2	324	Within Deck 5
49	UIC774Hwashil101Param˝Position 49.mys	Braking	300	600	Accelerating	456	756	37.70658875	2	136	Within Deck 3	-74.74569293	2	324	Within Deck 5
50	UIC774Hwashil101Param˝Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	37.52739186	2	135	Within Deck 3	-75.77620417	2	324	Within Deck 5
51	UIC774Hwashil101Param˝Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	37.39301419	2	135	Within Deck 3	-76.72617778	2	324	Within Deck 5
52	UIC774Hwashil101Param˝Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	37.28120431	2	135	Within Deck 3	-77.54557163	2	324	Within Deck 5
53	UIC774Hwashil101Param˝Position 53.mys	Braking	325	625	Accelerating	469	769	37.20481463	2	135	Within Deck 3	-78.22732876	2	324	Within Deck 5
54	UIC774Hwashil101Param˝Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	37.16097227	2	135	Within Deck 3	-78.31607366	2	324	Within Deck 5
55	UIC774Hwashil101Param˝Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	37.14911162	2	135	Within Deck 3	-78.47734061	2	324	Within Deck 5
56	UIC774Hwashil101Param˝Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	37.14354631	2	135	Within Deck 3	-78.43955876	2	324	Within Deck 5
57	UIC774Hwashil101Param˝Position 57.mys	Braking	350	650	Accelerating	482	782	37.14279869	2	135	Within Deck 3	-78.48548142	2	324	Within Deck 5
58	UIC774Hwashil101Param˝Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	37.14755195	2	135	Within Deck 3	-78.5338036	2	324	Within Deck 5
59	UIC774Hwashil101Param˝Position 59.mys	Braking	362.5	662.5	Accelerating	488.5	788.5	37.16083443	2	135	Within Deck 3	-78.53297254	2	324	Within Deck 5
60	UIC774Hwashil101Param˝Position 60.mys	Braking	368.75	668.75	Accelerating	491.75	791.75	37.17385564	2	135	Within Deck 3	-78.52473675	2	324	Within Deck 5
61	UIC774Hwashil101Param˝Position 61.mys	Braking	375	675	Accelerating	495	795	37.18934757	2	135	Within Deck 3	-78.50209127	2	324	Within Deck 5
62	UIC774Hwashil101Param˝Position 62.mys	Braking	381.25	681.25	Accelerating	498.25	798.25	37.20737582	2	135	Within Deck 3	-78.46331192	2	324	Within Deck 5
63	UIC774Hwashil101Param˝Position 63.mys	Braking	387.5	687.5	Accelerating	501.5	801.5	37.22581992	2	135	Within Deck 3	-78.41445256	2	324	Within Deck 5
64	UIC774Hwashil101Param˝Position 64.mys	Braking	393.75	693.75	Accelerating	504.75	804.75	37.24306053	2	135	Within Deck 3	-78.36222533	2	324	Within Deck 5
65	UIC774Hwashil101Param˝Position 65.mys	Braking	400	700	Accelerating	508	808	38.50686856	2	208	Within Deck 4	-78.32242058	2	324	Within Deck 5
66	UIC774Hwashil101Param˝Position 66.mys	Braking	406.25	706.25	Accelerating	511.25	811.25	39.80908765	2	211	Within Deck 4	-78.26784415	2	324	Within Deck 5
67	UIC774Hwashil101Param˝Position 67.mys	Braking	412.5	712.5	Accelerating	514.5	814.5	39.72069377	2	214	Within Deck 4	-78.20992072	2	324	Within Deck 5
68	UIC774Hwashil101Param˝Position 68.mys	Braking	418.75	718.75	Accelerating	517.75	817.75	38.49890075	2	216	Within Deck 4	-78.17967525	2	324	Within Deck 5
69	UIC774Hwashil101Param˝Position 69.mys	Braking	425	725	Accelerating	521	821	37.24044792	2	214	Within Deck 4	-78.181677	2	324	Within Deck 5
70	UIC774Hwashil101Param˝Position 70.mys	Braking	431.25	731.25	Accelerating	524.25	824.25	39.10269058	1	131	Within Deck 3	-78.27249198	2	324	Within Deck 5
71	UIC774Hwashil101Param˝Position 71.mys	Braking	437.5	737.5	Accelerating	527.5	827.5	39.93747777	1	137	Within Deck 3	-78.42259947	2	324	Within Deck 5
72	UIC774Hwashil101Param˝Position 72.mys	Braking	443.75	743.75	Accelerating	530.75	830.75	38.6079406	1	137	Within Deck 3	-78.60836779	2	324	Within Deck 5
73	UIC774Hwashil101Param˝Position 73.mys	Braking	450	750	Accelerating	534	834	38.01774132	1	136	Within Deck 3	-78.87303839	2	324	Within Deck 5
74	UIC774Hwashil101Param˝Position 74.mys	Braking	456.25	756.25	Accelerating	537.25	837.25	37.6475617	1	136	Within Deck 3	-79.08264706	2	324	Within Deck 5
75	UIC774Hwashil101Param˝Position 75.mys	Braking	462.5	762.5	Accelerating	540.5	840.5	37.35366474	1	135	Within Deck 3	-79.23538835	2	324	Within Deck 5
76	UIC774Hwashil101Param˝Position 76.mys	Braking	468.75	768.75	Accelerating	543.75	843.75	37.15443272	1	135	Within Deck 3	-79.36319567	2	324	Within Deck 5
77	UIC774Hwashil101Param˝Position 77.mys	Braking	475	775	Accelerating	547	847	37.05899831	1	135	Within Deck 3	-79.48875551	2	324	Within Deck 5
78	**UIC774Hwashil101Param˝Position 78.mys**	**Braking**	**481.25**	**781.25**	**Accelerating**	**550.25**	**850.25**	37.0119195	1	135	Within Deck 3	**-79.49300714**	**2**	**324**	**Within Deck 5**
79	UIC774Hwashil101Param˝Position 79.mys	Braking	487.5	787.5	Accelerating	553.5	853.5	36.98011457	1	135	Within Deck 3	-79.33719065	2	324	Within Deck 5
80	UIC774Hwashil101Param˝Position 80.mys	Braking	493.75	793.75	Accelerating	556.75	856.75	36.95351162	1	135	Within Deck 3	-79.13529527	2	324	Within Deck 5
81	UIC774Hwashil101Param˝Position 81.mys	Braking	500	800	Accelerating	560	860	36.92854253	1	135	Within Deck 3	-78.90724026	2	324	Within Deck 5
82	UIC774Hwashil101Param˝Position 82.mys	Braking	506.25	806.25	Accelerating	563.25	863.25	36.9031141	1	135	Within Deck 3	-78.60176608	2	324	Within Deck 5
83	UIC774Hwashil101Param˝Position 83.mys	Braking	512.5	812.5	Accelerating	566.5	866.5	38.18928849	1	212	Within Deck 4	-78.29855274	2	324	Within Deck 5
84	UIC774Hwashil101Param˝Position 84.mys	Braking	518.75	818.75	Accelerating	569.75	869.75	36.9711008	1	213	Within Deck 4	-78.05916959	2	324	Within Deck 5
85	UIC774Hwashil101Param˝Position 85.mys	Braking	525	825	Accelerating	573	873	36.82943033	1	135	Within Deck 3	-77.85896707	2	324	Within Deck 5
86	UIC774Hwashil101Param˝Position 86.mys	Braking	531.25	831.25	Accelerating	576.25	876.25	36.80565957	1	135	Within Deck 3	-77.75836111	2	324	Within Deck 5
87	UIC774Hwashil101Param˝Position 87.mys	Braking	537.5	837.5	Accelerating	579.5	879.5	36.78133921	1	135	Within Deck 3	-77.74759744	2	324	Within Deck 5
88	UIC774Hwashil101Param˝Position 88.mys	Braking	543.75	843.75	Accelerating	582.75	882.75	37.26465702	2	283	Within Deck 5	-77.82944753	2	324	Within Deck 5
89	UIC774Hwashil101Param˝Position 89.mys	Braking	550	850	Accelerating	586	886	38.85247728	2	286	Within Deck 5	-78.05058086	2	324	Within Deck 5

Figure 84: Axial Rail Stress Check Worksheet for Multiple Results Files

If valid basic combinations or envelopes that match the criteria described in "***Post-processing of automatically defined groups***" (page 63) are present in the model then additional results for these will be tabulated into the XLSX spreadsheet summary worksheets underneath the results for the temperature only and combined temperature and trainset rail loading results. A separate set of the peak results within these basic combinations will be highlighted in bold blue text as illustrated in the figures below for the longitudinal relative railbed displacement and longitudinal reaction results for a model that includes valid basic combinations.

Check of Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)

Job Title: UIC774-3 Model: UIC774HvashIP403bParamRail
Analysis Filename: UIC774HvashIP403bParamRail-BasicCombs:"Position 1--> UIC774HvashIP403bParamRail-BasicCombs:"Position 5
Model Directory: C:\Projects\JI2504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

			Track 1			Track 2						
	Analysis ID	Results Filename / Combination Name	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Peak Relative Longitudinal Displacement between Rail and Slab (m)	Track Number with Peak Displacement	Distance from Left End of Structure for Peak Displacement	Description o peak location
11	1	UIC774HvashIP403bParamRail-BasicCombs:"Position 1.mys	Temperature Only			Temperature Only			0.007380097	1	325	RH Abutment
12	1	UIC774HvashIP403bParamRail-BasicCombs:"Position 1.mys	Braking	0	300	Accelerating	270	570	0.007335564	2	325	RH Abutment
13	2	UIC774HvashIP403bParamRail-BasicCombs:"Position 2.mys	Braking	81.25	381.25	Accelerating	351.25	651.25	0.007373218	2	325	RH Abutment
14	3	UIC774HvashIP403bParamRail-BasicCombs:"Position 3.mys	Braking	162.5	462.5	Accelerating	432.5	732.5	0.00876083	1	175	Pier 7
15	**4**	**UIC774HvashIP403bParamRail-BasicCombs:"Position 4.(**	**Braking**	**243.75**	**543.75**	**Accelerating**	**513.75**	**813.75**	**0.009944269**	**1**	**250**	**Pier 10**
16	5	UIC774HvashIP403bParamRail-BasicCombs:"Position 5.mys	Braking	325	625	Accelerating	595	895	0.008857904	2	325	RH Abutment
17	Basic Combination	Position 1 including Self Weight							0.007086636	2	325	RH Abutment
18	Basic Combination	Position 2 including Self Weight							0.007134263	2	325	RH Abutment
19	Basic Combination	Position 3 including Self Weight							0.00854357	1	175	Pier 7
20	**Basic Combinat**	**Position 4 including Self Weight**							**0.009716083**	**1**	**250**	**Pier 10**
21	Basic Combination	Position 5 including Self Weight							0.008418956	2	325	RH Abutment

Warning: Basic combinations of nonlinear results are not strictly valid and should be used with caution

Figure 85: Longitudinal Relative Railbed Displacement Check Worksheet for Rail Track Analysis Results and Basic Combinations of these Results

Check of Longitudinal Reactions

Job Title: UIC 774-3 Model: UIC774HvashIP403bParamRail
Analysis Filename: UIC774HvashIP403bParamRail-BasicCombs:"Position 1--> UIC774HvashIP403bParamRail-BasicCombs:"Position 5
Model Directory: C:\Projects\JI2504\TrackStructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

			Track 1			Track 2				
	Analysis ID	Results Filename / Combination Name	Loading Type	Distance from Left End of the Model to the Starting Position	Distance from Left End of the Model to the Finishing	Loading Type	Distance from Left End of the Model to the Starting Position	Distance from Left End of the Model to the Finishing	Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction
11	1	UIC774HvashIP403bParamRail-BasicCombs:"Position 1.mys	Temperature Only			Temperature Only			300463.4131	Pier 5
12	1	UIC774HvashIP403bParamRail-BasicCombs:"Position 1.mys	Braking	0	300	Accelerating	270	570	287207.5788	Pier 5
13	2	UIC774HvashIP403bParamRail-BasicCombs:"Position 2.mys	Braking	81.25	381.25	Accelerating	351.25	651.25	-845077.2753	Pier 3
14	3	UIC774HvashIP403bParamRail-BasicCombs:"Position 3.mys	Braking	162.5	462.5	Accelerating	432.5	732.5	-937591.4175	Pier 3
15	**4**	**UIC774HvashIP403bParamRail-BasicCombs:"Position 4.mys**	**Braking**	**243.75**	**543.75**	**Accelerating**	**513.75**	**813.75**	**-1201042.32**	**Pier 8**
16	5	UIC774HvashIP403bParamRail-BasicCombs:"Position 5.mys	Braking	325	625	Accelerating	595	895	-1191058.888	Pier 11
17	Basic Combination	Position 1 including Self Weight							262674.6646	Pier 5
18	Basic Combination	Position 2 including Self Weight							-846660.0664	Pier 3
19	Basic Combination	Position 3 including Self Weight							-938174.2286	Pier 3
20	**Basic Combinatio**	**Position 4 including Self Weight**							**-1214172.798**	**Pier 8**
21	Basic Combination	Position 5 including Self Weight							-1199972.026	Pier 11

Warning: Basic combinations of nonlinear results are not strictly valid and should be used with caution

Figure 86: Longitudinal Reaction Check Worksheet for Rail Track Analysis Results and Basic Combinations of these Results

Performing Post-Processing without Charting

For a large Rail Track Analysis that may have included detailed modelling or possibly a greater number of tracks / Train Loading Groups / trainset positions per Train Loading Group there are some circumstances when the post-processing can be unsuccessful or the results spreadsheet can fail to load into the spreadsheet application you are using to view the XLSX spreadsheet, resulting in an error message being shown. If this occurs it may be possible to post-process the whole Rail Track Analysis by disabling the charting in the post-processing.

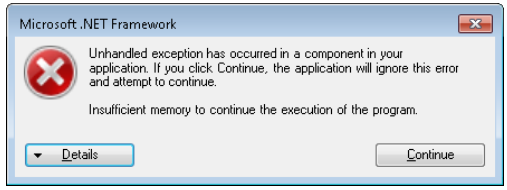


Figure 87: Insufficient Memory to Complete the Post-Processing

The post-processing provides the option to turn off all of the charting on the main dialog as highlighted in the figure that follows. When this option is turned off the output from the post-processing will be identical to the full post-processing but the only difference will be the omission of the charts in the separate worksheets for the tracks and the decks. The whole (or part – see next section) analysis can therefore be post-processed first with all of the enveloping and peak checking carried out, after which these spreadsheets can be inspected.

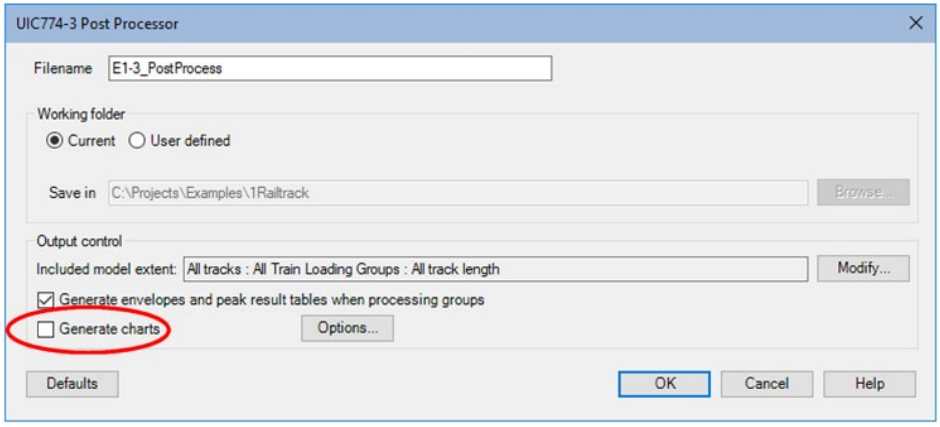


Figure 88: Disabling the Charting for the Post-Processing

Any aspects of the structure/analysis that warrant more detailed investigations can then be post-processed to separate spreadsheets with the charting turned back on but using the **Modify Included Output** dialog to target which tracks / Train Loading Groups / rail track extent and the **Chart Options** dialog to choose which charts are required – see "***Performing Post-Processing with Selective Output***" below.

Performing Post-processing with Selective Output

Targeted results output for the Rail Track Analysis can be obtained for the post-processing if a reduced set of tracks/Train Loading Groups/extent of railtrack are to be post-processed. This may be because of a need to investigate specific aspects of the track-structure interaction model more closely without all of the other effects or it could be because it was impossible to post-process the whole analysis into a single

spreadsheet (the spreadsheet was too large to write, or the application being used to view the spreadsheet was unable to load/view it).

The post-processor allows the full control of the tracks, Train Loading Groups and extent of the railtrack that are to be included in the results post-processing through the **Modify Included Output** dialog shown in the figure below (accessed by clicking on the **Modify...** button on the main post-processing dialog). In combination with the **Generate Charts** option (and the selection of which charts to create) this allows the creation of any results spreadsheets for track-structure interaction locations of interest.

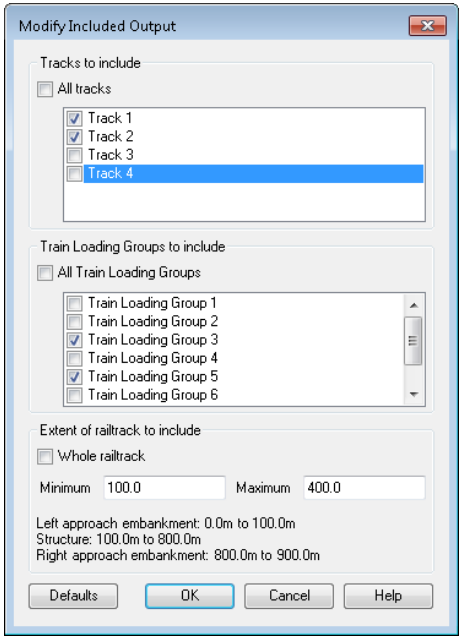


Figure 89: Modify Included Output Dialog with Selective Output for Rail Track Model with 4 Tracks, 8 Train Loading Groups and a 0.7 km Viaduct

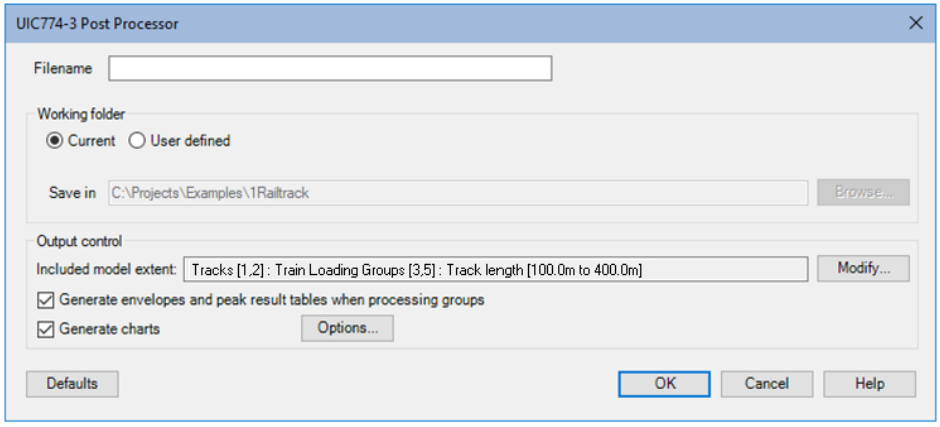


Figure 90: Associated Post-Processing Dialog Showing Selection Output for Rail Track Model with 4 Tracks, 8 Train Loading Groups and a 0.7 km Viaduct

For the viaduct being post-processed above the chosen input in the dialog will create the individual spreadsheets for the selective output as normal. These will, in addition to the data and charts, contain some warnings within the worksheets for the tracks, decks and the peak quantities as a reminder that it is possible for a more onerous result to be present for a different track / Train Loading Group or trainset position / within a different rail track extent if the selection within the current results spreadsheet has not included the worst effects.

Note. If for some reason a spreadsheet file is not produced due to insufficient memory post-processing of the whole model without charts is recommended as a first step if selected output is being used, this way the peak results for the whole analysis are obtained prior to carrying out selective post-processing.

Caution. If selective output is being used when it has not previously failed it is still recommended that the whole model (or at absolute minimum the left abutment to the right abutment) is post-processed without charts as a first step to ensure that the peak results and their locations are known prior to carrying out selective post-processing.

Figure 91 shows the results worksheet created for track 1 of the model. Clearly visible at the top of the worksheet is the following warning highlighted in red:

Warning: Only selected Train Loading Groups and track length (100.0m to 400.0m) were included in the results. Exclusion of results could lead to peak behaviours being missed and more critical conditions being excluded from the design process

The same message will also be repeated at the top of the results worksheets for track 2 and the decks along with the associated envelope worksheets if this option has been selected. The exact message reflects the choices within the **Modify Included Output** dialog.

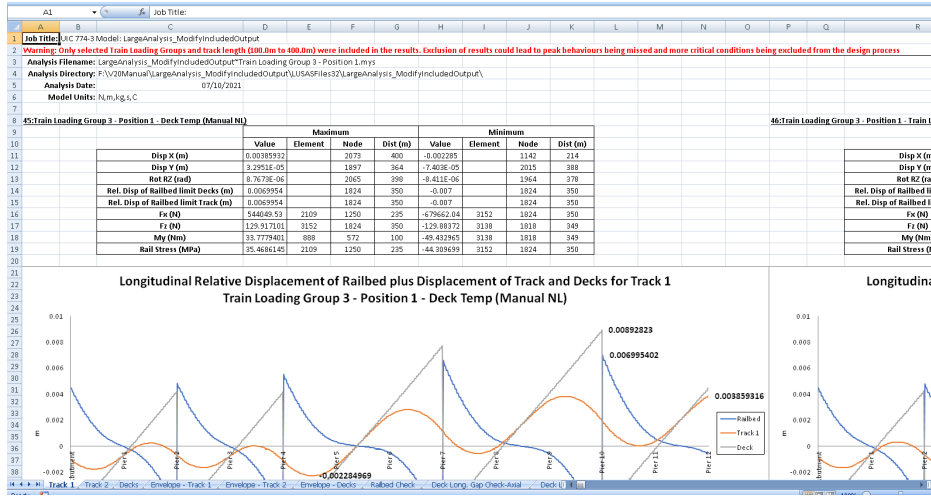


Figure 91: Selective Rail Track Extents Results for Track 1

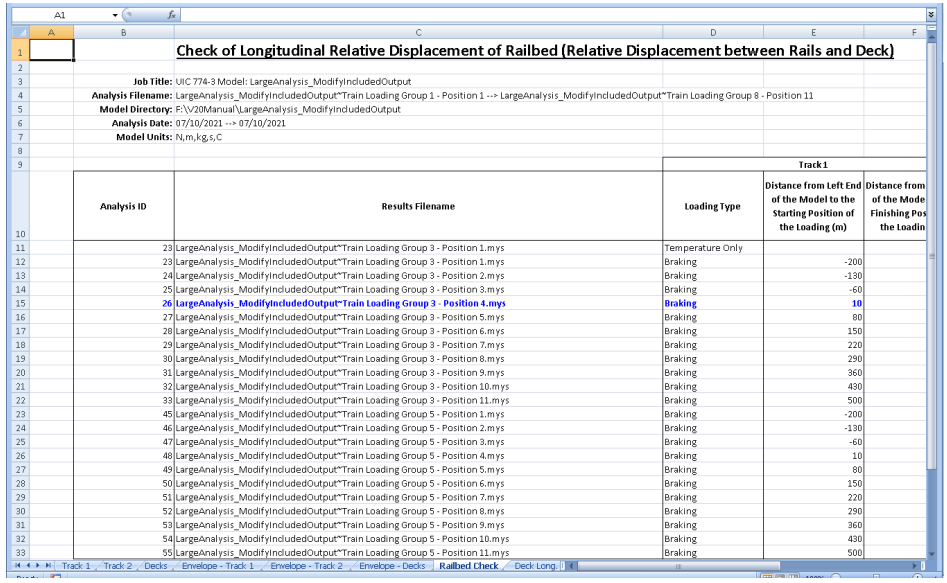
Figure 92 to Figure 94 show the peak result table worksheet for the longitudinal relative railbed displacement. In the table only loadings applied to the tracks chosen for post-processing are output and therefore only tracks 1 and 2 are tabulated, tracks 3 and 4 have been omitted. The peak longitudinal relative railbed displacements reported in the table will also only come from tracks 1 and 2. Furthermore, only Train Loading Groups 3 and 5 were chosen for post-processing and are output in the table, Train Loading Groups 1, 2, 4 and 6 to 8 have been omitted. Finally, the selection of the rail track extent to only be from 100 m (the left-hand abutment) to 400 m means that the full length of the rail track has not been considered for the determination of the peak longitudinal relative railbed displacement which could mean that the peak value might occur outside the extent that has been chosen. As a result of the restriction of the post-processing to the limited tracks / Train Loading Groups / rail track extent the post-processor has issued the warnings underneath the table shown in Figure 94 and repeated below:

Warning: Only selected tracks were included in the enveloping and the table above. Exclusion of tracks could result in peak behaviours in tracks being missed and more critical conditions being excluded from the design process.

Warning: Only selected Train Loading Groups were included in the main results, enveloping and the table above. Exclusion of Train Loading Groups could result in peak behaviours from excluded results being missed and more critical conditions being excluded from the design process.

Warning: Only selected track length (100.0m to 400.0m) was included in the enveloping and the table above. Exclusion of track length could result in peak behaviours in tracks being missed and more critical conditions being excluded from the design process.

The same messages will also be repeated at the bottom of the peak results worksheet for axial rail stress since the choice of tracks / Train Loading Groups / rail track extent will have an identical effect on the extent of the tabular output for the axial rail stress. The exact messages reported reflect the choices within the **Modify Included Output** dialog.

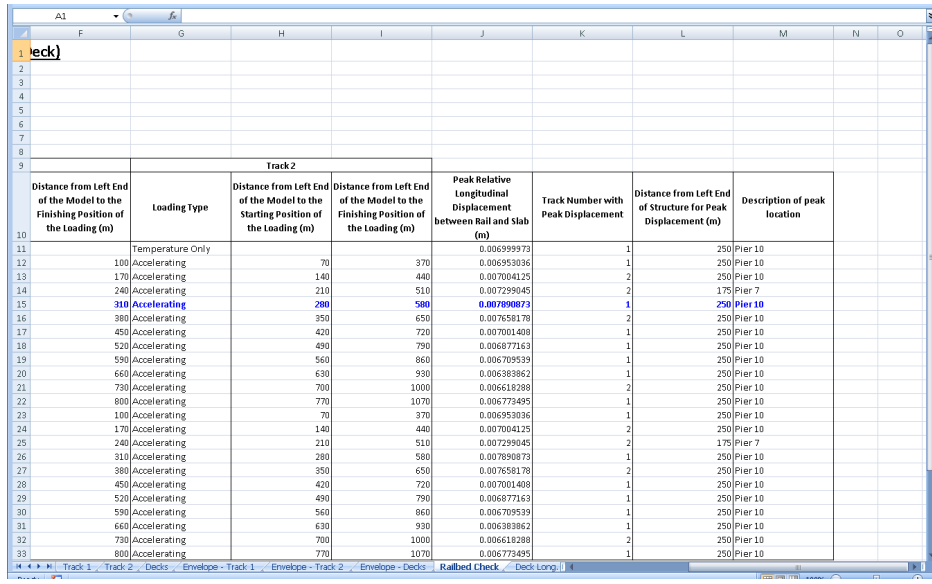


Check of Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)

Job Title: UIC 774-3 Model: LargeAnalysis_ModifyIncludedOutput
Analysis Filename: LargeAnalysis_ModifyIncludedOutput~Train Loading Group 1 - Position 1 --> LargeAnalysis_ModifyIncludedOutput~Train Loading Group 8 - Position 11
Model Directory: F:\V20Manual\LargeAnalysis_ModifyIncludedOutput
Analysis Date: 07/10/2021 --> 07/10/2021
Model Units: N,m,kg,s,C

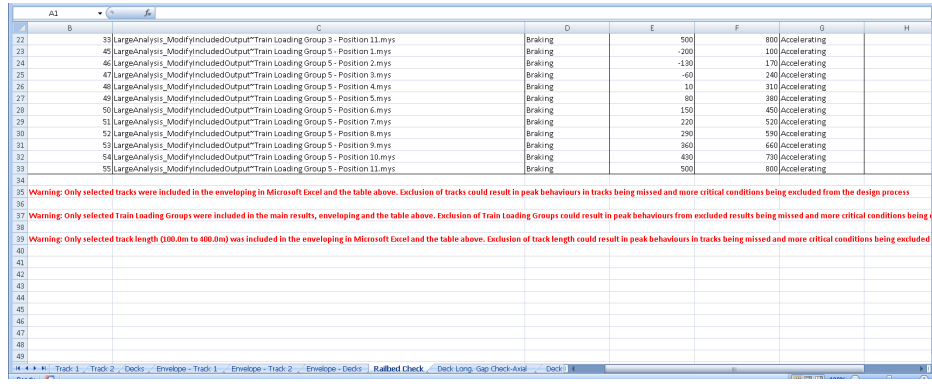
		Track 1		
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from of the Mode Finishing Pos the Loadin
23	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 1.mys	Temperature Only		
23	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 1.mys	Braking	-200	
24	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 2.mys	Braking	-130	
25	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 3.mys	Braking	-60	
26	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 4.mys	Braking	10	
27	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 5.mys	Braking	80	
28	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 6.mys	Braking	150	
29	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 7.mys	Braking	220	
30	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 8.mys	Braking	290	
31	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 9.mys	Braking	360	
32	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 10.mys	Braking	430	
33	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 11.mys	Braking	500	
45	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 1.mys	Braking	-200	
46	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 2.mys	Braking	-130	
47	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 3.mys	Braking	-60	
48	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 4.mys	Braking	10	
49	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 5.mys	Braking	80	
50	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 6.mys	Braking	150	
51	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 7.mys	Braking	220	
52	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 8.mys	Braking	290	
53	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 9.mys	Braking	360	
54	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 10.mys	Braking	430	
55	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 11.mys	Braking	500	

Figure 92: Longitudinal Relative Railbed Displacement Results for Tracks 1 and 2, Train Loading Groups 3 and 5, Rail Track Extent 100m to 400m (1 of 3)



	Track 2						
Distance from Left End of the Model to the Finishing Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Peak Relative Longitudinal Displacement between Rail and Slab (m)	Track Number with Peak Displacement	Distance from Left End of Structure for Peak Displacement (m)	Description of peak location
	Temperature Only			0.006999973	1	250	Pier 10
100	Accelerating	70	370	0.006953036	1	250	Pier 10
170	Accelerating	140	440	0.007004125	2	250	Pier 10
240	Accelerating	210	510	0.007299045	2	175	Pier 7
310	**Accelerating**	**280**	**580**	**0.007890873**	**1**	**250**	**Pier 10**
380	Accelerating	350	650	0.007658178	2	250	Pier 10
450	Accelerating	420	720	0.007001408	1	250	Pier 10
520	Accelerating	490	790	0.006877163	1	250	Pier 10
590	Accelerating	560	860	0.006709539	1	250	Pier 10
660	Accelerating	630	930	0.006383862	1	250	Pier 10
730	Accelerating	700	1000	0.006618288	2	250	Pier 10
800	Accelerating	770	1070	0.006773495	1	250	Pier 10
100	Accelerating	70	370	0.006953036	1	250	Pier 10
170	Accelerating	140	440	0.007004125	2	250	Pier 10
240	Accelerating	210	510	0.007299045	2	175	Pier 7
310	Accelerating	280	580	0.007890873	1	250	Pier 10
380	Accelerating	350	650	0.007658178	2	250	Pier 10
450	Accelerating	420	720	0.007001408	1	250	Pier 10
520	Accelerating	490	790	0.006877163	1	250	Pier 10
590	Accelerating	560	860	0.006709539	1	250	Pier 10
660	Accelerating	630	930	0.006383862	1	250	Pier 10
730	Accelerating	700	1000	0.006618288	2	250	Pier 10
800	Accelerating	770	1070	0.006773495	1	250	Pier 10

Figure 93: Longitudinal Relative Railbed Displacement Results for Tracks 1 and 2, Train Loading Groups 3 and 5, Rail Track Extent 100m to 400m (2 of 3)



33	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 3 - Position 11.mys	Braking	500	800	Accelerating
45	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 1.mys	Braking	-200	100	Accelerating
46	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 2.mys	Braking	-130	170	Accelerating
47	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 3.mys	Braking	-60	240	Accelerating
48	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 4.mys	Braking	10	310	Accelerating
49	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 5.mys	Braking	80	380	Accelerating
50	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 6.mys	Braking	150	450	Accelerating
51	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 7.mys	Braking	220	520	Accelerating
52	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 8.mys	Braking	290	590	Accelerating
53	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 9.mys	Braking	360	660	Accelerating
54	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 10.mys	Braking	430	730	Accelerating
55	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 11.mys	Braking	500	800	Accelerating

Warning: Only selected tracks were included in the enveloping in Microsoft Excel and the table above. Exclusion of tracks could result in peak behaviours in tracks being missed and more critical conditions being excluded from the design process

Warning: Only selected Train Loading Groups were included in the main results, enveloping and the table above. Exclusion of Train Loading Groups could result in peak behaviours from excluded results being missed and more critical conditions being

Warning: Only selected track length (100.0m to 400.0m) was included in the enveloping in Microsoft Excel and the table above. Exclusion of track length could result in peak behaviours in tracks being missed and more critical conditions being excluded

Figure 94: Longitudinal Relative Railbed Displacement Results for Tracks 1 and 2, Train Loading Groups 3 and 5, Rail Track Extent 100m to 400m (3 of 3)

In a similar manner to the longitudinal relative railbed displacement and axial rail stress peak table worksheets, the deck displacement peak displacement worksheets will also adjust their output based on the **Modify Included Output** dialog and provide associated feedback. Figure 95 to Figure 97 show the peak result table worksheet for the longitudinal relative displacement between the deck ends (total effects) which is a measure of the movement of the end of one deck relative to the next. In the table only loadings applied to the tracks chosen for post-processing is output and therefore only

tracks 1 and 2 are tabulated, tracks 3 and 4 have been omitted. It should be noted though that tracks 3 and 4 were still included within the analysis so any loading that was applied to them would have still been included in the track-structure-interaction analysis – the information is simply not being reported here because the tracks are excluded from the post-processing.

For the post-processing only Train Loading Groups 3 and 5 were chosen for post-processing and are output in the table, Train Loading Groups 1, 2, 4 and 6 to 8 have been omitted. The restriction of the rail track extent has no effect on the calculation of the displacements between the ends of decks since these calculations do not relate to the track, any modification of the rail track extent is therefore ignored in the **Modify Included Output** dialog.

As a result of any restriction of the post-processing the post-processor has issued the following message and warning below the table:

Note: Selected tracks were included in the enveloping and only these are listed in the table above. The effects of loading on excluded tracks is still considered in the model and all results reported in this table relate to the structure only.

Warning: Only selected Train Loading Groups were included in the main results, enveloping and the table above. Exclusion of Train Loading Groups could result in peak behaviours from excluded results being missed and more critical conditions being excluded from the design process.

The same messages will also be repeated at the bottom of the peak results worksheet for all end of deck displacements and longitudinal reactions since the choice of tracks and Train Loading Groups will have an identical effect on the extent of the tabular output. The exact messages reported reflect the choices within the **Modify Included Output** dialog.

Check of Longitudinal Relative Displacement between Ends of Decks (Total Effects)

Job Title: UIC 774-3 Model: LargeAnalysis_ModifyIncludedOutput
Analysis Filename: LargeAnalysis_ModifyIncludedOutput~Train Loading Group 1 - Position 1 --> LargeAnalysis_ModifyIncludedOutput~Train Loading Group 8 - Position 11
Model Directory: F:\\V20Manual\LargeAnalysis_ModifyIncludedOutput
Analysis Date: 07/10/2021 --> 07/10/2021
Model Units: N,m,kg,s,C

			Track 1		
	Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from of the Mode Finishing Pos the Loadin
11	23	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 1.mys	Temperature Only		
12	23	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 1.mys	Braking	-200	
13	24	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 2.mys	Braking	-130	
14	25	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 3.mys	Braking	-60	
15	26	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 4.mys	Braking	10	
16	27	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 5.mys	Braking	80	
17	28	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 6.mys	Braking	150	
18	29	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 7.mys	Braking	220	
19	30	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 8.mys	Braking	290	
20	31	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 9.mys	Braking	360	
21	**32**	**LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 10.mys**	**Braking**	**430**	
22	33	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 3 - Position 11.mys	Braking	500	
23	45	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 1.mys	Braking	-200	
24	46	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 2.mys	Braking	-130	
25	47	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 3.mys	Braking	-60	
26	48	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 4.mys	Braking	10	
27	49	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 5.mys	Braking	80	
28	50	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 6.mys	Braking	150	
29	51	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 7.mys	Braking	220	
30	52	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 8.mys	Braking	290	
31	53	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 9.mys	Braking	360	
32	54	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 10.mys	Braking	430	
33	55	LargeAnalysis_ModifyIncludedOutput~Train Loading Group 5 - Position 11.mys	Braking	500	

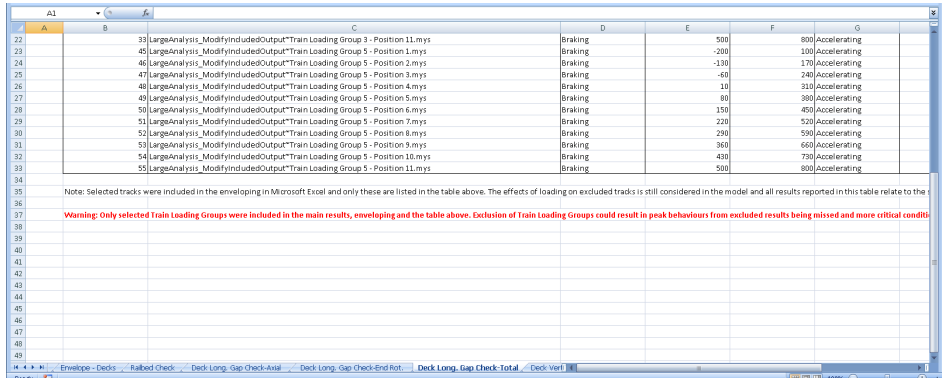
Railbed Check | Deck Long. Gap Check-Axial | Deck Long. Gap Check-End Rot. | Deck Long. Gap Check-Total | Ded

Figure 95: Longitudinal Relative Displacement between Ends of Decks (Total Effects) Results for Tracks 1 and 2, Train Loading Groups 3 and 5, Rail Track Extent 100m to 400m (1 of 3)

		Track 2			
	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Peak Relative Longitudinal Displacement between Ends of Decks. Positive = Opening, Negative = Closing (m)	Pier Number / Location Supporting Decks with Peak Displacement
11		Temperature Only			-0.014427929	Pier 25
12	100	Accelerating	70	370	-0.014421211	Pier 25
13	170	Accelerating	140	440	-0.014426145	Pier 25
14	240	Accelerating	210	510	-0.014582524	Pier 7
15	310	Accelerating	280	580	-0.015759047	Pier 10
16	380	Accelerating	350	650	-0.01617827	Pier 13
17	450	Accelerating	420	720	-0.01618732	Pier 16
18	520	Accelerating	490	790	-0.016075464	Pier 19
19	590	Accelerating	560	860	-0.016238693	Pier 19
20	660	Accelerating	630	930	-0.016617575	Pier 22
21	**730**	**Accelerating**	**700**	**1000**	**-0.01717358**	**Pier 25**
22	800	Accelerating	770	1070	-0.014748286	Pier 25
23	100	Accelerating	70	370	-0.014421211	Pier 25
24	170	Accelerating	140	440	-0.014426145	Pier 25
25	240	Accelerating	210	510	-0.014582524	Pier 7
26	310	Accelerating	280	580	-0.015759047	Pier 10
27	380	Accelerating	350	650	-0.01617827	Pier 13
28	450	Accelerating	420	720	-0.01618732	Pier 16
29	520	Accelerating	490	790	-0.016075464	Pier 19
30	590	Accelerating	560	860	-0.016238693	Pier 19
31	660	Accelerating	630	930	-0.016617575	Pier 22
32	730	Accelerating	700	1000	-0.01717358	Pier 25
33	800	Accelerating	770	1070	-0.014748286	Pier 25

Railbed Check | Deck Long. Gap Check-Axial | Deck Long. Gap Check-End Rot. | Deck Long. Gap Check-Total | Ded

Figure 96: Longitudinal Relative Displacement between Ends of Decks (Total Effects) Results for Tracks 1 and 2, Train Loading Groups 3 and 5, Rail Track Extent 100m to 400m (2 of 3)



33	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 3 - Position 11.mys	Braking	500	800	Accelerating
45	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 1.mys	Braking	-200	100	Accelerating
46	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 2.mys	Braking	-130	170	Accelerating
47	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 3.mys	Braking	-60	240	Accelerating
48	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 4.mys	Braking	10	310	Accelerating
49	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 5.mys	Braking	80	380	Accelerating
50	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 6.mys	Braking	150	450	Accelerating
51	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 7.mys	Braking	220	520	Accelerating
52	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 8.mys	Braking	290	590	Accelerating
53	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 9.mys	Braking	360	660	Accelerating
54	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 10.mys	Braking	430	730	Accelerating
55	LargeAnalysis_ModifyIncludedOutput"Train Loading Group 5 - Position 11.mys	Braking	500	800	Accelerating

Note: Selected tracks were included in the enveloping in Microsoft Excel and only these are listed in the table above. The effects of loading on excluded tracks is still considered in the model and all results reported in this table relate to the

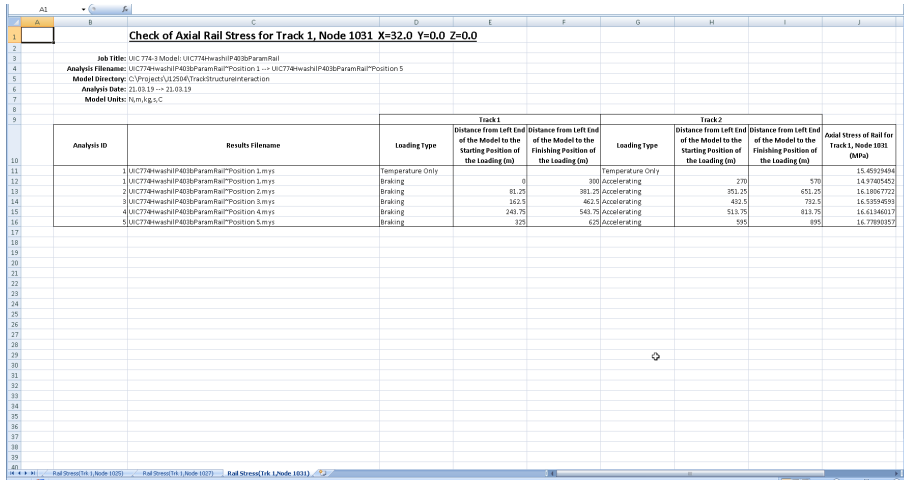
Warning: Only selected Train Loading Groups were included in the main results, enveloping and the table above. Exclusion of Train Loading Groups could result in peak behaviours from excluded results being missed and more critical conditi

Figure 97: Longitudinal Relative Displacement between Ends of Decks (Total Effects) Results for Tracks 1 and 2, Train Loading Groups 3 and 5, Rail Track Extent 100m to 400m (3 of 3)

Post-processing of Selected Track / Rail Nodes

If spot checks need to be performed at specific locations on the tracks, the nodes of the track/rail can be post-processed individually. To perform the post-processing the selection in the LUSAS model created by the Rail Track Analysis spreadsheet must contain nodes that are part of the track/rail. If nodes from other parts of the model are selected, then these nodes will be ignored. All other selected objects will also be ignored.

Figure 98 shows sample output from the post-processing of a track. For each results file that is loaded the axial stress at the node(s) will be reported in a separate worksheet for each node.



Check of Axial Rail Stress for Track 1, Node 1031 X=32.0 Y=0.0 Z=0.0

Job Title: UIC774-3 Model: UIC774HwashIP403bParamRail
Analysis Filename: UIC774HwashIP403bParamRail"Position 1 --> UIC774HwashIP403bParamRail"Position 5
Model Directory: C:\Projects\UI2040\TrackStructureInteraction
Analysis Date: 21.03.19 --> 21.03.19
Model Units: N,m,kg,s,C

		Track 1			Track 2			
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Axial Stress of Rail for Track 1, Node 1031 (MPa)
1	UIC774HwashIP403bParamRail"Position 1.mys	Temperature Only			Temperature Only			15.45929494
1	UIC774HwashIP403bParamRail"Position 1.mys	Braking	0	300	Accelerating	270	570	14.97405452
2	UIC774HwashIP403bParamRail"Position 2.mys	Braking	81.25	381.25	Accelerating	351.25	651.25	16.18067722
3	UIC774HwashIP403bParamRail"Position 3.mys	Braking	162.5	462.5	Accelerating	432.5	732.5	16.53594593
4	UIC774HwashIP403bParamRail"Position 4.mys	Braking	243.75	543.75	Accelerating	513.75	813.75	16.61346017
5	UIC774HwashIP403bParamRail"Position 5.mys	Braking	325	625	Accelerating	595	895	16.77890357

Figure 98: Sample Output from an Individual Track/Rail Node

Note. The stresses reported in the track/rail node worksheets are the averaged nodal stresses. The stresses reported previously in the post-processing performed on the UIC774-3 groups are the unaveraged nodal stresses and therefore the values will differ slightly. The averaged nodal stresses can be obtained for the post-processing of the UIC77-3 groups by averaging the values reported for the elements either side of the node.

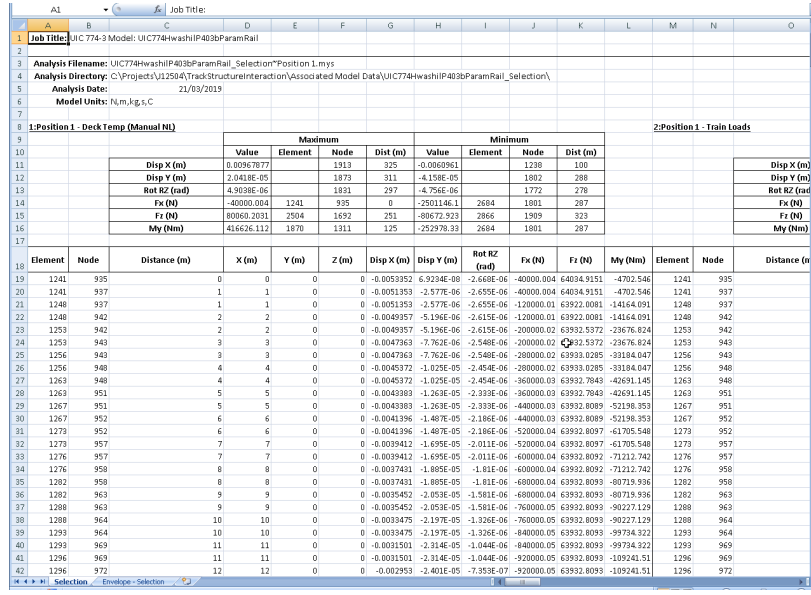
Post-processing of Selected Lines if Groups are Missing

If the model does not contain the expected rail track model group names (“Track 1”, “Track 2”, etc and “Decks”) or expected group contents then post-processing can be carried out on a line by line basis. To use this option the selection must contain lines that have 3D Thick Beam elements assigned. All other lines and objects will be ignored by the post-processor.

When post-processing selected lines it is assumed that these lines define a single path which travels in the direction of increasing line ID number. The lines will therefore be post-processed in increasing line ID order and the lowest line ID start point will be assumed to provide the reference position for the x-coordinate used to calculate the distances reported.

The output is almost identical to the output that is generated for the decks group with a summary table and tabulated output reported for all of the elements associated with the lines that have been selected. No graphs are generated for the post-processing of the selected lines since the distances may not be sequential if lines of the tracks / rails or decks have been omitted from the selection as illustrated in Figure 99 where there is a jump between distances of 10 and 32 m. Results are output for the temperature only (Increment 1) and the combined temperature and trainset loading (Increment 2) with

additional results files tabulated from left to right in the worksheet. If basic combinations or envelopes have been defined in the LUSAS model the results from these will also be output to the worksheet if they can be post-processed.



A1 Job Title:

Job Title: UIC 774-3 Model: UIC774HwashIP403bParamRail

Analysis Filename: UIC774HwashIP403bParamRail_Selection~Position 1.mys
Analysis Directory: C:\Projects\\12504\TrackStructureInteraction\Associated Model Data\UIC774HwashIP403bParamRail_Selection\
Analysis Date: 21/03/2019
Model Units: N,m,kg,s,C

1:Position 1 - Deck Temp (Manual Nt)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00967877		1913	325	-0.0060961		1238	100
Disp Y (m)	2.0418E-05		1873	311	-4.158E-05		1802	288
Rot RZ (rad)	4.9038E-06		1831	297	-4.756E-06		1772	278
Fx (N)	-40000.004	1241	935	0	-250114.6.1	2684	1801	287
Fz (N)	80860.2031	2504	1692	251	-80672.923	2866	1909	323
My (Nm)	416626.112	1870	1311	125	-252978.33	2684	1801	287

2:Position 1 - Train Loads

Disp X (m)	
Disp Y (m)	
Rot RZ (rad	
Fx (N)	
Fz (N)	
My (Nm)	

Element	Node	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Fx (N)	Fz (N)	My (Nm)	Element	Node	Distance (m
1241	935	0	0	0	0	-0.0053952	6.9234E-08	-2.668E-06	-40000.004	64034.9151	-4702.546	1241	935	
1241	937	1	1	0	0	-0.0051353	-2.577E-06	-2.655E-06	-40000.004	64034.9151	-4702.546	1241	937	
1248	937	1	1	0	0	-0.0051353	-2.577E-06	-2.655E-06	-120000.01	63922.0081	-14164.091	1248	937	
1248	942	2	2	0	0	-0.0049357	-5.196E-06	-2.615E-06	-120000.01	63922.0081	-14164.091	1248	942	
1253	942	2	2	0	0	-0.0049357	-5.196E-06	-2.615E-06	-200000.02	63932.5372	-23676.824	1253	942	
1253	943	3	3	0	0	-0.0047363	-7.762E-06	-2.548E-06	-200000.02	63932.5372	-23676.824	1253	943	
1256	943	3	3	0	0	-0.0047363	-7.762E-06	-2.548E-06	-280000.02	63933.0285	-33184.047	1256	943	
1256	948	4	4	0	0	-0.0045372	-1.025E-05	-2.454E-06	-280000.02	63933.0285	-33184.047	1256	948	
1263	948	4	4	0	0	-0.0045372	-1.025E-05	-2.454E-06	-360000.03	63932.7843	-42691.145	1263	948	
1263	951	5	5	0	0	-0.0043383	-1.263E-05	-2.333E-06	-360000.03	63932.7843	-42691.145	1263	951	
1267	951	5	5	0	0	-0.0043383	-1.263E-05	-2.333E-06	-440000.03	63932.8089	-52198.353	1267	951	
1267	952	6	6	0	0	-0.0041396	-1.487E-05	-2.186E-06	-440000.03	63932.8089	-52198.353	1267	952	
1273	952	6	6	0	0	-0.0041396	-1.487E-05	-2.186E-06	-520000.04	63932.8097	-61705.548	1273	952	
1273	957	7	7	0	0	-0.0039412	-1.695E-05	-2.011E-06	-520000.04	63932.8097	-61705.548	1273	957	
1276	957	7	7	0	0	-0.0039412	-1.695E-05	-2.011E-06	-600000.04	63932.8092	-71212.742	1276	957	
1276	958	8	8	0	0	-0.0037431	-1.885E-05	-1.81E-06	-600000.04	63932.8092	-71212.742	1276	958	
1282	958	8	8	0	0	-0.0037431	-1.885E-05	-1.81E-06	-680000.04	63932.8093	-80719.936	1282	958	
1282	963	9	9	0	0	-0.0035452	-2.053E-05	-1.581E-06	-680000.04	63932.8093	-80719.936	1282	963	
1288	963	9	9	0	0	-0.0035452	-2.053E-05	-1.581E-06	-760000.05	63932.8093	-90227.129	1288	963	
1288	964	10	10	0	0	-0.0033475	-2.197E-05	-1.326E-06	-760000.05	63932.8093	-90227.129	1288	964	
1293	964	10	10	0	0	-0.0033475	-2.197E-05	-1.326E-06	-840000.05	63932.8093	-99734.322	1293	964	
1293	969	11	11	0	0	-0.0031501	-2.314E-05	-1.044E-06	-840000.05	63932.8093	-99734.322	1293	969	
1296	969	11	11	0	0	-0.0031501	-2.314E-05	-1.044E-06	-920000.05	63932.8093	-109241.51	1296	969	
1296	972	12	12	0	0	-0.002953	-2.401E-05	-7.353E-07	-920000.05	63932.8093	-109241.51	1296	972	

Selection | Envelope - Selection

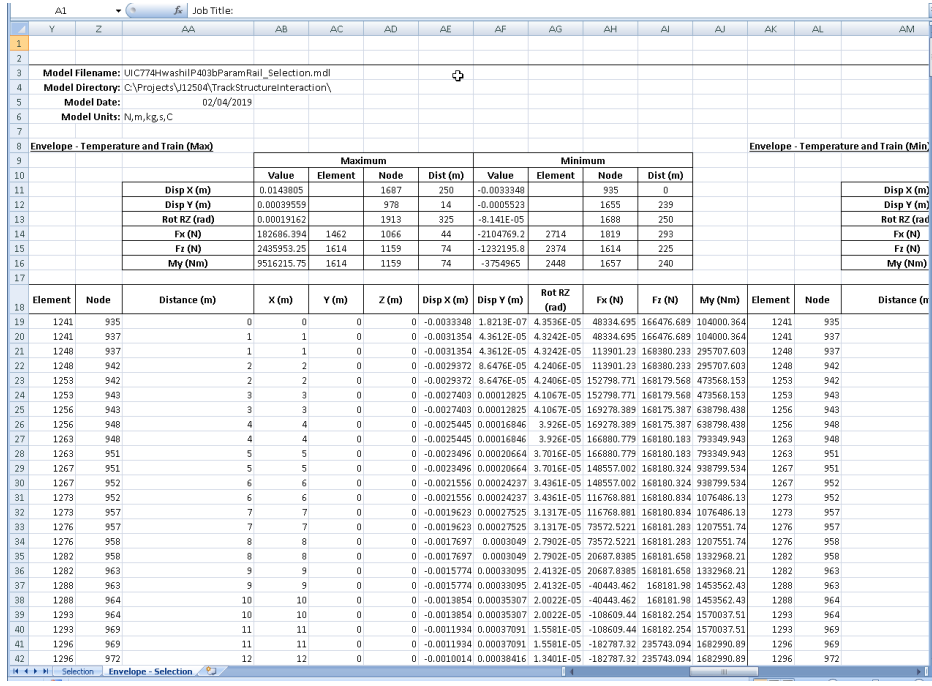
Figure 99: Sample Output from Post-Processing of Selected Lines when the Groups are Missing or Invalid

If more than one results file is loaded, basic combinations are defined in the model that may be post-processed (see the restrictions under the **Post-processing of automatically defined groups** section on page 63) and enveloping has been selected then the spreadsheet will contain an additional worksheet that holds these enveloping results. The envelopes generated will be the same as those for the tracks and decks:

- **Maximum and minimum envelopes for temperature loading only**
- **Maximum and minimum envelopes for temperature and trainset rail loading**
- **Maximum and minimum envelopes for all of the basic combinations defined in the model (if valid basic combinations are present)**
- **Maximum and minimum envelopes for all configurations (an envelope of the above results)**

The following figure illustrates the tabulated enveloped results when selected lines are post-processed if expected model groups are either missing or invalid. No automatic graphing is possible when post-processing with enveloping is carried out on selected lines (since these lines may not be continuous). Should graphs of the results be required

then these can either be defined manually within the generated spreadsheet or the data can be copied and pasted from the spreadsheet.



A1 Job Title:

Model Filename: UIC774HwashiIP403bParamRail_Selection.mdl
Model Directory: C:\Projects\J12504\TrackStructureInteraction\
Model Date: 02/04/2019
Model Units: N,m,kg,s,C

Envelope - Temperature and Train (Max)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.0143805		1687	250	-0.0033348		935	0
Disp Y (m)	0.00039559		978	14	-0.0005523		1655	239
Rot RZ (rad)	0.00019162		1913	325	-8.141E-05		1688	250
Fx (N)	182686.394	1462	1066	44	-2104769.2	2714	1819	293
Fz (N)	2435953.25	1614	1159	74	-1232195.8	2374	1614	225
My (Nm)	9516215.75	1614	1159	74	-3754965	2448	1657	240

Envelope - Temperature and Train (Min)

Disp X (m)	
Disp Y (m)	
Rot RZ (rad	
Fx (N)	
Fz (N)	
My (Nm)	

Element	Node	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Fx (N)	Fz (N)	My (Nm)	Element	Node	Distance (m
1241	935	0	0	0	0	-0.0033348	1.8213E-07	4.3536E-05	48334.695	166476.689	104000.364	1241	935	
1241	937	1	1	0	0	-0.0031354	4.3612E-05	4.3242E-05	48334.695	166476.689	104000.364	1241	937	
1248	937	1	1	0	0	-0.0031354	4.3612E-05	4.3242E-05	113901.23	168380.233	295707.603	1248	937	
1248	942	2	2	0	0	-0.0029372	8.6476E-05	4.2406E-05	113901.23	168380.233	295707.603	1248	942	
1253	942	2	2	0	0	-0.0029372	8.6476E-05	4.2406E-05	152798.771	168179.568	473568.153	1253	942	
1253	943	3	3	0	0	-0.0027403	0.00012825	4.1067E-05	152798.771	168179.568	473568.153	1253	943	
1256	943	3	3	0	0	-0.0027403	0.00012825	4.1067E-05	169278.389	168175.387	638798.438	1256	943	
1256	948	4	4	0	0	-0.0025445	0.00016846	3.926E-05	169278.389	168175.387	638798.438	1256	948	
1263	948	4	4	0	0	-0.0025445	0.00016846	3.926E-05	166880.779	168180.183	793349.943	1263	948	
1263	951	5	5	0	0	-0.0023496	0.00020664	3.7016E-05	166880.779	168180.183	793349.943	1263	951	
1267	951	5	5	0	0	-0.0023496	0.00020664	3.7016E-05	148557.002	168180.324	938799.534	1267	951	
1267	952	6	6	0	0	-0.0021556	0.00024237	3.4361E-05	148557.002	168180.324	938799.534	1267	952	
1273	952	6	6	0	0	-0.0021556	0.00024237	3.4361E-05	116768.881	168180.834	1076486.13	1273	952	
1273	957	7	7	0	0	-0.0019623	0.00027525	3.1317E-05	116768.881	168180.834	1076486.13	1273	957	
1276	957	7	7	0	0	-0.0019623	0.00027525	3.1317E-05	73572.5221	168181.283	1207551.74	1276	957	
1276	958	8	8	0	0	-0.0017697	0.0003049	2.7902E-05	73572.5221	168181.283	1207551.74	1276	958	
1282	958	8	8	0	0	-0.0017697	0.0003049	2.7902E-05	20687.8385	168181.658	1332968.21	1282	958	
1282	963	9	9	0	0	-0.0015774	0.00033095	2.4132E-05	20687.8385	168181.658	1332968.21	1282	963	
1288	963	9	9	0	0	-0.0015774	0.00033095	2.4132E-05	-40443.462	168181.98	1453562.43	1288	963	
1288	964	10	10	0	0	-0.0013854	0.00035307	2.0022E-05	-40443.462	168181.98	1453562.43	1288	964	
1293	964	10	10	0	0	-0.0013854	0.00035307	2.0022E-05	-108609.44	168182.254	1570037.51	1293	964	
1293	969	11	11	0	0	-0.0011934	0.00037091	1.5581E-05	-108609.44	168182.254	1570037.51	1293	969	
1296	969	11	11	0	0	-0.0011934	0.00037091	1.5581E-05	-182787.32	235743.094	1682990.89	1296	969	
1296	972	12	12	0	0	-0.0010014	0.00038416	1.3401E-05	-182787.32	235743.094	1682990.89	1296	972	

Selection | Envelope - Selection

Figure 100: Sample Output from Post-Processing of Envelopes for Selected Lines when the Groups are Missing or Invalid

Limitations of Use

- Since the analysis is two-dimensional (even though three-dimensional elements are used) the offsets are not modelled for the bearing/section centrelines nor for the section/rail centrelines (see figure below). Currently all track centrelines are coincident with the centreline of the deck.
- Curved bridges cannot be modelled.

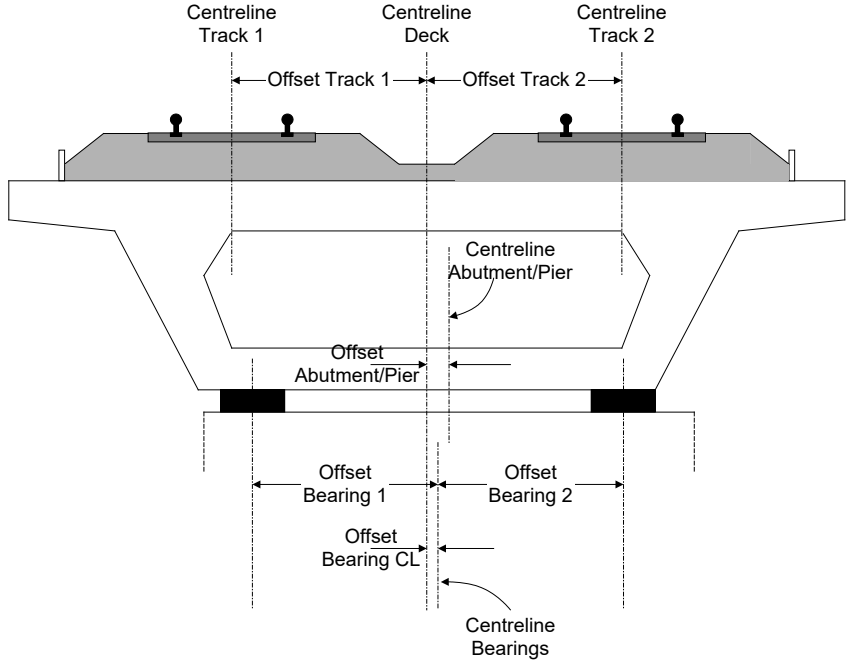


Figure 101: Offsets of Tracks/Bearings/Piers from Centreline Of Deck

References

B1 BS EN 1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges

U1 UIC Code 774-3, Track/bridge Interaction. Recommendations for calculations. 2nd Edition, (October 2001)

Appendix A: Verification Testing

Introduction

This appendix includes some background to the calculation of the UIC774-3 track/bridge interaction analyses in LUSAS. It explains why results from running a LUSAS nonlinear analysis that considers all thermal and train effects for the test cases in question in one analysis does not over-predict the rail stresses occurring under the combined thermal and rail loading - unlike results from simplified hand calculations or from results from other finite element analysis software systems where thermal and train effects are carried out by running separate nonlinear analyses.

From the verification testing carried out we can say that…

Even though a computer program may be validated against the standard test cases in the UIC774-3 code of practice, in situations when combined thermal and train loading from separate analyses gives track-structure interaction forces that exceed the stated yield resistance of the track-restraint system (i.e. the ballast) then the separate analysis method will potentially overpredict the rail stresses unless the loaded track yield surface is reduced by the mobilised track resistance over the extent of the train loading. Rail stress over-predictions of up to 30% have been seen when thermal and train loading results are combined from separate analyses.

Description

The rail track analysis (UIC774-3) option in LUSAS allows the construction and solution of finite element models to study the interaction between the rail track and a bridge. This forms an essential part of the design process as the stresses within the rails of the tracks must remain within specified limits based upon the design and the state of maintenance. A number of calculation methods are available and each of these can lead to a slightly different solution for the combined thermal and rail loading condition. Each of these methods (except the hand calculation) has been investigated in this technical note prior to carrying out the analysis in LUSAS using the rail track analysis option. In all tests 1.0 m element sizes have been used.

The Hwashil Viaduct, a railway bridge in South Korea, has been used for this testing with continuous welded rail (CWR) and thermal effects only present in the structure for the following analyses:

- **Combination of Separate Thermal And Rail Loading**
- **Analysis Of Combined Thermal And Rail Loading (One Step)**
- **Analysis Of Combined Thermal And Rail Loading Taking Account Of Effects Of Material Change Under Rail Loading**

In addition, two of the UIC standard test cases have also been reinvestigated to demonstrate that these results can be matched even if the analysis type is potentially invalid prior to providing guidance and conclusions on this type of analysis. These analyses were:

- **Revisit Of UIC774-3 Test E1-3 Using The Separate And LUSAS Methods Of Analysis**
- **Revisit Of UIC774-3 Test H1-3 Using The Separate And LUSAS Methods Of Analysis**

Combination of Separate Thermal and Rail Loading

In this form of analysis two or more separate analyses are carried out with each analysis considering a different loading regime to the structure. This is the simplest form of analysis of the track/bridge interaction as it assumes that superposition is valid for a nonlinear system and, according to the UIC774-3 code of practice, can generally overestimate the rail stresses with percentage errors up to 20 to 30% be it through hand calculation or computer methods.

This analysis procedure is replicated in LUSAS by performing two separate nonlinear analyses. The first considers only the thermal effects and uses the unloaded resistance bilinear curve for modelling the interaction between the track and bridge. The results of this analysis are identical for the two tracks in the model and so only the results for the first track are presented in the following figure.

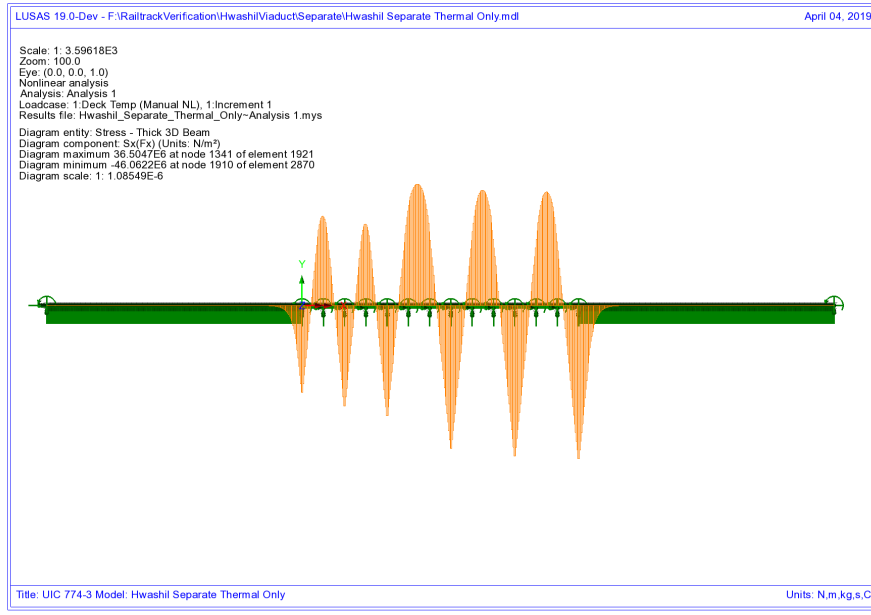


Figure 102: Axial Stress In Rails Due To Thermal Effects Only

These thermal effects give a peak compressive rail stress of 46.06 N/mm^2. Having carried out the thermal analysis the rail loading will be considered in a separate analysis (both horizontal and vertical loading) for the 'worst' conditions. This rail load analysis is again a nonlinear analysis but it has no knowledge of the history from the thermal effects and therefore assumes a zero strain initial state prior to the application of the load. In addition to this unstrained condition, the loaded resistance bilinear curve is used underneath the locations of the rail loading while the unloaded lengths of track use the unloaded resistance bilinear curve. The results from the rail loading analyses are presented in the following two figures, the first being the track that has the braking train loading and the second being the track that has the accelerating train loading.

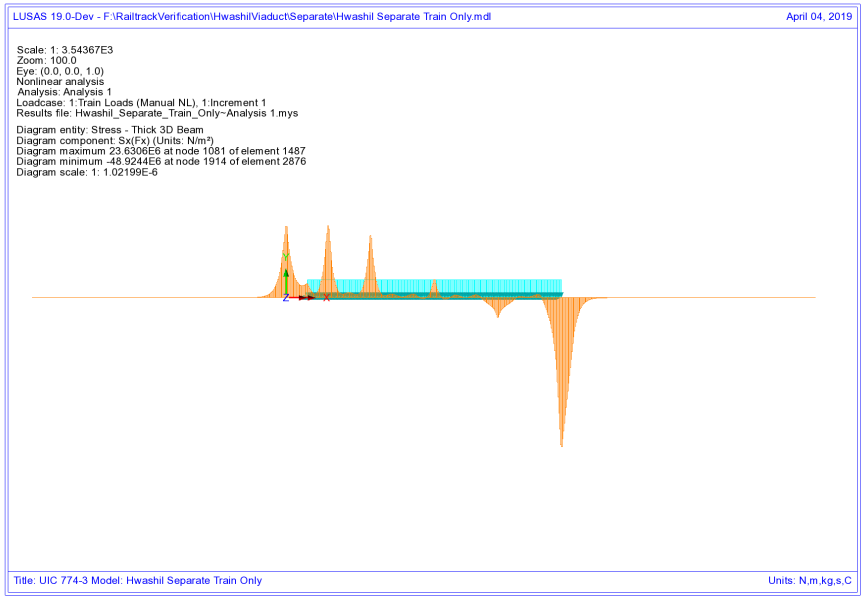


Figure 103: Axial Stress In Rails Due To Braking Train Loads On Track 1

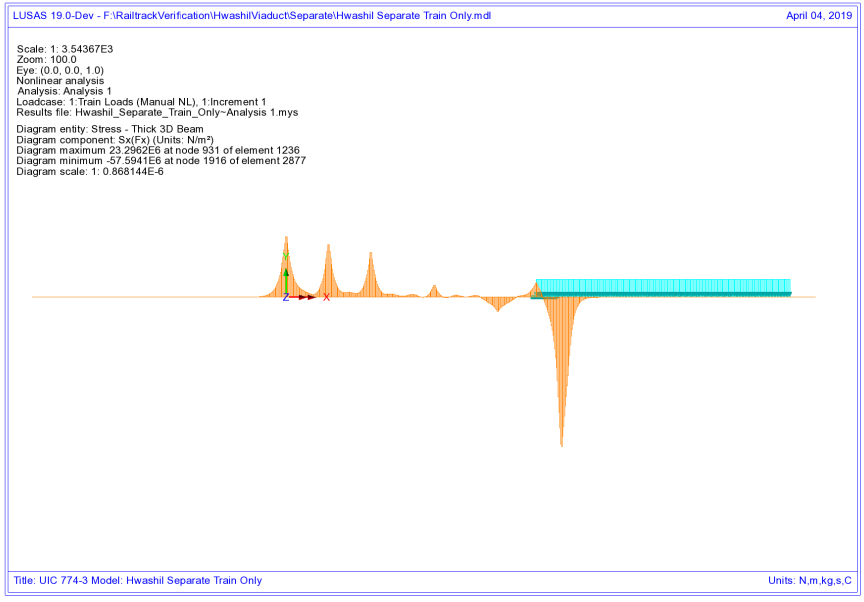


Figure 104: Axial Stress In Rails Due To AcceleratingTrain Loads On Track 2

From these results the peak compressive rail stresses for the two tracks are as follows:

Track 1:	**48.92 N/mm^2**
Track 2:	**57.59 N/mm^2**

A basic combination of the loading can be defined to add the results from the thermal and rail loading analyses together which gives the following track peak compressive stresses (see following figures):

Track 1:	**94.99 N/mm^2**
Track 2:	**103.66 N/mm^2**

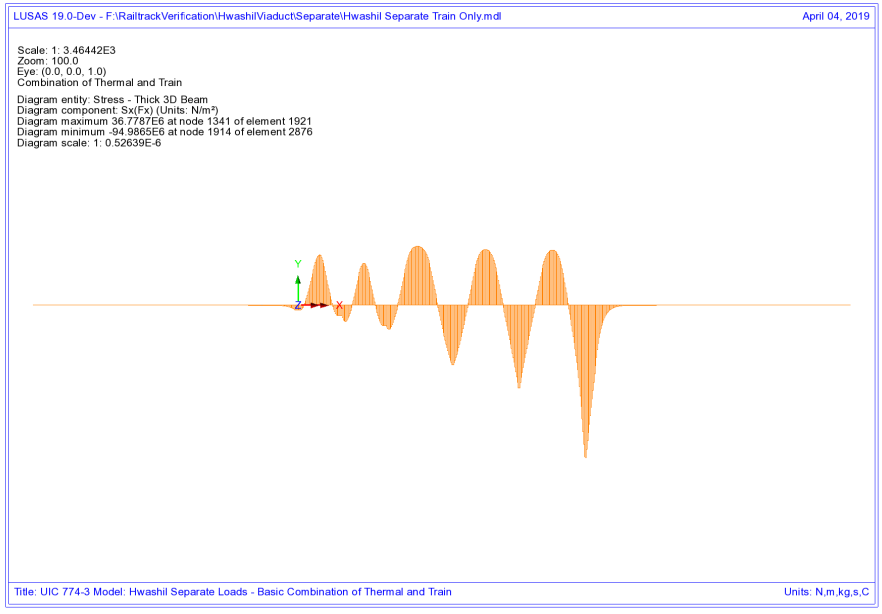


Figure 105: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 1

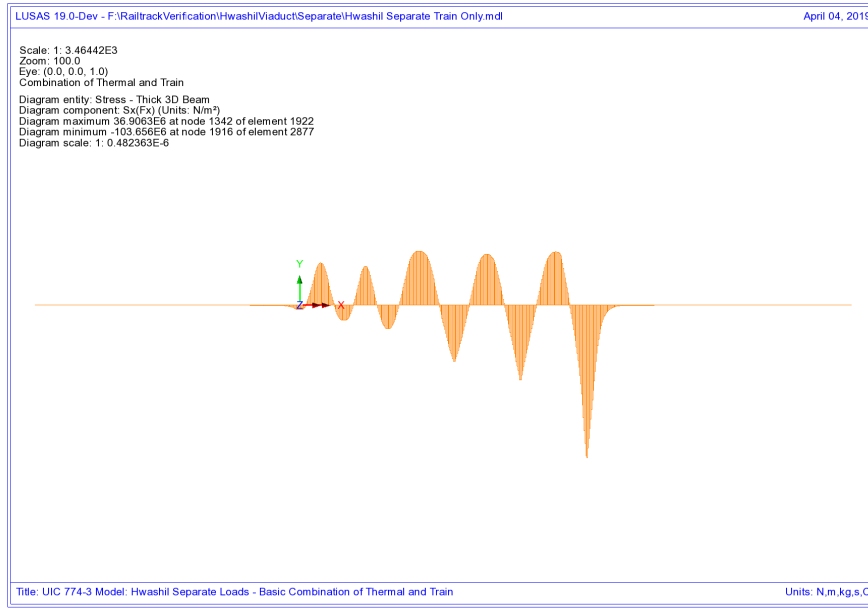


Figure 106: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 2

Inspection of the two plots shows that there is a reduction in the axial rail stresses over the first two deck transition piers towards the left end of the structure for track 1 only (subjected to the braking train). The following figures show zoomed plots of the rail axial stress for this location with the thermal diagram showing identical values either side of these piers for all of the decks in the model. The reason for the reduction in the axial stress becomes clear from the axial stress diagram for the train braking load alone, Figure 108, where the axial stress has a positive peak over the deck transition piers which is not symmetrical. Looking at the transition from the first deck to the second (2nd pier from left abutment) the axial stress in the rail over the end of the first deck is equal to a tensile stress of 23.63 N/mm^2 while the axial stress over the start of the second deck is equal to a tensile stress of 22.47 N/mm^2. Like for like comparison of the elements a certain distance from the pier for each deck shows that the second deck is consistently lower and this difference has caused the non-symmetric nature of the combined axial rail stress diagram over the deck transition piers when the axial rail stresses from the train loading are combined with the axial rail stresses from the thermal loading.

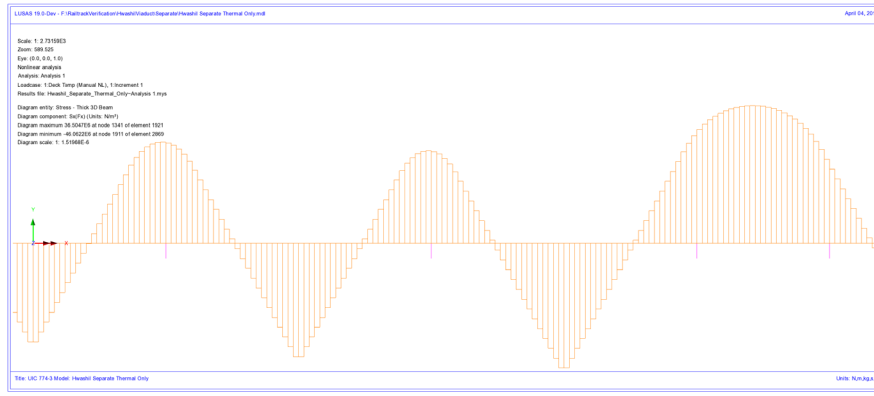


Figure 107: Zoomed Axial Stress In Rails Due To Thermal Effects Only

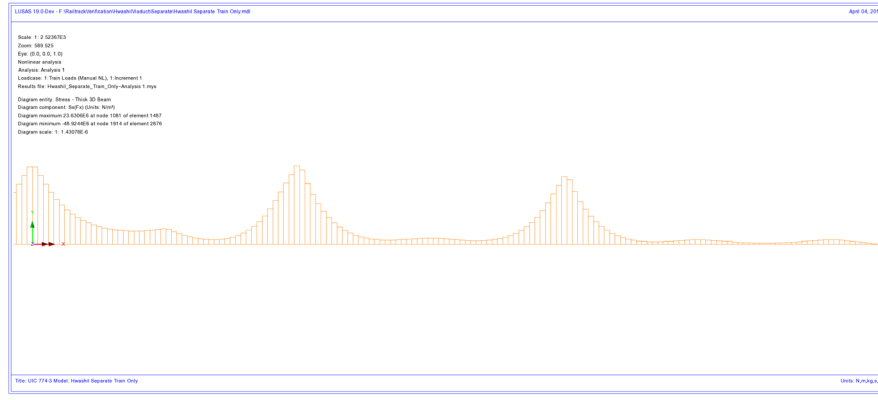


Figure 108: Zoomed Axial Stress In Rails Due To Braking Train Loads On Track 1

NOTE: When viewing this axial force diagram it should be recognised that while the first two decks (2*25m each) have identical geometry and pier/bearing properties, the first span segment of the first deck does not carry any of the braking train load and this is contributing to the difference in the behaviours observed over the piers.

Looking at the yield in the track/bridge interaction for this track, Figure 109, the reason for the differences in axial stress either side of the pier becomes clear as yielding has occurred to the left but not to the right of the deck transition pier for these first two decks.

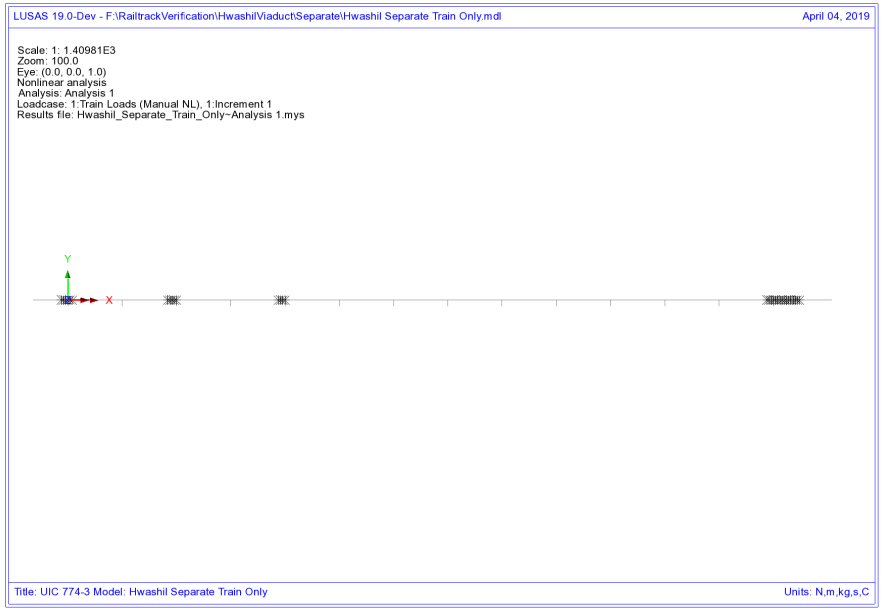


Figure 109: Yield In Track/Bridge Interaction Due To Train Braking Load On Track 1

Looking now at the second track where the accelerating train is at the right-hand end of the structure, the interaction remains unloaded and so the rail axial stress observed is basically due to the bending of the bridge deck due to the action of the braking train load on the other track. Because there is no direct loading to the track then the axial stress in the rail displays a continuous variation over the span transition piers and therefore no reduction is observed in the combined diagram for this track.

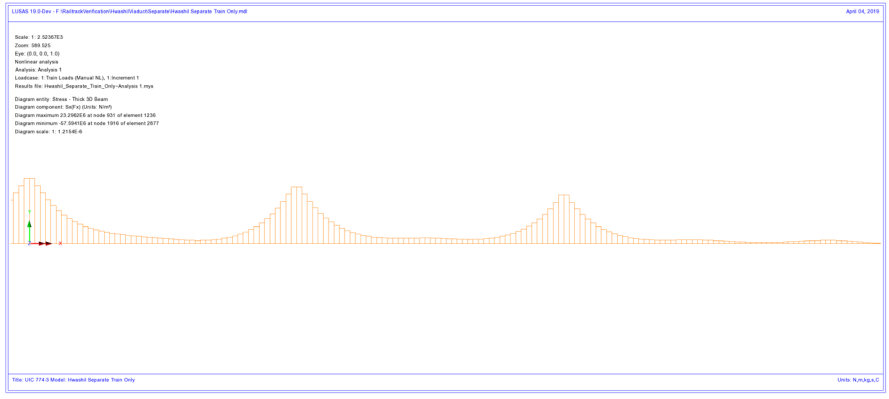


Figure 110: Zoomed Axial Force In Rails Due To Accelerating Train Loads On Track 2

Looking again at the yielding, Figure 111, the difference between this track and the one with the braking train becomes obvious as, without the action of any train load over the deck transition for this track, the yield is roughly symmetrical and occurring across the transition between decks – colour change indicates changing yield direction. This yield over the whole region of the deck transition is the whole reason why a smooth behaviour is observed in the rail stress in the second track as opposed to the first track that has the braking train load.

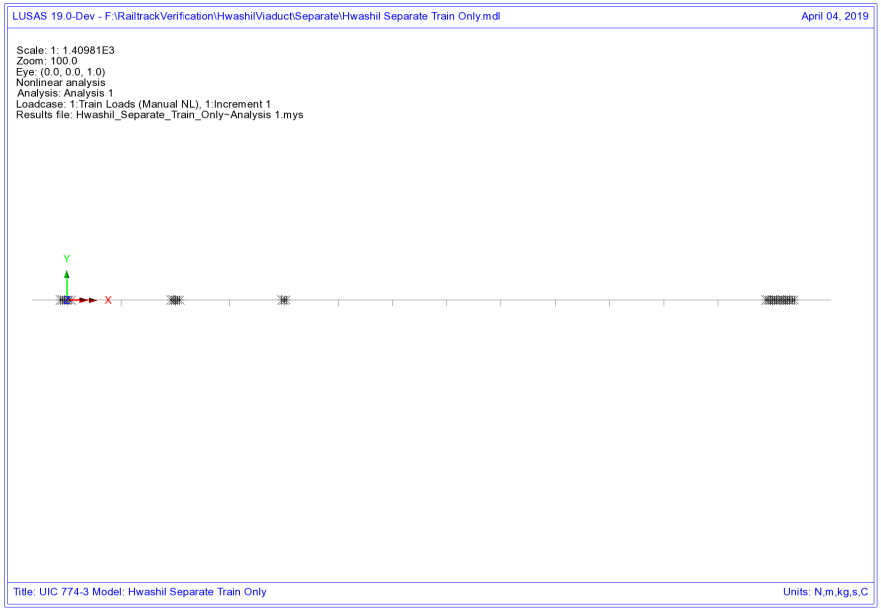


Figure 111: Yield In Track/Bridge Interaction Due To Train Acceleration Load On Track 2

Analysis of Combined Thermal and Rail Loading (One Step)

In this form of analysis a single nonlinear analysis is carried out where the thermal and rail loading are applied concurrently to the model. In terms of the track/bridge interaction, the resistance bilinear curves used in the modelling are determined by the positioning of the rail loading so that loaded properties are used where the rail loading is applied and unloaded properties everywhere else. As with the separate method highlighted above, this analysis ignores any initial straining of the track/bridge interaction under pure thermal loading and therefore assumes that the loaded resistance properties are active under the thermal loading over the extent of the train loading.

The results from the analysis are shown in the following figures and give the following results for the track peak compressive stresses:

Track 1:	**85.61 N/mm^2**
Track 2:	**100.61 N/mm^2**

NOTE: For this analysis the reduction in axial rail stress is not observed at the span discontinuities towards the left end of the structure.

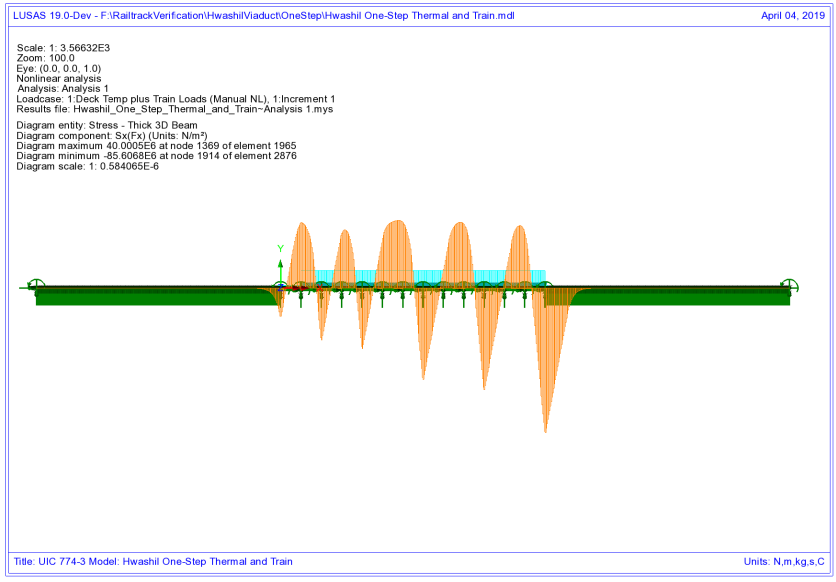


Figure 112: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 1 (One Step)

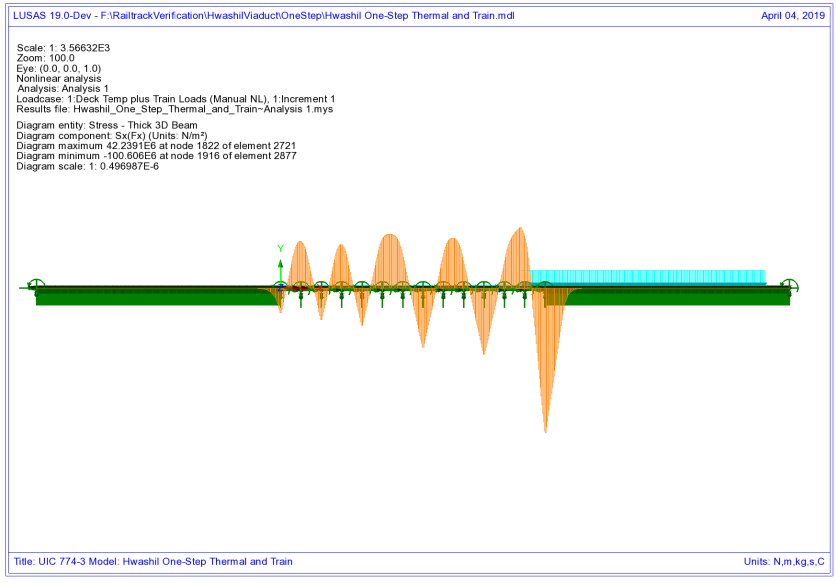


Figure 113: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 2 (One Step)

Analysis of Combined Thermal and Rail Loading Taking Account of Effects of Material Change Under Rail Loading

The previous two analysis methods fail to take account of the train rail loading being applied to the rail when it has already undergone movement/stresses due to thermal effects alone. In this current form of analysis (implemented into LUSAS) the initial thermal effects are considered prior to the application of the train rail loading and the behaviour under this rail loading takes account of this history.

To illustrate the analysis, consider the following:

When the train is not on the track the stresses in the rails are governed purely by the thermal effects. For the Hwashil Viaduct the thermal effects due to the bridge only are considered and therefore the action of this causes the structure to move thus inducing relative movement between the track and the bridge and therefore an associated stress in the rail. For this condition the unloaded resistance properties apply across the whole extent of the track

As the train load arrives over a particular part of the bridge the initial relative movement of the track/bridge from the thermal effects remains and therefore the application of the train load changes the resistance state from unloaded to loaded without the loss of this initial rail stress caused by the relative movement

The train load causes increased slip of the interaction based on the loaded resistance with the end of the force-displacement curve for the unloaded resistance used as the starting point for the loaded resistance

If it was modelled, the departure of the train load would change the resistance state back to unloaded

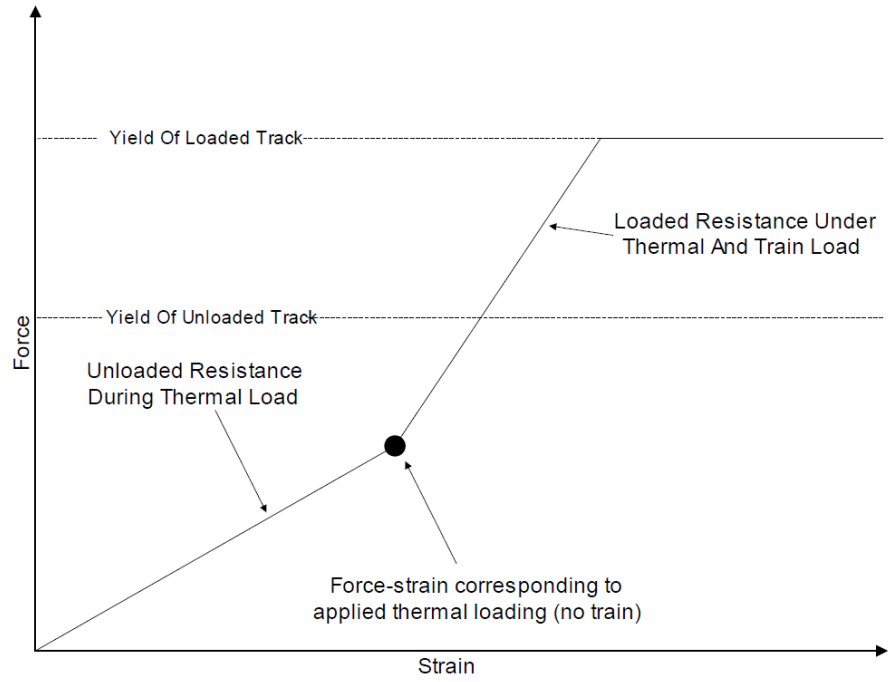


Figure 114: Representation of Transition From Unloaded To Loaded In LUSAS

The key is that the interaction resistance switches from unloaded to loaded the moment the rail load arrives thereby 'locking in' any initial movement that has occurred under the thermal loading until that rail load departs. The results from this form of analysis are shown in the following figures which give peak compressive rail stresses of:

Track 1 and 2 (Thermal Only):	**46.06 N/mm^2**
Track 1 (Thermal and Train):	**79.06 N/mm^2**
Track 2 (Thermal and Train):	**92.60 N/mm^2**

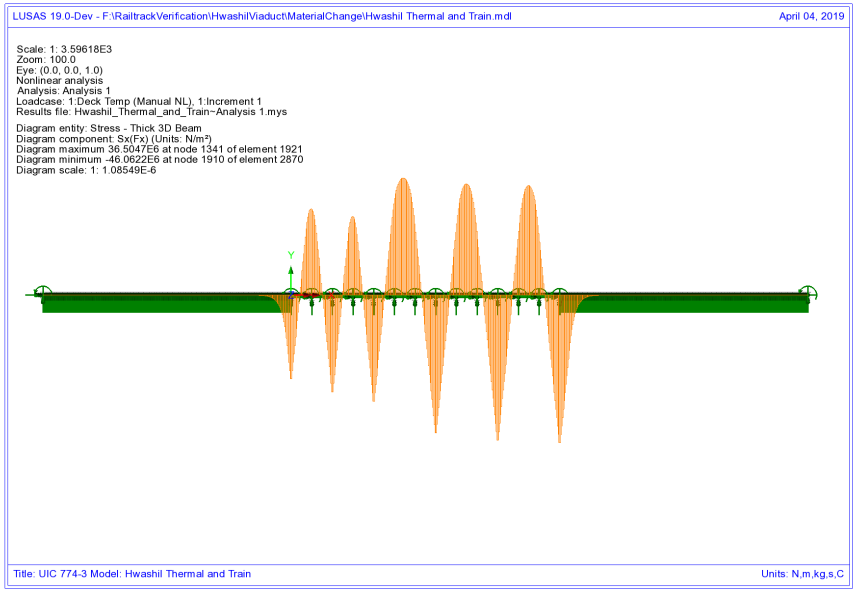


Figure 115: Axial Stress In Rails Due To Thermal Only

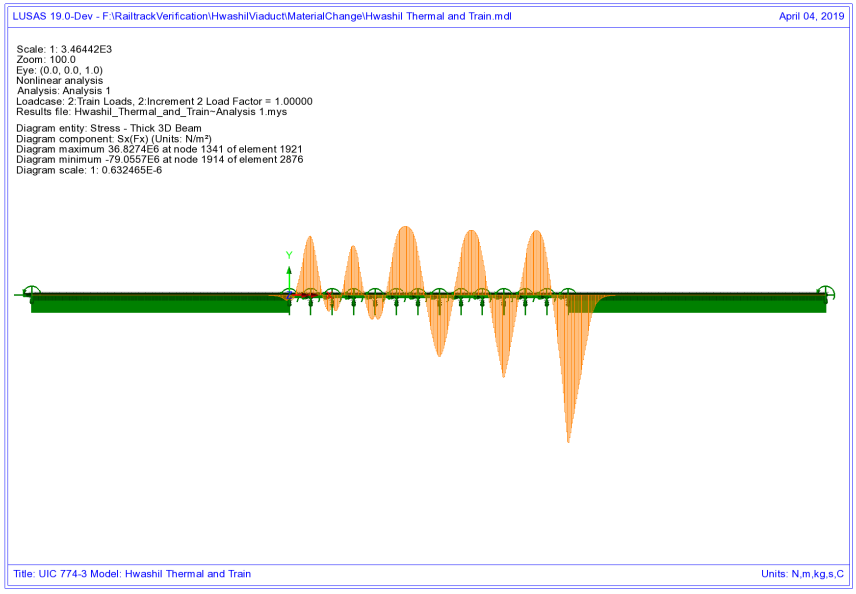


Figure 116: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 1

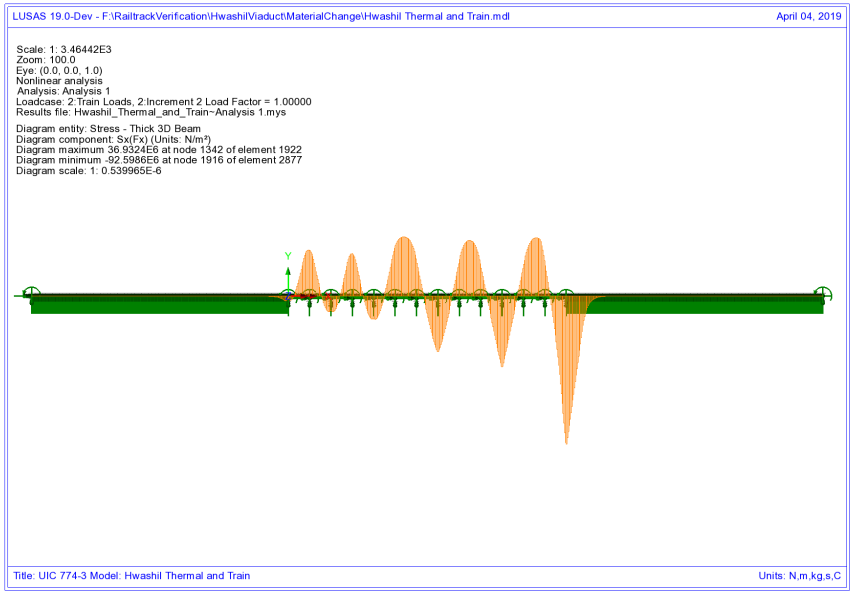


Figure 117: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 2

The analyses produced using this method can give a lower peak compressive stress in the rails than observed using the other approaches but agrees closely with the published test cases using rigorous methods in UIC774-3 as observed in the following sections for test E1-3 and H1-3.

Discussion

The peak compressive stresses in track/rail 2 which has the accelerating load and track/rail 1 that is subjected to the braking train show differences in the peak compressive stress in the rails based on the position of the train loads used in the analysis. As the loading and geometry of the models are identical the differences can only be associated with the track resistance modelling/behaviour. It has been noted previously above that the transition from unloaded resistance to loaded resistance is only incorporated into the LUSAS modelling so this track resistance is investigated by looking at the yield under the effects of the rail loading.

Looking first at the second track/rail that has the accelerating load, the yielding occurring from the three analyses are shown in the following figures. Comparing the yield layout for the LUSAS analysis (Figure 121) and the concurrent thermal/train loading analysis (Figure 120) shows that the amount of yielding of the interaction joints (ballast) at the right-hand abutment is similar but the yielding diminishes away from the accelerating locomotive at the front of the train which has only just entered the

structure at the right-hand abutment in the LUSAS analysis whereas in the concurrent loading analysis it is predicting large regions of yielded interaction joints. In the LUSAS analysis yielding may have previously occurred of unloaded material under thermal only loading but relieving of the forces in the unloaded interaction joints away from the accelerating train has caused them to return to elastic behaviour with a permanent deformation, hence the absence of indicated active yield flags.

Looking now at the separate analysis, the yield layout for the concurrent thermal/train analysis is comparable to the yield layout for the thermal effects alone (Figure 118). In the separate train loading analysis very little yielding is indicated as being associated with the accelerating train loading analysis (Figure 119). This is due to the accelerating train only just entering the bridge with the majority of the loads over the right approach embankment, which are vertical not horizontal. The potential relieving effects of the train loading in this analysis are combined through a basic combination (unlike in the LUSAS material change method) but for this separate analysis the yield strength of both the unloaded and loaded materials are both counted so if both analyses yield at the same position (as is the case at the right-hand abutment and elsewhere) then it is possible that the interaction joints / ballast could be considered too strong – see below.

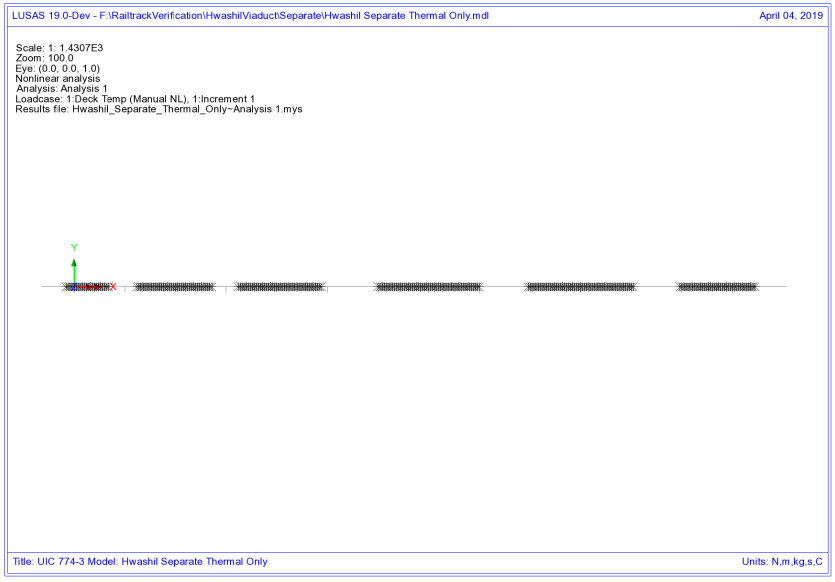


Figure 118: Track/Rail 2 Yield Due To Thermal Load On Track Alone

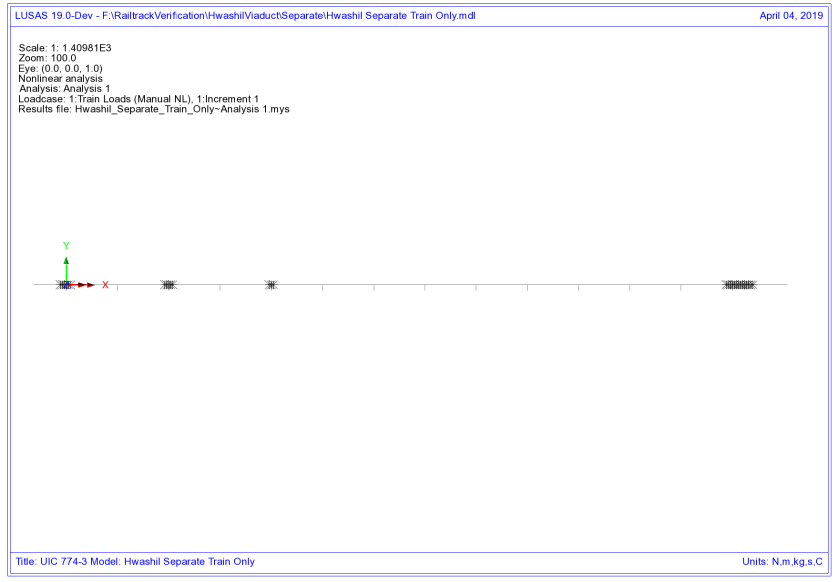


Figure 119: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 – Separate Analysis

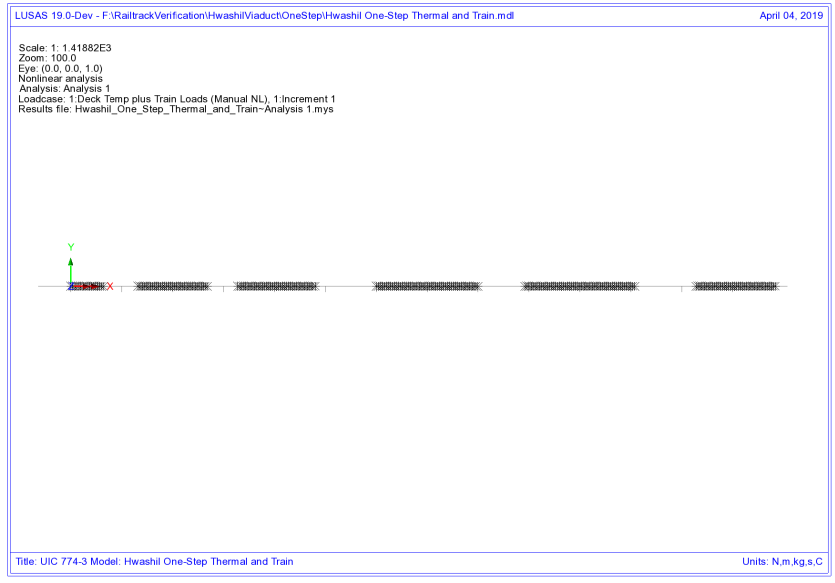


Figure 120: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 - Thermal And Rail Applied Concurrently

Figure 121: Track/Rail 2 Yield Due To Accelerating Train Load On Track 2 - LUSAS Combined Analysis

Looking at what is effectively happening in these analyses, Figure 122, the concurrent loading analysis uses the loaded resistance throughout the analysis and follows the loaded stiffness curve from the origin and potentially gives the location indicated on the plastic part of this curve as illustrated with a force in the interaction limited to the resistance of the loaded track. For the separate analysis, the thermal effects use the unloaded curve and the behaviour of this part of the analysis is limited by the resistance of the unloaded track. Under these conditions the analysis may give a location indicated by the ‘Thermal Alone’ point on the unloaded curve. Separate consideration of the train loading effectively places the origin of the loaded bilinear curve at this ‘Thermal Alone’ position and any loading could potentially give the location indicated by the ‘Separate Train Load Added To Thermal’ position. This could give an apparent increase in the resistance of the track and therefore increase rail stresses in the loaded track.

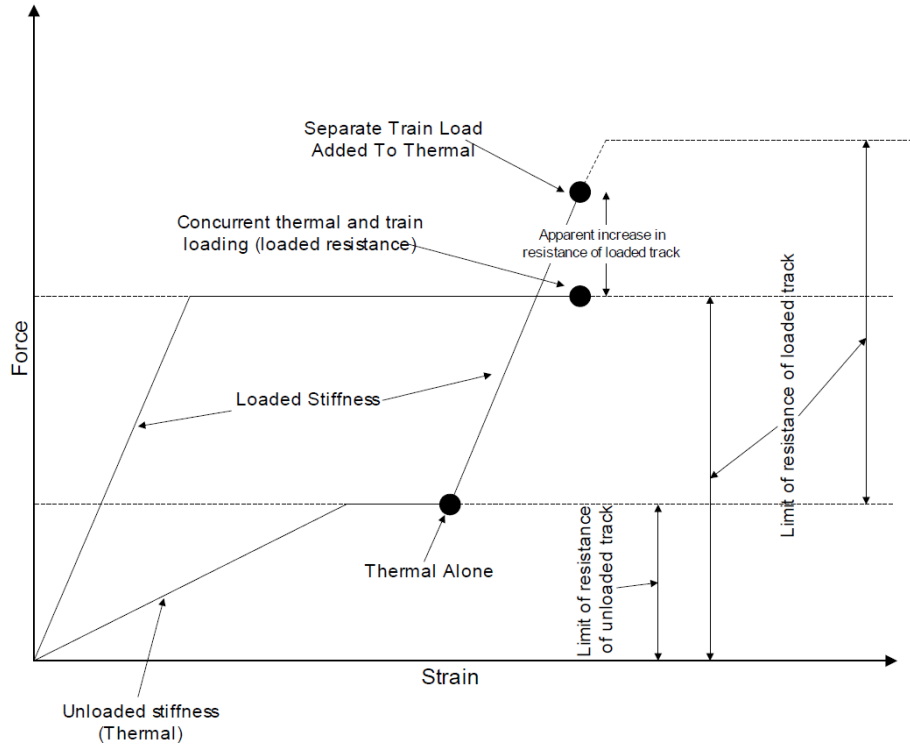


Figure 122: Illustration Of Behaviour Of Separate Analysis Vs. Concurrent Thermal And Rail Loading

Similar comparisons can be made between the separate analysis and the LUSAS analysis - Figure 123. While both of these effectively use the 'Thermal Alone' location as an origin for the loaded resistance curve, the key difference between the two approaches is that the LUSAS analysis enforces the track resistance at which plasticity occurs instead of allowing the potential for an apparent increase in the track resistance equal up to the unloaded plus the loaded track resistance.

These differences have affected the peak compressive rail stresses in the track subjected to accelerating train loads with all three analyses predicting stresses in the range of 92.6 to 103.7 N/mm^2.

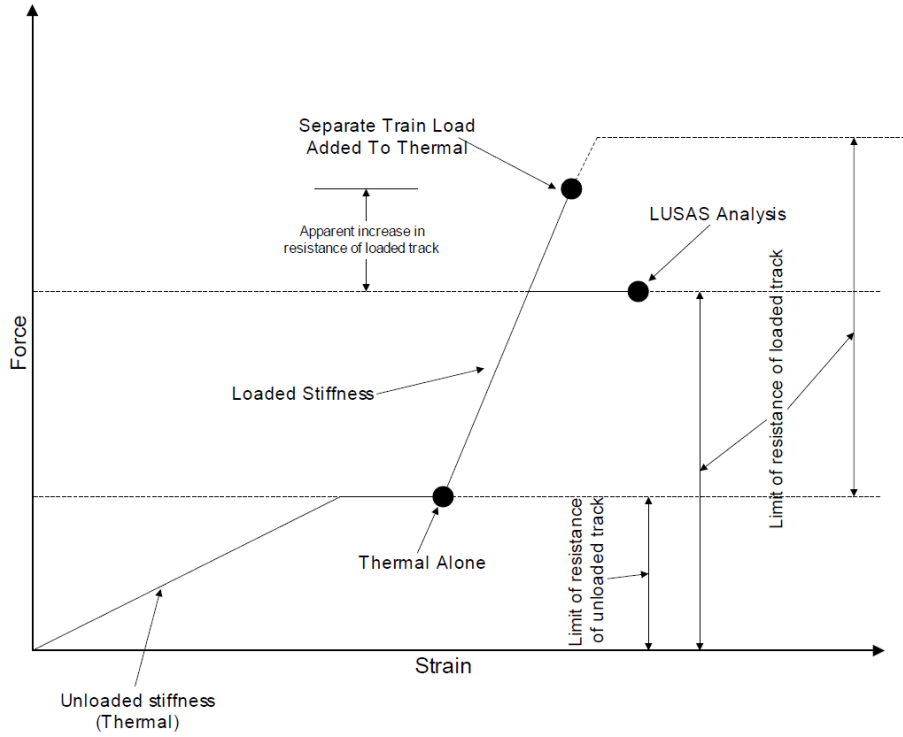


Figure 123: Illustration Of Behaviour Of Separate Analysis Vs. LUSAS Analysis

Looking now at the track/rail that has the braking train on it, the following figures show the same yield plots for this track/rail resistance. The immediate observation again is the different yield behaviour observed for the LUSAS analysis. Looking initially at the separate analysis and the concurrent thermal and rail loading analysis the yielding observed in the thermal alone for the separate analysis (Figure 124) shows close similarity to the yielding observed when the thermal and train loading are applied concurrently (Figure 126) – minimal yielding is observed under the action of the train load alone in the separate analysis (Figure 125).

Concentrating on the LUSAS analysis, the front of the braking train load is just over the right end of the structure and the carriages cover most of the remaining bridge. This has the effect, unlike the accelerating track, of changing nearly all of the resistance from unloaded to loaded for this track over the bridge and therefore the interaction is no longer under yield because the loaded resistance now governs plastic yield. The LUSAS analysis however does not display the possible apparent increase in the resistance of the track that can be observed with the separate analysis method. This means the track interaction around the front of the braking train resisting the movement of the rails cannot sustain the same level of loading and therefore yield to a larger

extent than observed in the separate analysis, thereby reducing the compressive stress in the rails underneath the train – compare Figure 125 and Figure 127 where the yielding underneath the braking train is greater for the LUSAS analysis than in the separate rail load analysis.

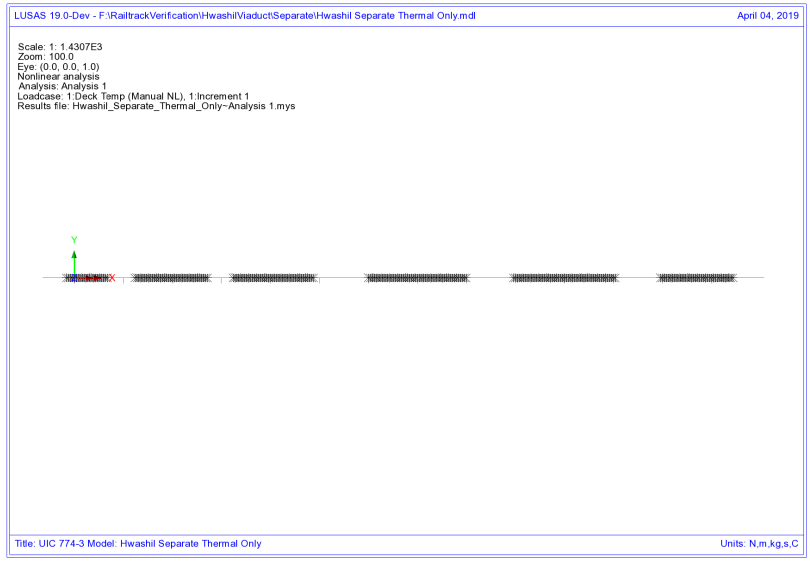


Figure 124: Track/Rail 1 Yield Due To Thermal Load On Track Alone

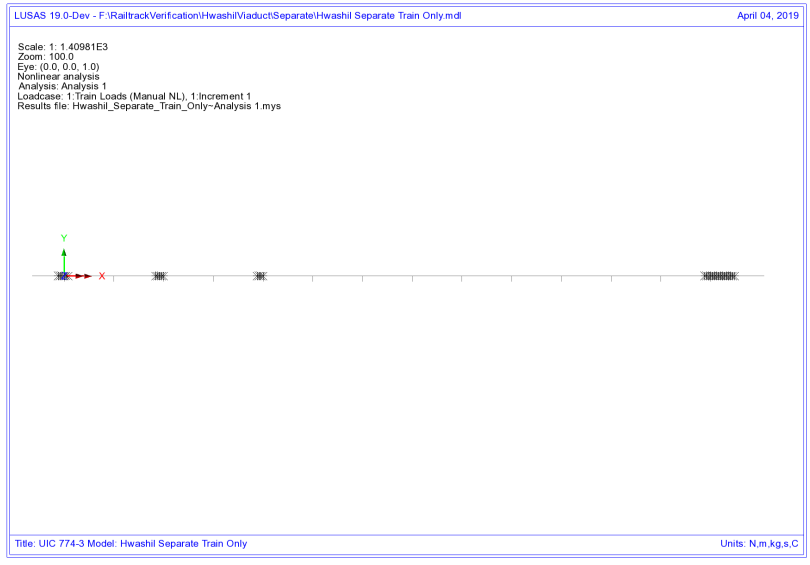


Figure 125: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 – Separate Analysis

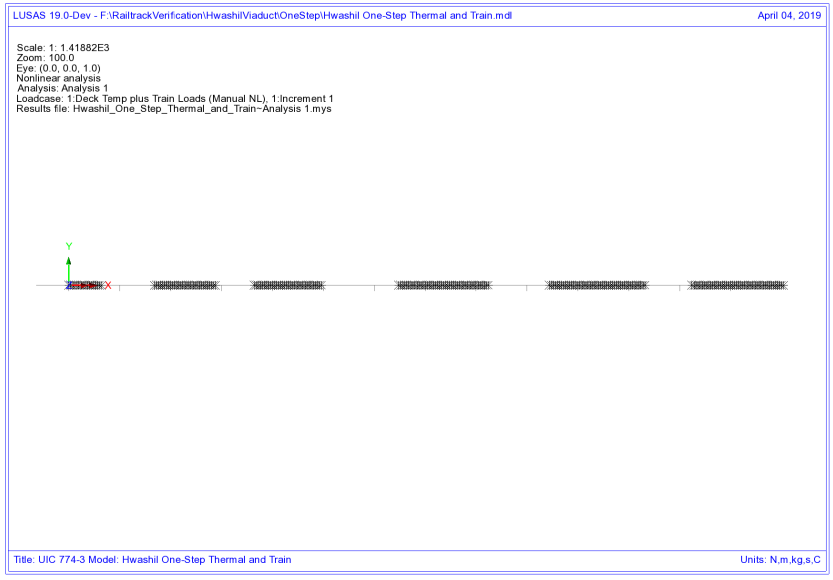


Figure 126: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 - Thermal And Rail Applied Concurrently

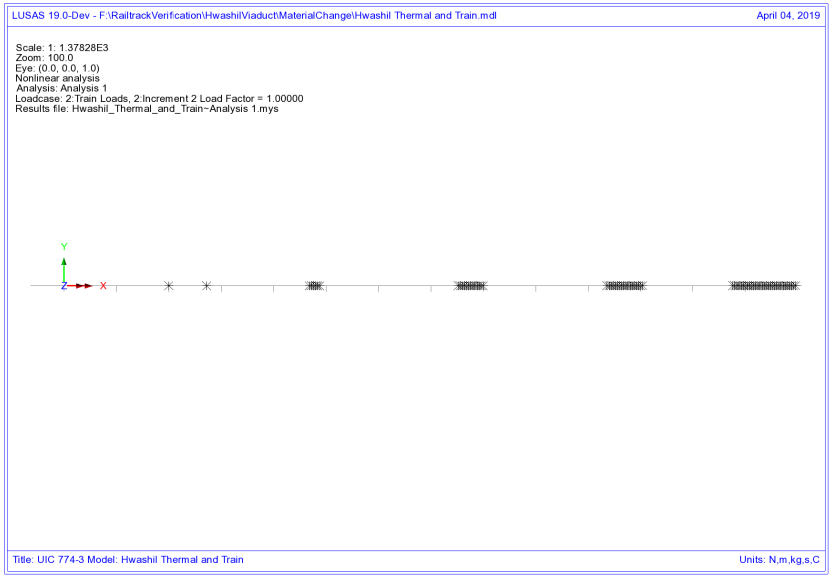


Figure 127: Track/Rail 1 Yield Due To Braking Train Load On Track 1 - LUSAS Combined Analysis

Looking at the behaviour of the track interaction for the separate analysis we can plot the values of the force per metre length for the track subjected to the braking train loads. Figure 128 and Figure 129 show the forces per metre length for the thermal loading and the train braking loading for the separate analyses. Clearly, near the right-hand abutment, the force per metre length under the thermal loading is equal to 40kN/m and due to the train loading is equal to 60kN/m. Combination of these two results means that the track interaction has mobilised 100kN/m in this region when it is actually only able to mobilise 60kN/m based on the loaded track resistance bilinear curve – the separate analysis method is giving an apparent increase in the loaded track resistance that can be mobilised before plastic yielding occurs. This apparent increase in the loaded track resistance has the consequence of allowing the rail stresses to increase beyond the value that would occur if the true loaded track resistance was used as in the LUSAS modelling where the track resistance is correctly limited to the loaded value of 60kN/m – Figure 130.

NOTE: This difference in the amount of track resistance that can be mobilised in the loaded condition is the main reason for the differences in the solutions obtained for the separate and LUSAS methods and demonstrates that the correct modelling of the interaction is critical to the solution.

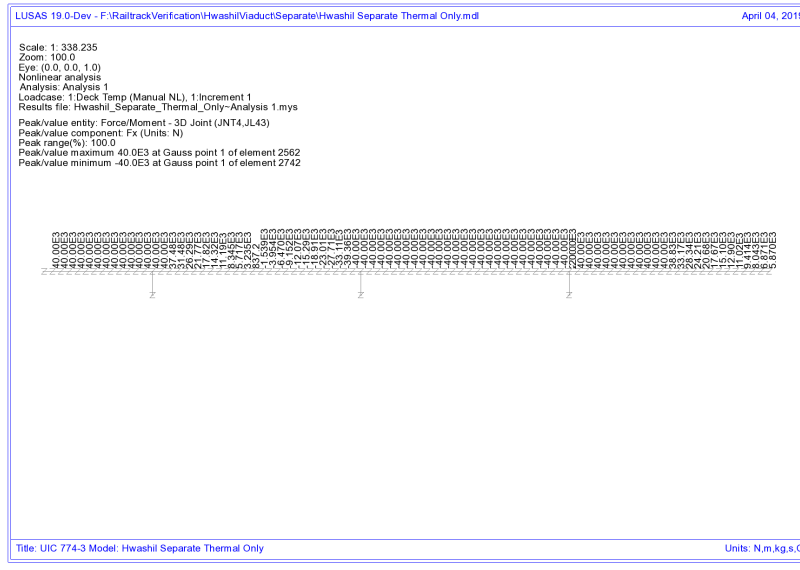


Figure 128: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 – Separate Thermal Loading (N/m length)

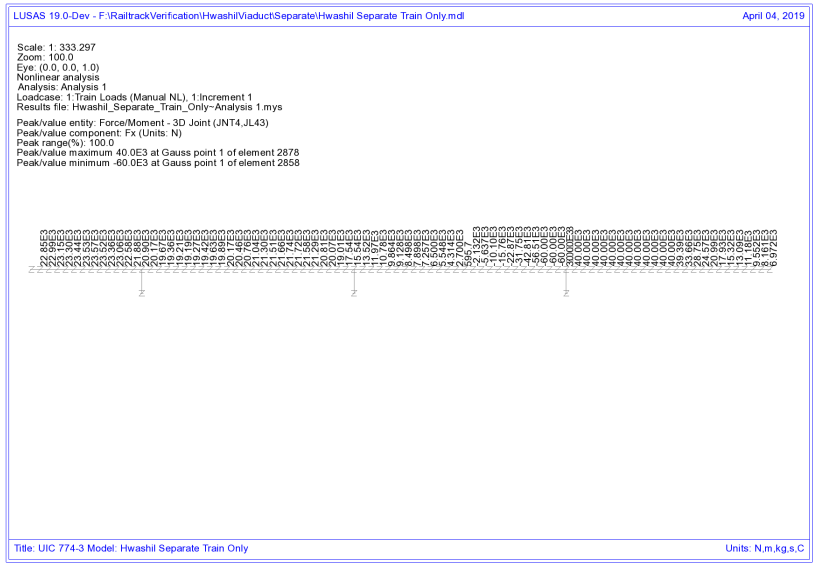


Figure 129: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 - Separate Train Loading (N/m length)

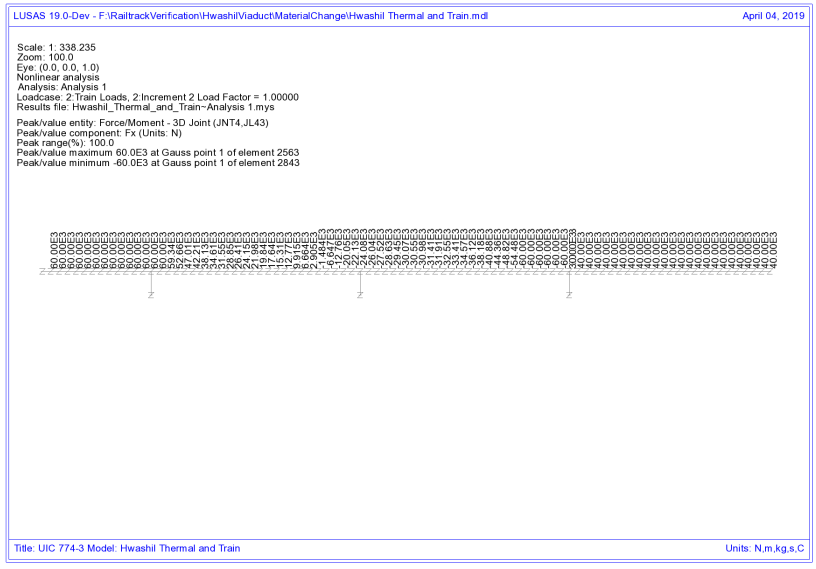


Figure 130: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 – LUSAS Nonlinear (N/m length)

Revisit of UIC774-3 Test E1-3 Using the Separate and LUSAS Methods of Analysis

The standard UIC774-3 test E1-3 has been reanalysed using the following two approaches:

- **Separate analysis of thermal and rail loading effects**
- **LUSAS full nonlinear analysis**

The results of these two analyses are presented in the following sections and then discussed briefly.

Separate Analyses

The analysis of the thermal effects due to the temperature in the bridge and rail are presented in the following figure. These two thermal effects give a peak compressive rail stress of 155.63 N/mm^2 which compares well with the code of practice value of 156.67 N/mm^2.

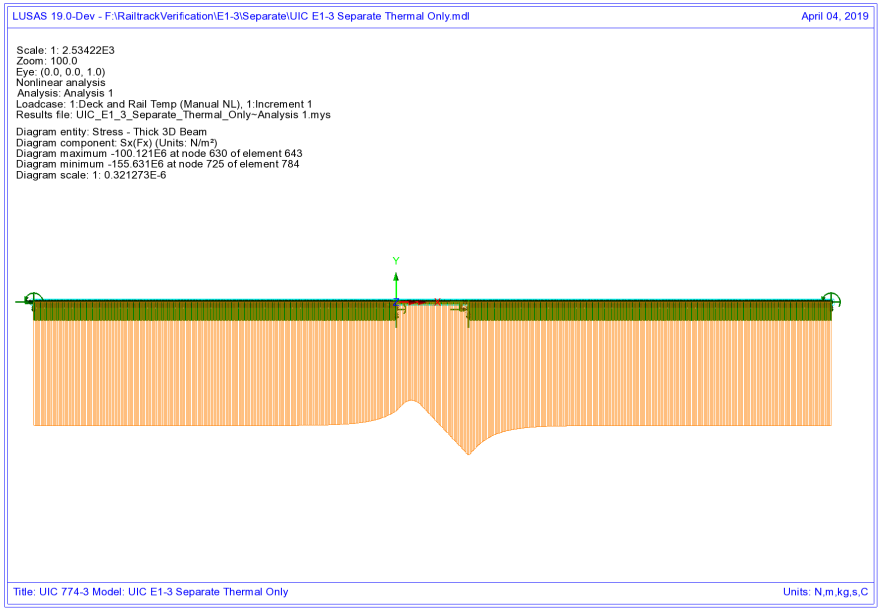


Figure 131: Axial Stress In Rails Due To Temperature In Bridge And Rail

To determine the worst location of the train load for compressive rail stresses the bridge has been analysed with the rail loading at 31 separate locations (starting from the left abutment of the bridge and finishing 90m from the right abutment of the bridge

– train moving from left to right) and these results enveloped. The results of this analysis are presented in the following figure which give a peak compressive rail stress of 40.64 N/mm^2.

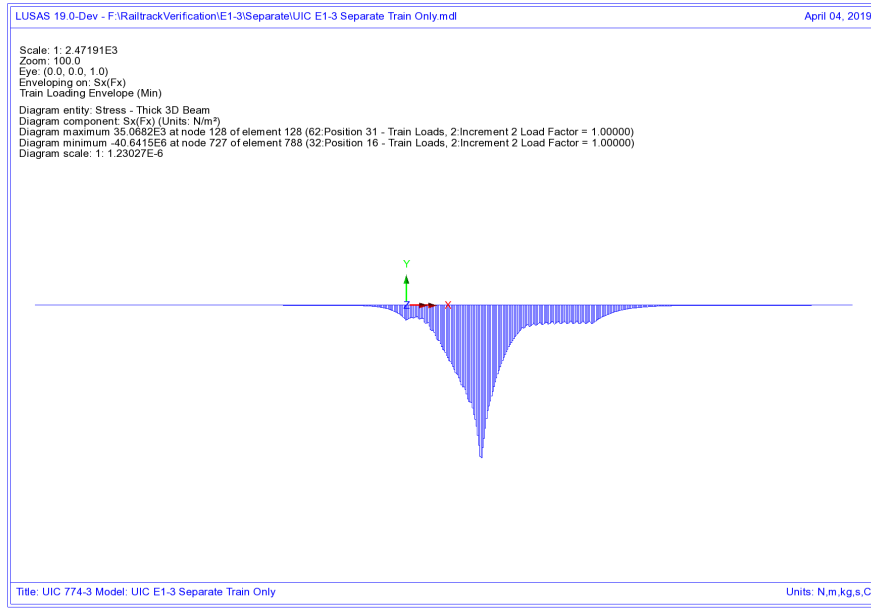


Figure 132: Envelope Of Axial Stress In Rails Due To Rail Loading

Manual combination of the peaks would give a peak compressive rail stress of 196.27 N/mm^2 (ignoring locations of the peaks) and combination of the results in LUSAS gives the same peak compressive rail stress of 196.27 N/mm^2 which occurs over the transition from the structure to the embankment at the right-hand abutment.

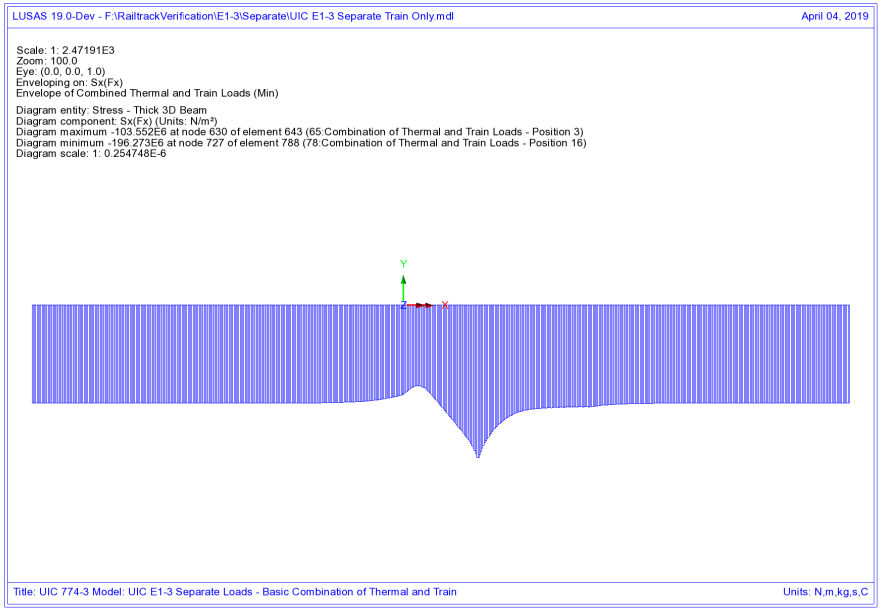


Figure 133: Axial Stress In Rails Due To Combined Temperature And Rail Loading

Comparison of these results with the UIC774-3 code of practice test results shows that the result compares well with the 190.07 N/mm^2 compressive rail stress from the simplified analysis in the test case (which is based on evaluating the effect of each part of the loading separately).

LUSAS Nonlinear Analysis

The UIC774-3 E1-3 test case has been reanalysed using the LUSAS rail option and gives the following peak compressive rail stress for the thermal loading alone and the combined thermal and rail loading:

Thermal:	**155.63 N/mm^2**
Thermal & Rail:	**193.06 N/mm^2**

Comparison of the results shows that the rail stresses are in excellent agreement for both parts of the analysis with the peak compressive rail stress of the combined thermal and train loading having a percentage error of 5.8% when compared against the target rigorous solution of 182.4 N/mm^2.

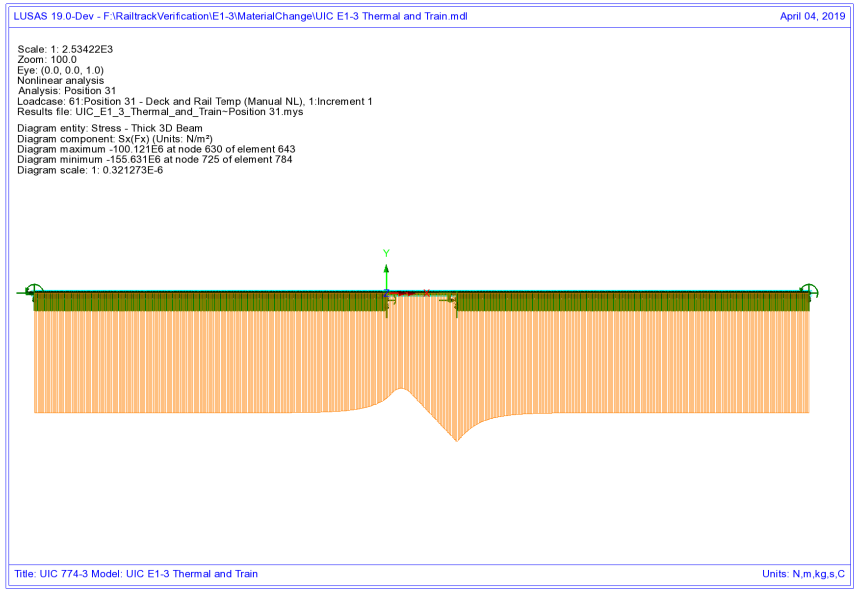


Figure 134: Axial Stress In Rails Due To Temperature In Bridge And Rail

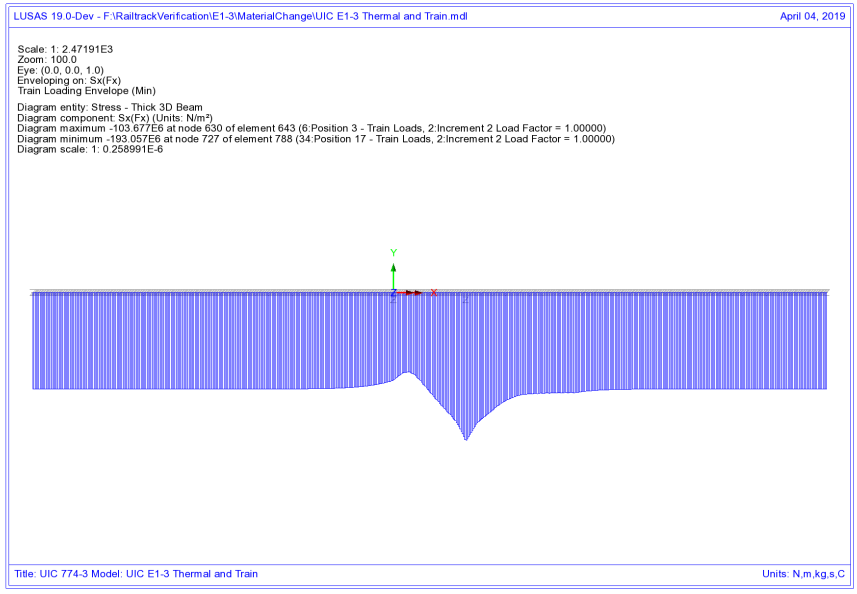


Figure 135: Axial Stress In Rails Due To Combined Temperature And Enveloped Rail Loading

Discussion

For this test case the difference in the results due to the track resistance modelling between the two methods is minimal. Combining the results of two nonlinear analysis, while invalid, gives almost identical results to the LUSAS analysis which correctly represents the transition from unloaded to loaded resistance on arrival of the train load. The train load position that gives the worst compressive stress in the rail does however differ slightly between the two analyses with the separate analysis giving a train front position of 75m from the left abutment of the bridge and the LUSAS combined analysis giving a train front position of 80m from the left abutment of the bridge.

Looking at the yield behaviour it becomes clear why the two methods agree so closely for this UIC774-3 standard test case and not for the Hwashil Viaduct. For both analyses, the rail stresses and interaction yield over the single span bridge due to thermal loading are identical – Figure 136. On consideration of the train loading, the right-hand end of the structure (roller bearing) where the peak compressive rail stresses are observed shows no sign of yield with yield only occurring over the left end and embankment – Figure 137 and Figure 138. This indicates that the separate analysis, while invalid due to the linear combination of two nonlinear analyses, is giving the correct result and this only occurs because the interaction over the structure at this location is nowhere near yield.

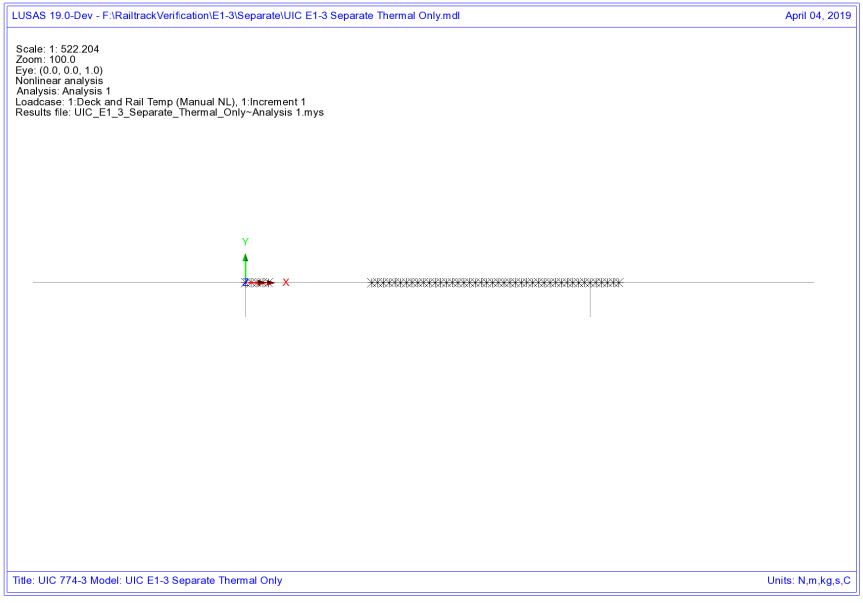


Figure 136: Yield Layout For Thermal Loading Only

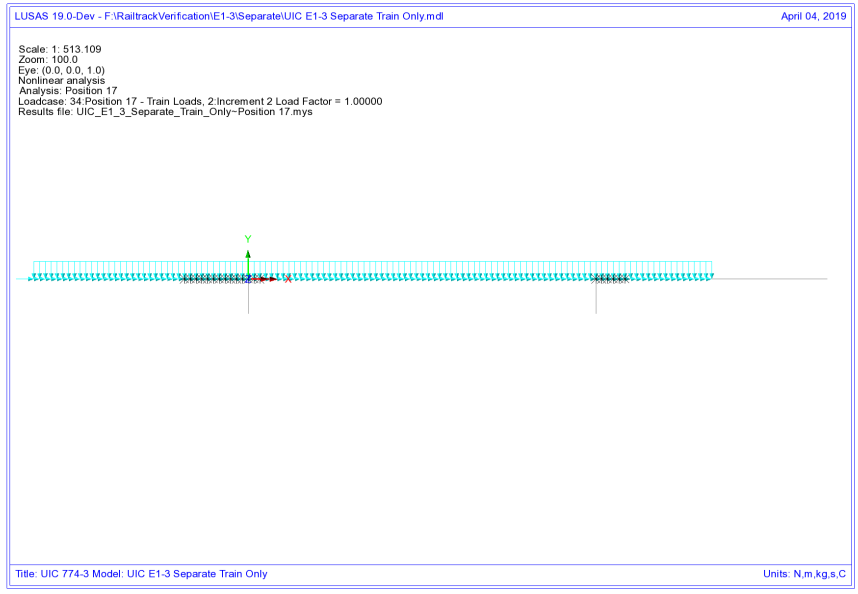


Figure 137: Yield Layout For Train Loading Only From Separate Analysis

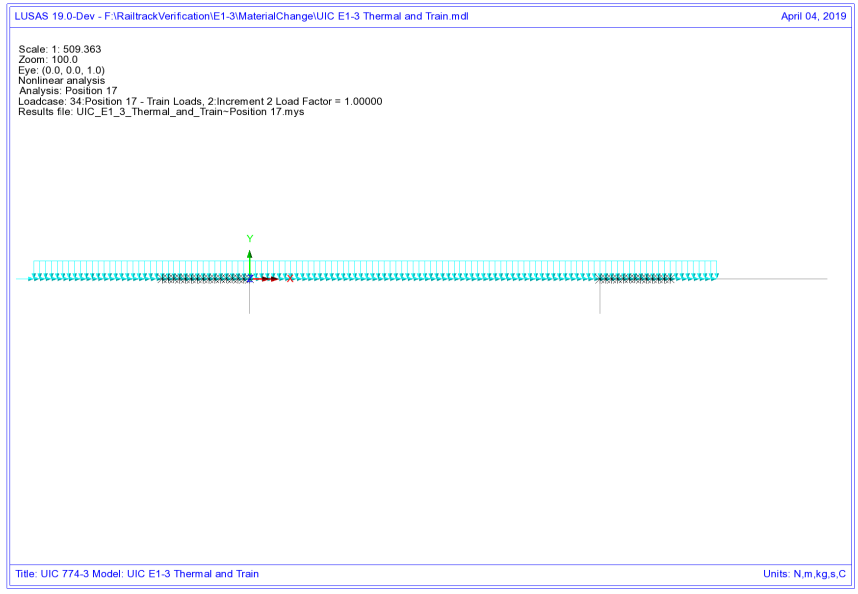


Figure 138: Yield Layout For Combined Thermal And Train Loading From LUSAS Nonlinear Analysis

The following two plots show the forces in the interaction joints for the thermal and train loads from the separate analysis at the transition of the right-hand of the deck to the embankment. The thermal loading has caused yielding of the unloaded track interaction with a value of 20 kN/m in accordance with the unloaded resistance but the train loads have only induced up to about 25.6 kN/m over the structure. Combining these two results means that the total force per unit length for the separate analysis is 45.6 kN/m which is comparable to the LUSAS nonlinear solution of 40.5 kN/m – see Figure 141. Because the interaction is well below yield for the loaded interaction resistance of 60 kN/m the two solution method effectively have identical solutions and their behaviour can be visualised in Figure 142.

If, however, the train loading had induced interaction forces in the region of 40 kN/m (taking account of the track resistance already mobilised by the thermal loading) instead of the observed 25.6 kN/m then significant differences could be observed in the two analysis methods as the separate method would still allow a further 20 kN/m track resistance to be mobilised before the onset of plastic yielding and the separate analysis would potentially over predict the rail stresses occurring. This potentially means that…

***…even though a computer program is validated against the standard test cases in the UIC774-3 code of practice, it may be predicting excessive rail stresses if it does not correctly take account of the loaded track resistance that can be mobilised*.**

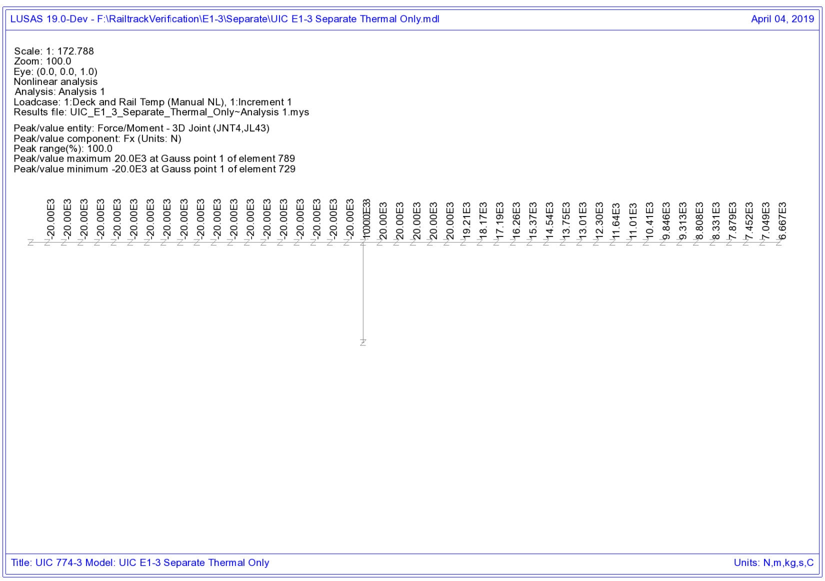


Figure 139: Force Per Metre Length In Interaction From Thermal Loading - Separate Analysis

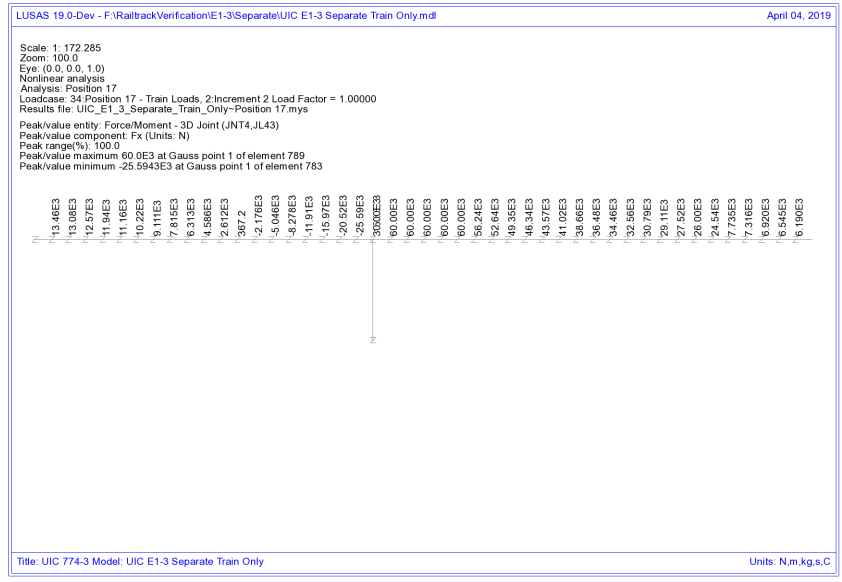


Figure 140: Force Per Metre Length In Interaction From Train Loading - Separate Analysis

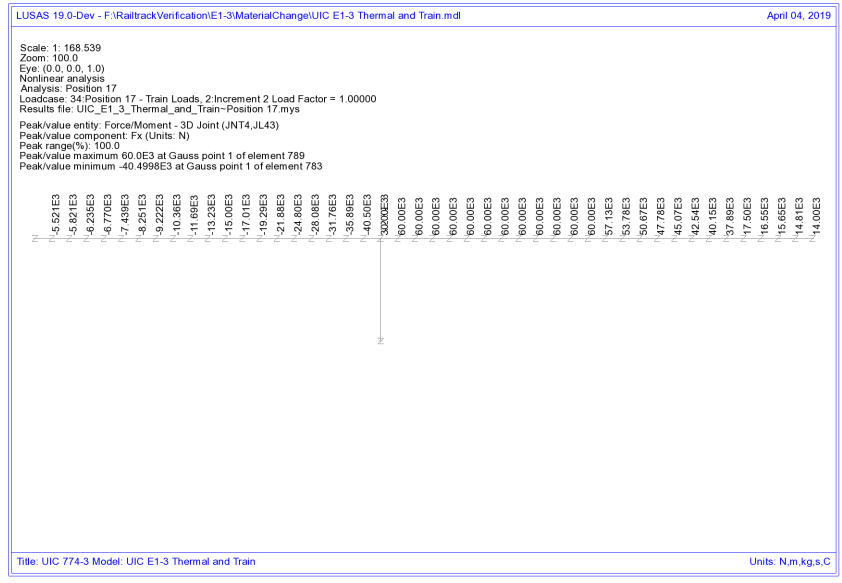


Figure 141: Force Per Metre Length In Interaction From Combined Loading - LUSAS Analysis

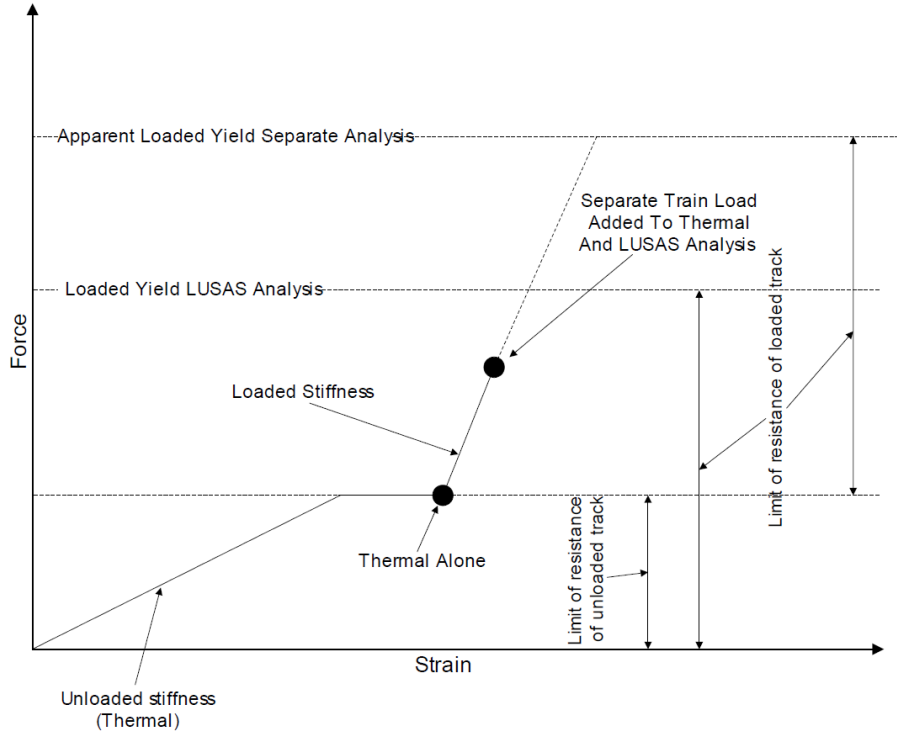


Figure 142: Illustration Of Behaviour For UIC774-3 Standard Test E1-3 For Separate And LUSAS Analyses

Revisit of UIC774-3 Test H1-3 Using the Separate and LUSAS Methods of Analysis

The previous test case (E1-3) is one of the key test cases that must be matched for computer programs carrying out this form of analysis with the results for both the separate method and the LUSAS method being in close agreement to the results required. The deck type for this test is however a concrete slab underlain by I-section steel beams which does not compare with the deck being used for Hwashil Viaduct. For this reason the H1-3 test is also revisited and solved using the two methods of analysis.

Separate Analyses

The analysis of the thermal effects due to the temperature in the bridge and rail are presented in the following figure. These two thermal effects give a peak compressive rail stress of 167.77 N/mm^2 which compares very well with the code of practice value of 169.14 N/mm^2.

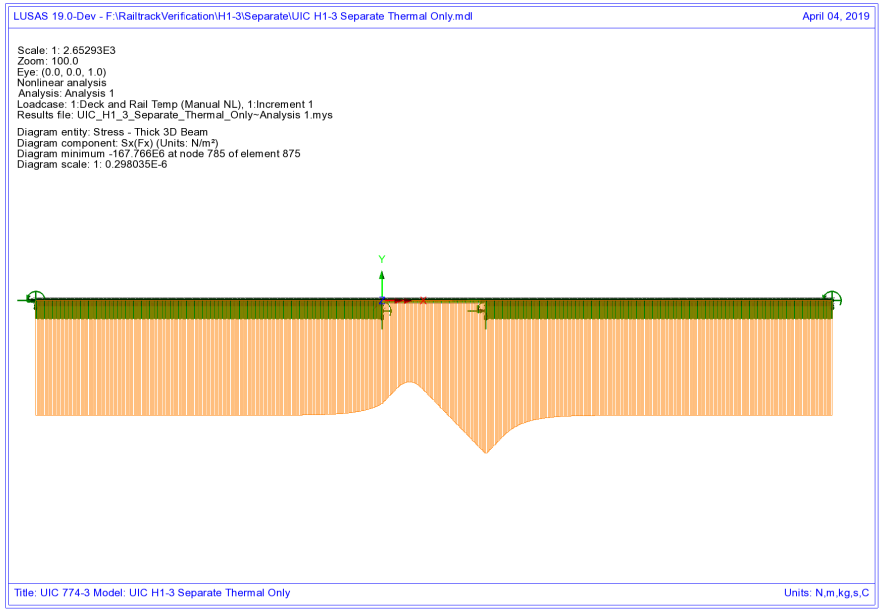


Figure 143: Axial Stress In Rails Due To Temperature In Bridge And Rail

To determine the worst location of the train load for compressive rail stresses the bridge has been analysed with the rail loading at 37 separate locations (starting from the left abutment of the bridge and finishing 90m from the right abutment of the bridge – train moving from left to right) and these results enveloped. The results of this

analysis are presented in the following figure which give a peak compressive rail stress of 29.09 N/mm^2.

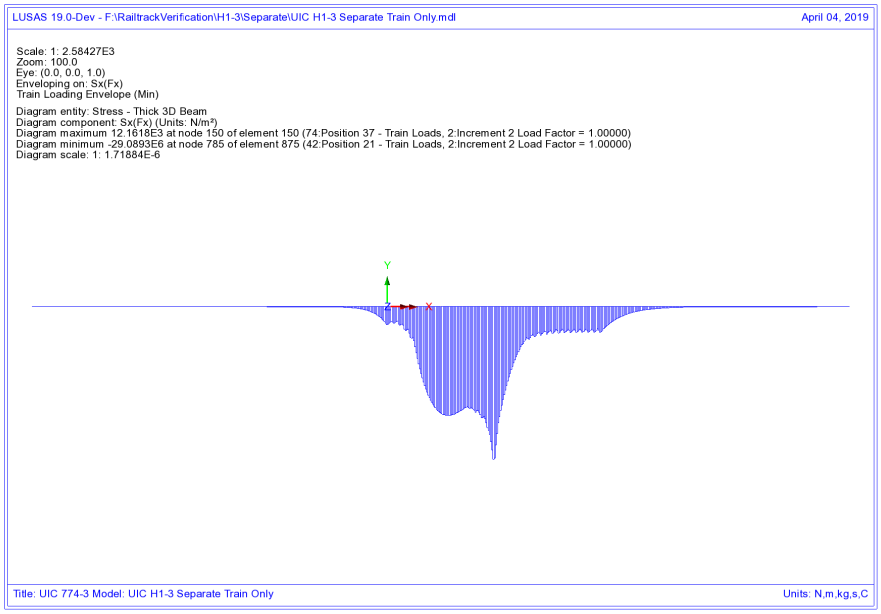


Figure 144: Envelope Of Axial Stress In Rails Due To Rail Loading

Manual combination of the peaks would give a peak compressive rail stress of 196.86 N/mm^2 (ignoring locations of the peaks) and combination of the results in LUSAS gives 196.86 N/mm^2 which occurs over the transition from the structure to the embankment at the right-hand abutment.

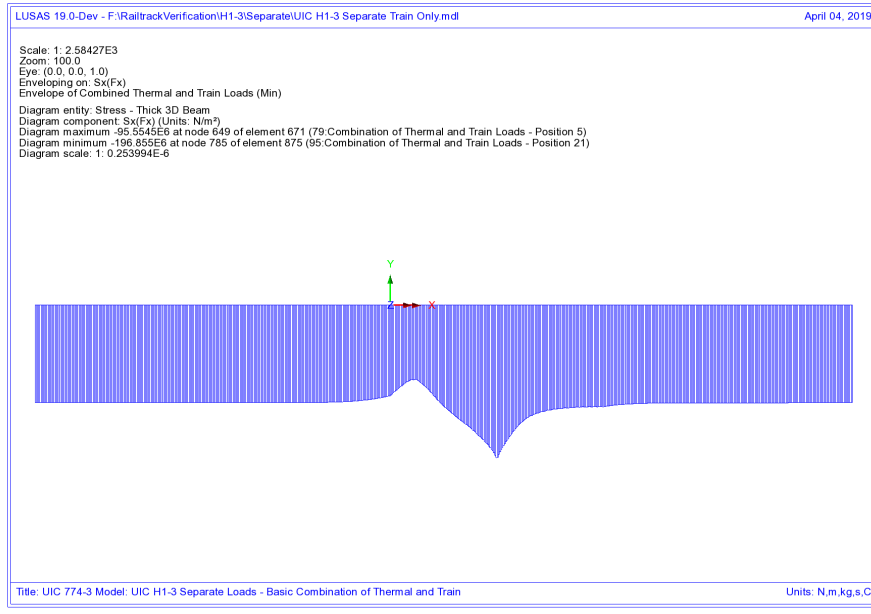


Figure 145: Axial Stress In Rails Due To Combined Temperature And Rail Loading

Comparison of these results with the UIC774-3 code of practice test results shows that the result compares well with the 211.37 N/mm^2 compressive rail stress from the simplified and the 188.23 N/mm^2 compressive rail stress from the rigorous analysis in the test case.

LUSAS Nonlinear Analysis

The UIC774-3 H1-3 test case has been reanalysed using the LUSAS rail option and gives the following peak compressive rail stress for the thermal loading alone and the combined thermal and rail loading:

Thermal:	**167.77 N/mm^2**
Thermal & Rail:	**195.91 N/mm^2**

Comparison of the results shows that the rail stresses are in excellent agreement for both parts of the analysis with the peak compressive rail stress of the combined thermal and train loading having a percentage error of 4.1% when compared against the target rigorous solution of 188.23 N/mm^2.

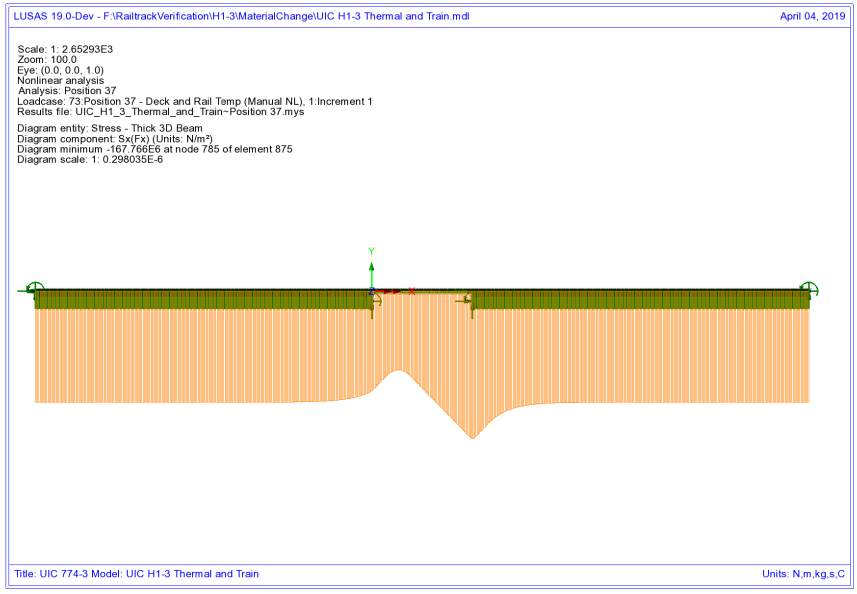


Figure 146: Axial Stress In Rails Due To Temperature In Bridge And Rail

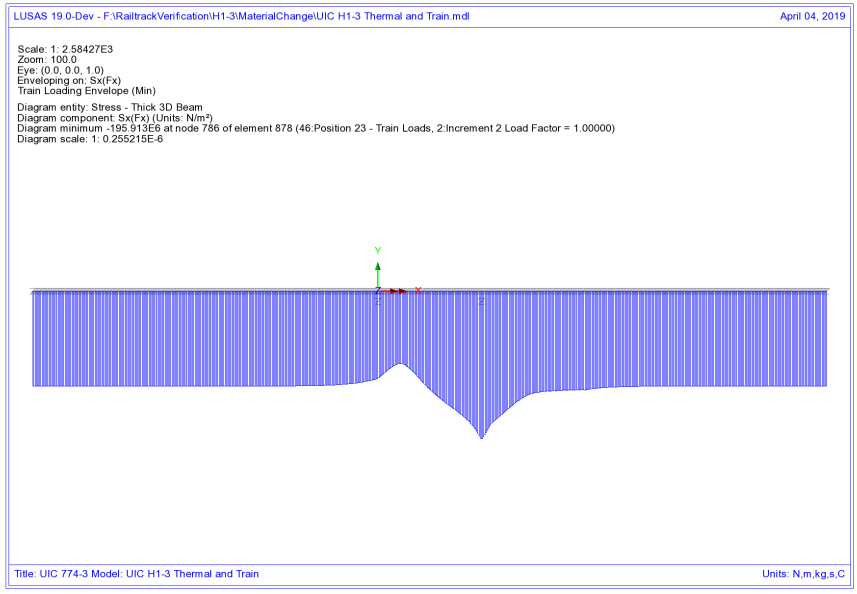


Figure 147: Axial Stress In Rails Due To Combined Temperature And Enveloped Rail Loading

Discussion

As with the previous E1-3 test case, the difference in the results due to the track resistance modelling between the two methods is minimal. Combining the results of two nonlinear analysis, while invalid, gives almost identical results to the LUSAS analysis which correctly represents the transition from unloaded to loaded resistance on arrival of the train load. The train load position that gives the worst compressive stress in the rail does however differ slightly between the two analyses with the separate analysis giving a train front position of 100m from the left abutment of the bridge and the LUSAS combined analysis giving a train front position of 110m from the left abutment of the bridge.

Referring back to test E1-3, similar plots can be generated for the yield and forces in the interaction. These, as with the E1-3 test, show that the train loading is not bringing the force per metre length in the interaction close the loaded yield resistance of 60 kN/m and therefore the separate analysis and LUSAS analysis methods agree even though the separate method potentially allows more track resistance to be mobilised than is allowed when the thermal and rail results are combined.

Separate:	**27.6 kN/m**
LUSAS:	**26.1 kN/m**

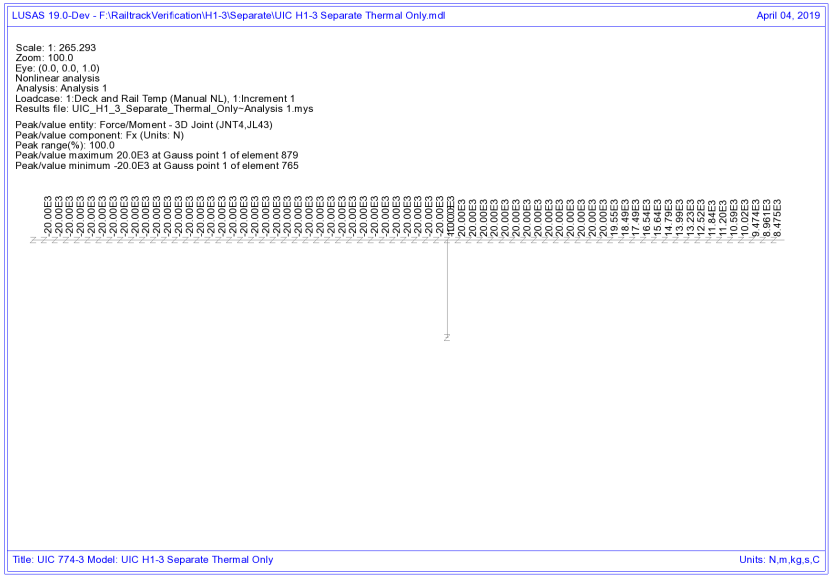


Figure 148: Force Per Metre Length In Interaction From Thermal Loading - Separate Analysis

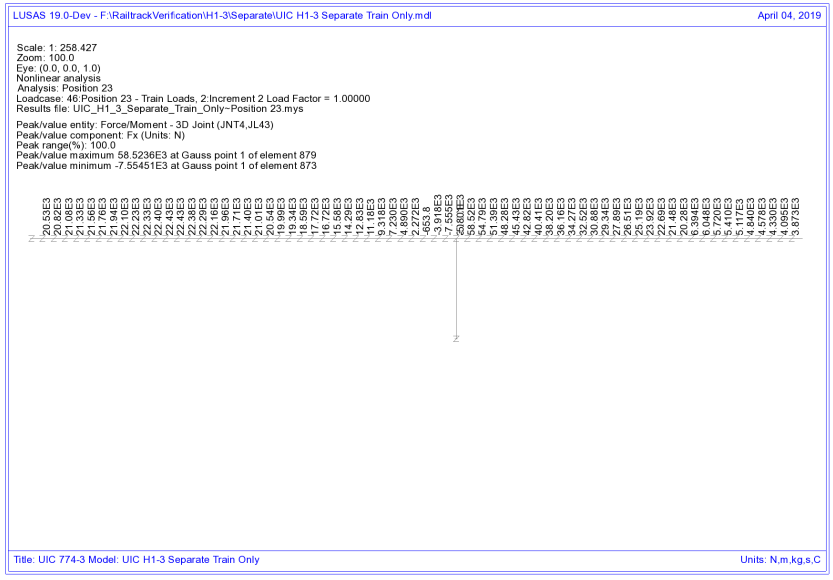


Figure 149: Force Per Metre Length In Interaction From Train Loading - Separate Analysis

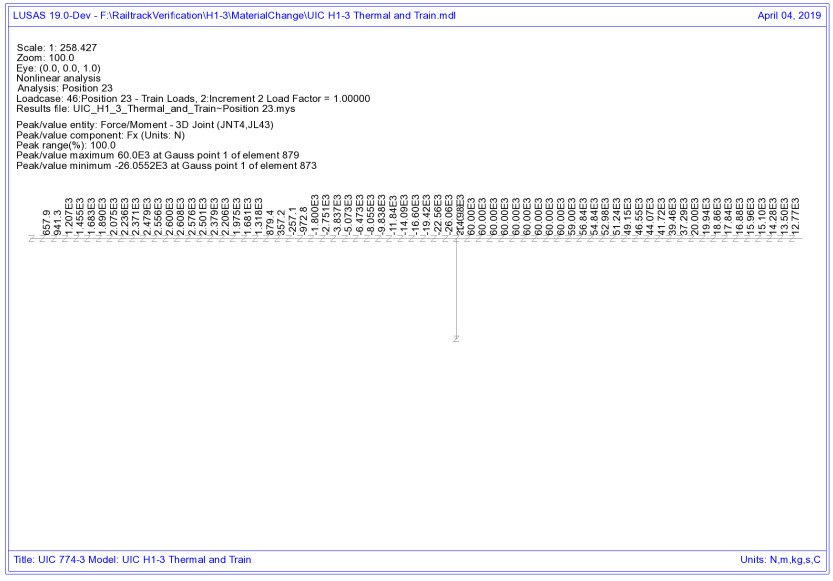


Figure 150: Force Per Metre Length In Interaction From Combined Loading - LUSAS Analysis

Conclusions

Three solution methods for carrying out the UIC track/bridge interaction analyses have been investigated and differences observed in the assumed behaviour and results highlighted. The key observations were as follows:

Separate Thermal and Rail Loading Analysis

- Correct unloaded track resistance used for thermal effects across whole model
- Correct yielding of unloaded ballast/frozen ballast-no ballast track under thermal effects
- Incorrect yielding of loaded ballast/frozen ballast-no ballast track assuming that thermal effects are present, only correct if there are no thermal effects
- Invalid combination of two nonlinear analyses results gives apparent increase in the resistance of the track due to stresses in ballast/frozen ballast-no ballast track from the unloaded thermal effects being ignored in the ultimate yield of the loaded analysis – to correctly model the reduction of the resistance of the track before yielding occurs under loaded conditions, the yield resistance for the loaded condition should be reduced by the amount of resistance already mobilised due to the thermal effects
- Separate analysis ignores the movement that has already occurred under the thermal effects when the load from the train acts on the rails

Concurrent Thermal and Rail Loading Analysis

- Incorrect loaded track resistance used for thermal effects under location of train loads
- Incorrect yielding of ballast/frozen ballast-no ballast track under thermal effects as loaded track resistance used
- Correct track resistance for yielding under the train loading
- Movement due to thermal effects alone only approximated

LUSAS Nonlinear Thermal and Rail Analysis with Material Change

- Correct unloaded track resistance used for thermal effects across whole model
- Correct yielding of unloaded ballast/frozen ballast-no ballast track under thermal effects

- Correct yielding of loaded ballast/frozen ballast-no ballast track under action of combined thermal and train loading effects as track resistance correctly modelled (yield occurs at the correct loading – no apparent increase in the yield value)
- Instantaneous change from unloaded to loaded track resistance correctly takes account of movement that has already occurred under thermal effects alone.

Referring back to Figure 122 and Figure 123, the key issue with the separate analysis approach is the ability for the track resistance to be overestimated by the combination of the two nonlinear analyses and potentially cause the rail stresses to be overestimated.

In the concurrent loading and LUSAS rail option analyses the limit of track resistance is correctly modelled as the value determined from the loaded bilinear curve and therefore this potentially leads to reduced rail stresses observed in the analyses.

As the initial movement under pure thermal loading in the concurrent analysis uses the loaded track resistance, this will give different results to the LUSAS rail option analysis.

Referring back to the Hwashil Viaduct analyses, the rail stresses observed for the three analysis types are:

	Separate Analysis Of Thermal And Train Loading	Concurrent Thermal And Train Loading	LUSAS Nonlinear Thermal And Train Loading With Material Change
Track 1 (Braking)	94.99	85.61	79.06
Track 2 (Accelerating)	103.66	100.61	92.60

Table 2: Comparison Of Peak Compressive Rail Stresses (in N/mm^2) For Different Analysis Methods

Comparison of the results for the separate and LUSAS analyses shows that the peak compressive stress for the separate analysis is 1.2 times that of the LUSAS analysis for track 1 and 1.12 times for track 2. It should be noted however that the separate analysis could be giving an apparent increase in track resistance of up to 1.6 times that of the loaded track due to the combination of the nonlinear results.

The concurrent analysis gave results that are between the separate and LUSAS analysis as expected since the correct limit of loaded track resistance is modelled even though the thermal effects are only approximated.

One overall conclusion is obvious from these test case analyses and discussions made in this appendix:

When a combined thermal and train loading from a separate analysis gives interaction forces that exceed the stated yield resistance then the separate analysis method will potentially over predict the rail stresses unless the loaded track yield surface is reduced by the mobilised track resistance over the extent of the train loading.

References

U1 UIC Code 774-3 R. Track/bridge Interaction. Recommendations for Calculations (2001) Union Internationale des Chemins de fer, Paris, France

Appendix B: Definition of Complex Trainset Configurations

Introduction

Although some trainsets can be simplified with a few uniformly distributed loads (UDLs) to describe the loading pattern, many trainsets are more complex than this and require the definition of multiple components to describe the overall pattern of loading. Some of these trainset configurations require the modelling of point loads, Uniformly Distributed Loads (UDLs) or the combination of the two. This appendix includes some examples of the definition of more complex trainset configurations which require such loading patterns.

Definition of Trainset Configurations With UDLs Alone

The UDL loading allows the definition of trainset configurations where the load is spread over lengths of the track as illustrated by the example shown in Figure 151. In this configuration the vertical load varies along the length of the trainset and the acceleration / traction load acts only over the length of the locomotive(s). In the definition the train is accelerating to the left for any structure model it is applied to with the origin of the trainset loading defined at the left-hand extent of the configuration. Any number of UDLs can be used for the definition of the trainsets in the **Loading** worksheet of the input Excel or compatible XLSX spreadsheet to allow more complex configurations to be defined.

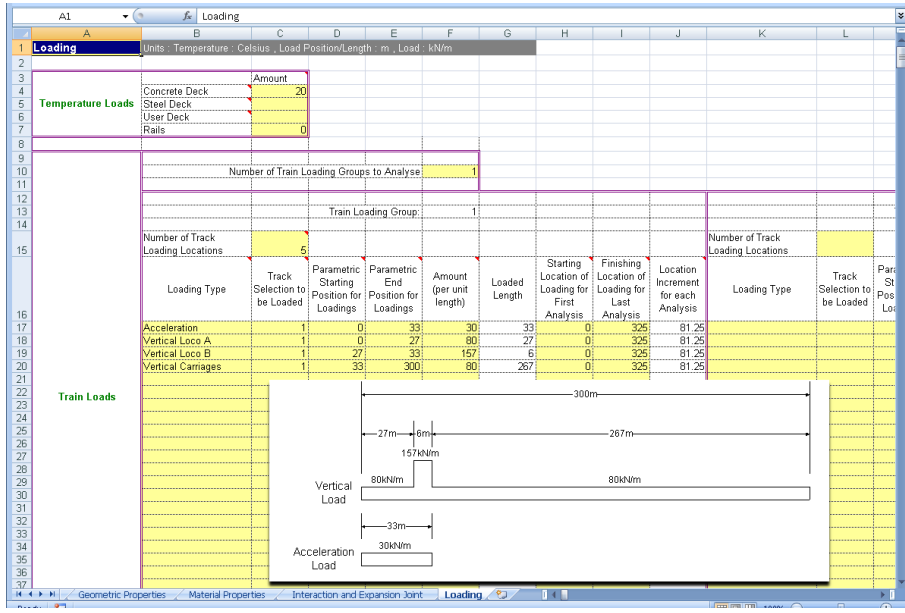


Figure 151: More Complex Train Loading Definition in Spreadsheet

Additional simple examples were illustrated in Figure 44 on page 42 showing the types of loading configurations that can be defined.

EuroCode Load Model SW/0 Loading Configuration

The SW/0 vertical loading pattern is shown in Figure 152 which has two separated UDLs. In addition, Note 1 of Clause 6.5.3 'Actions due to traction and braking' within BS EN 1991-2:2003 states that *'For Load Models SW/0 and SW/2 traction and braking forces need only be applied to those parts of the structure which are loaded according to Figure 6.2 and Table 6.1'* where this figure is equivalent to Figure 152 below. The definition of the SW/0 trainset configuration will therefore be described below according to these conditions.

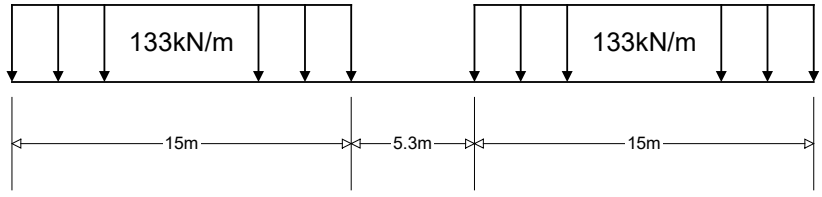


Figure 152: EuroCode Load Model SW/0 Train Vertical Load Pattern

For trainset loading configurations such as EuroCode SW/0 (and also SW/2) it is often best (but not essential) to define the origin of the trainset configuration at the centre of the load pattern.

Considering first the vertical loading, if we take the centre of the load configuration as the origin we can define the UDLs as follows:

Loading Type	Left Coordinate (m)	Right Coordinate (m)	Amount per Unit Length (kN/m)
Vertical SW/0 (Left UDL)	-17.65	-2.65	133.0
Vertical SW/0 (Right UDL)	+2.65	+17.65	133.0

Table 3: SW/0 Parametric Vertical Loading Definition

As stated in BS EN 1991-2:2003 Clause 6.5.3, the braking load from the SW/0 trainset should be defined as a UDL over the parts that are loaded and with a value of 20kN/m (limited to 6000kN total load) in the direction of travel. Assuming that we are defining the SW/0 trainset travelling to the right in the Rail Track Analysis model the loading configuration will be as illustrated in Figure 153 with the loading origin at the centre.

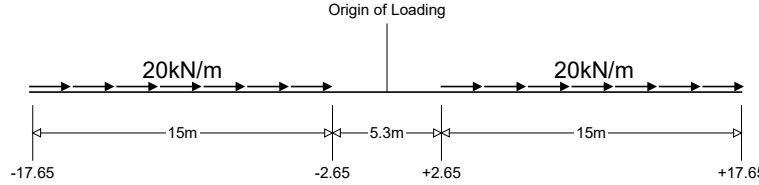


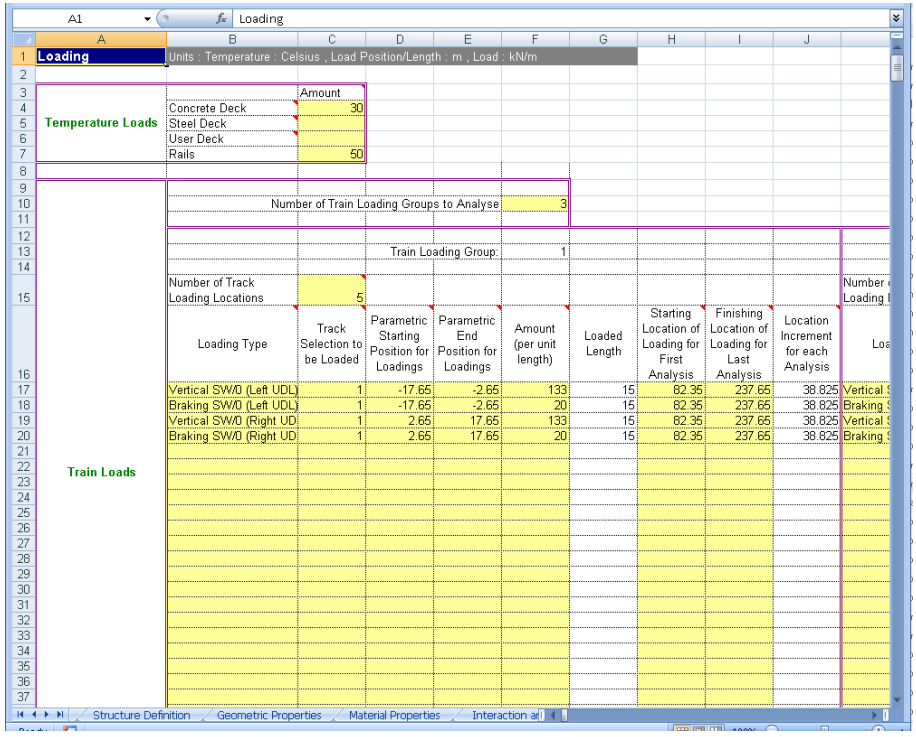
Figure 153: EuroCode SW/0 Train Braking Load Pattern

The total braking load in accordance with the figure above will be only 600kN which is below the limit, therefore the braking load requires no adjustment and can be defined as follows:

Loading Type	Left Coordinate (m)	Right Coordinate (m)	Amount per Unit Length (kN/m)
Braking SW/0 (Left UDL)	-17.65	-2.65	20.0
Braking SW/0 (Right UDL)	+2.65	+17.65	20.0

Table 4: SW/0 Parametric Braking Loading Definition

The overall SW/0 trainset loading definition can therefore be input into the **Loading** worksheet of the XLSX spreadsheet as shown in the following figure and the loading positions defined as required.



1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
3	Temperature Loads		Amount							
4		Concrete Deck	30							
5		Steel Deck								
6		User Deck								
7		Rails	50							
9	Train Loads									
10		Number of Train Loading Groups to Analyse				3				
13				Train Loading Group:		1				
15		Number of Track Loading Locations	5							Number Loading
16		Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis	Loa
17		Vertical SW/0 (Left UDL)	1	-17.65	-2.65	133	15	82.35	237.65	38.825	Vertical
18		Braking SW/0 (Left UDL)	1	-17.65	-2.65	20	15	82.35	237.65	38.825	Braking
19		Vertical SW/0 (Right UD	1	2.65	17.65	133	15	82.35	237.65	38.825	Vertical
20		Braking SW/0 (Right UD	1	2.65	17.65	20	15	82.35	237.65	38.825	Braking

Figure 154: Complete SW/0 Trainset Configuration

Definition of Trainset Configurations With Concentrated Loads

Concentrated loads can be approximated in the Rail Track Analysis tool by defining a UDL which acts only over a small length of track. With the 1m to 2m element sizes typically used for the modelling this approach is sufficiently accurate for the representation of these load types (a contact length that is 5 to 10% of the element length or smaller should be suitable for most applications).

EuroCode Load Model 71 Loading Configuration

The Load Model 71 vertical loading pattern is shown in Figure 155. This trainset load pattern has two UDLs either side and four concentrated loads in the centre. BS EN 1992-2:2003 Clause 6.5.3 ‘Actions due to traction and braking’ describes the

longitudinal braking and traction loads that should be considered with Load Model 71 but these are not considered here. For this example we will only consider the definition of the four 250kN concentrated loads shown in Figure 156 (with the origin of the loading taken at the centre) and how these can be approximated within the Rail Track Analysis tool.

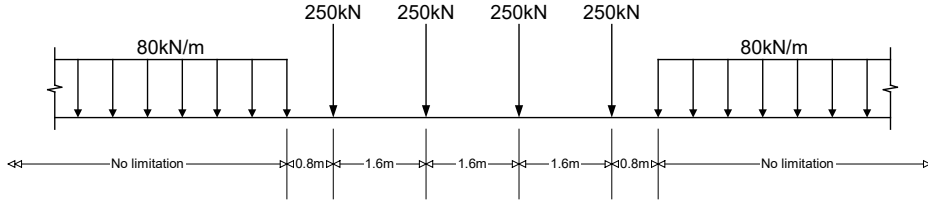


Figure 155: EuroCode Load Model 71 Train Vertical Load Pattern

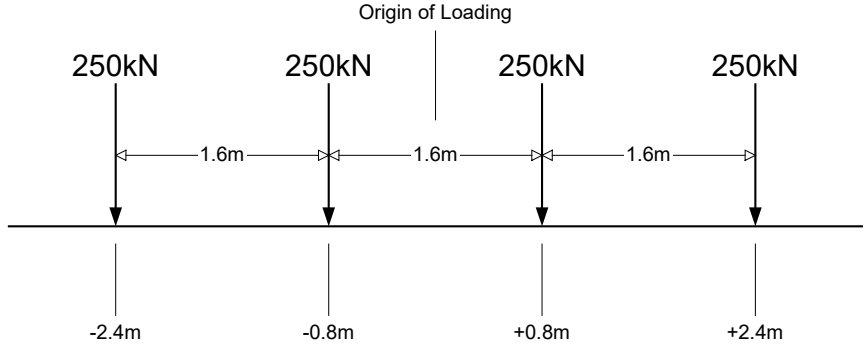


Figure 156: Load Model 71 Concentrated Loads Only

Although the Rail Track Analysis tool only allows the input of trainset loading through UDLs these concentrated loads can be defined by recognising that for the size of elements used in the model the concentrated load is equivalent to a UDL over a very small length. If our structural modelling has element lengths of 1.0 to 2.0m then the setting of the contact length as 1 to 5% of this length (0.01 to 0.05m for 1.0m and 0.02 to 0.1m for 2.0m elements) should be sufficient to define the equivalent UDL to the concentrated load for a good number of structural configurations. Obviously the smaller the contact length the closer the equivalent UDL comes to a concentrated load.

Note. The choice of the contact length to be used to define the equivalent UDL to a concentrated load must be decided by the user based on the configuration of the model

and the element lengths used for the meshing of that model. The illustration here should be viewed as a guide on how to incorporate concentrated loads with a trainset definition and not as the de facto contact length to be used for all circumstances.

Taking the contact length for this example as 0.01m the equivalent UDLs for the modelling will therefore have a value of:

UDL = Conc.Load/ContactLength = 250kN/0.01m = 25000kN/m

The definition of the four concentrated loads of Load Model 71 now becomes the four UDLs indicated in Figure 157.

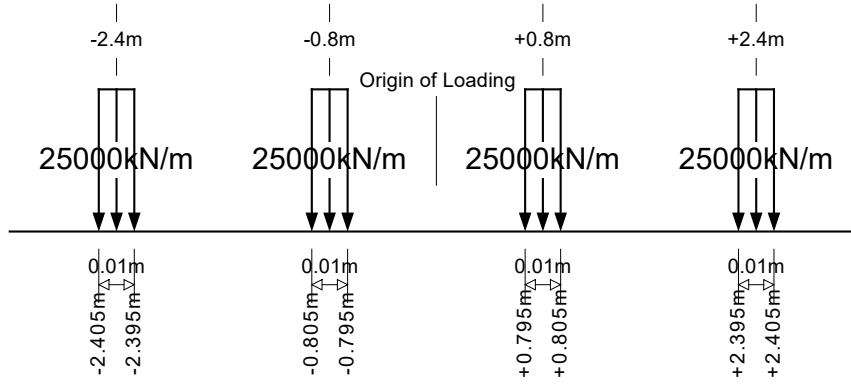
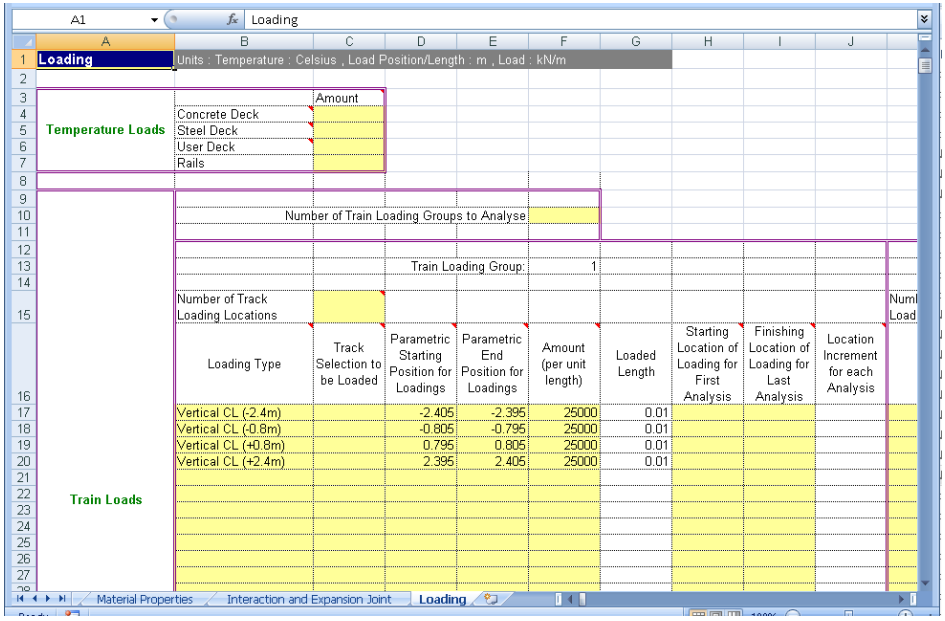


Figure 157: Load Model 71 Equivalent UDLs to Concentrated Loads

This UDL definition of the four concentrated loads of Load Model 71 can now be defined in the **Loading** worksheet of the input XLSX spreadsheet as illustrated in Figure 158.



	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
2										
3			Amount							
4	Temperature Loads	Concrete Deck								
5		Steel Deck								
6		User Deck								
7		Rails								
8										
9	Train Loads									
10		Number of Train Loading Groups to Analyse								
11										
12										
13				Train Loading Group:		1				
14										
15		Number of Track Loading Locations								Numl Load
16		Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis
17		Vertical CL (-2.4m)		-2.405	-2.395	25000	0.01			
18		Vertical CL (-0.8m)		-0.805	-0.795	25000	0.01			
19		Vertical CL (+0.8m)		0.795	0.805	25000	0.01			
20		Vertical CL (+2.4m)		2.395	2.405	25000	0.01			
21										
22										
23										
24										
25										
26										
27										

Material Properties | Interaction and Expansion Joint | Loading

Figure 158: Sample Loading Definition for Load Model 71 Concentrated Loads

EuroCode Load Model HSLM-A Loading Configuration

The previous example illustrating the definition of the four concentrated loads of Load Model 71 can easily be defined manually. The definition of more complex trainset configurations consisting of numerous concentrated loads (and possibly UDLs) cannot be defined easily without the risk of error. For these types of loading configurations it is advisable to define the loading using a more automated approach. This will be demonstrated using the VBScripting capabilities of LUSAS Modeller for Load Type HSLM-A.

The HSLM-A Load Model representing a universal train, Figure 159,consists of multiple concentrated loads with the magnitude and configuration which is dependent upon the universal train type (A1 to A10).

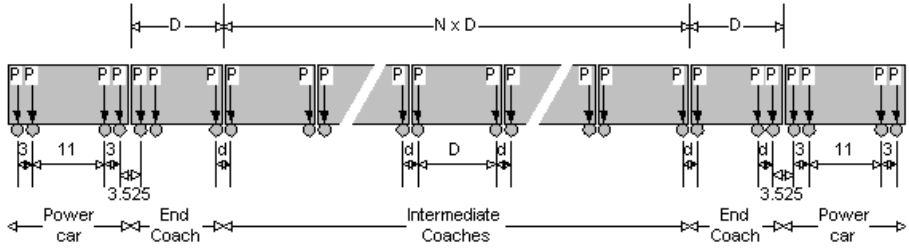
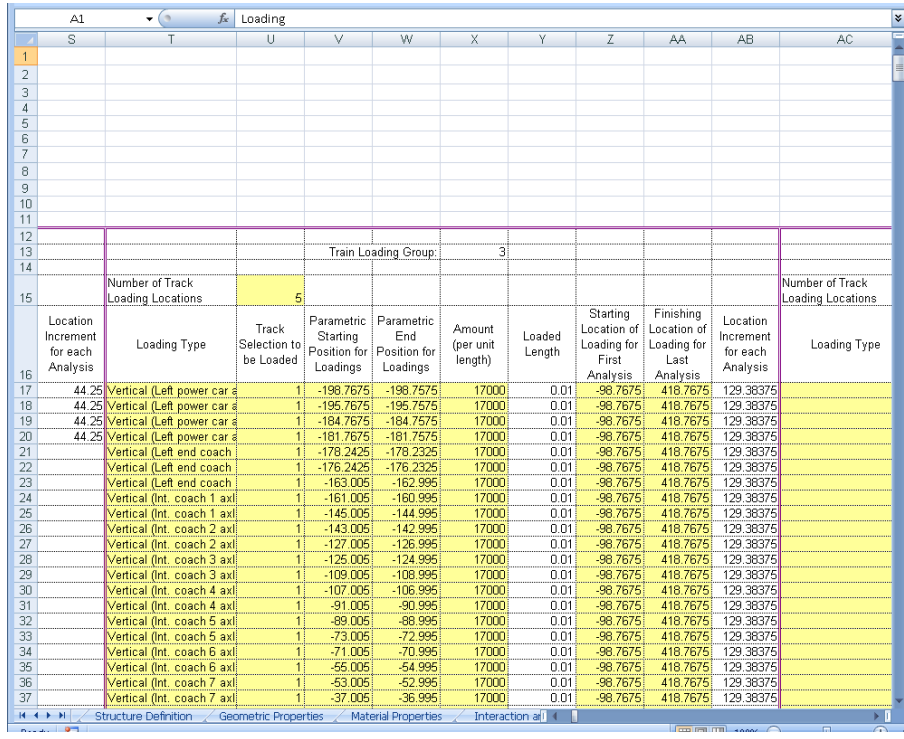


Figure 159: EuroCode Load Model HSLM-A Train Vertical Load Pattern

Figure 160 shows a HSLM-A1 trainset (with braking loads) which has been defined in the **Loading** worksheet using the equivalent UDL approach for the concentrated loads. The input just for the single HSLM-A1 braking trainset requires 51 rows of data input to define all of the axle loads and the braking load.



A1 | Loading

Train Loading Group: 3

Number of Track Loading Locations: 5

Location Increment for each Analysis	Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis	Loading Type
44.25	Vertical (Left power car a	1	-198.7675	-198.7575	17000	0.01	-98.7675	418.7675	129.38375	
44.25	Vertical (Left power car a	1	-195.7675	-195.7575	17000	0.01	-98.7675	418.7675	129.38375	
44.25	Vertical (Left power car a	1	-184.7675	-184.7575	17000	0.01	-98.7675	418.7675	129.38375	
44.25	Vertical (Left power car a	1	-181.7675	-181.7575	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Left end coach	1	-178.2425	-178.2325	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Left end coach	1	-176.2425	-176.2325	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Left end coach	1	-163.005	-162.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 1 axl	1	-161.005	-160.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 1 axl	1	-145.005	-144.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 2 axl	1	-143.005	-142.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 2 axl	1	-127.005	-126.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 3 axl	1	-125.005	-124.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 3 axl	1	-109.005	-108.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 4 axl	1	-107.005	-106.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 4 axl	1	-91.005	-90.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 5 axl	1	-89.005	-88.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 5 axl	1	-73.005	-72.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 6 axl	1	-71.005	-70.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 6 axl	1	-55.005	-54.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 7 axl	1	-53.005	-52.995	17000	0.01	-98.7675	418.7675	129.38375	
	Vertical (Int. coach 7 axl	1	-37.005	-36.995	17000	0.01	-98.7675	418.7675	129.38375	

Structure Definition | Geometric Properties | Material Properties | Interaction at

Figure 160: HSLM-A1 Trainset Defined In Loading Worksheet

It would take some time (and be prone to errors) to manually input all of the equivalent UDLs for the concentrated loads illustrated above for the HSLM-A trainset

configuration. These loads should therefore be defined through an automated method such as another an Excel or compatible XLSX spreadsheet which defines the required data or by using the VBScript capabilities of LUSAS Modeller to parametrically define the trainset loads. Such a VBScript has been written as a demonstration for these HSLM-A trainset configurations.

Note. The VBScript included within this appendix was used to generate the data used in the worked example. The implementation has a number of assumptions which are detailed below.

The HSLM-A trainset definition VBScript is written based on the following assumptions (code is listed at the end of this appendix and is also available from the User Area on the LUSAS website):

- The braking trainset load definition assumes that the HSLM-A train is moving from left to right, the accelerating trainset load definition assumes that the HSLM-A train is moving from right to left (these can be changed by simply reversing the sign of the longitudinal loading values)
- Traction loads are applied as a UDL between the front and back axles of each of the power cars only. If the maximum load of 1000kN stated in Clause 6.5.3 of BS EN 1991-2:2003 is exceeded the loading is factored to ensure only 1000kN is defined
- Braking loads are applied as a UDL over the whole length of the trainset between the first and last axles. If the maximum load of 6000kN stated in Clause 6.5.3 of BS EN 1991-2:2003 is exceeded the loading is factored to ensure only 6000kN is defined
- The point loads are defined as equivalent UDLs using a user defined contact length (default = 0.01m)
- The origin of the HSLM-A trainset is defined at the centre of the trainset configuration when specifying the locations for the trainset across the embankments and structure
- The units are kN and m in accordance with the input requirements of the Rail Track Analysis tool.

The VBScript is run as follows:

1) Run the “Define_HSLM-A_for_RTA.vbs” VBScript

2) Enter the HSLM-A universal train ID (1 to 10) as shown below:

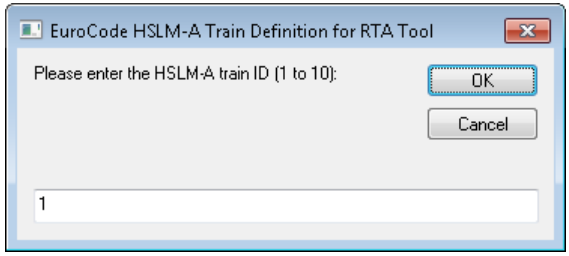


Figure 161: Input of the HSLM-A Train Configuration ID

3) Enter the contact length for the equivalent UDLs to represent the axle concentrated loads (in m):

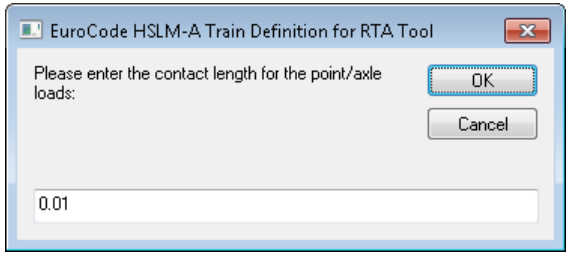


Figure 162: Input of the Contact Length for the UDLs Equivalent to the Concentrated Loads

4) Enter the filename for the generated TAB delimited trainset loading definition (with the *.prn extension):

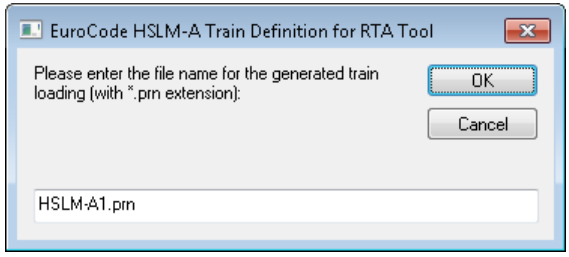


Figure 163: Input of the Filename for the Output of the HSLM-A Train Configuration

On clicking OK the VBScript will now process the HSLM-A loading and generate a TAB delimited text file defining all of the loading for a braking train and an accelerating train as indicated in Figure 164 and Figure 165 (for a HSLM-A1 trainset with 0.01m contact length for the equivalent UDLs).

F:\V20Manual\HSLM-A1.prm - Notepad++

```
This TAB delimited file defines the HSLM-A1 train definitions for a braking train travelling in the
positive (to the right) direction in the RTA model
and an accelerating train travelling in the negative (to the left) direction in the RTA model.

The vertical and braking loads for the braking train are defined first, followed by the vertical and
traction loads for the accelerating train.
After importing into Microsoft Excel the appropriate loads for the analysis being considered can be
copied and pasted into the input spreadsheet.

Contact length for point/axle loads = 0.01
Origin for loading is the middle of the trainset.



BRAKING HSLM-A1 TRAIN
Vertical (Left power car axle 1)    TrackID -198.7675   -198.7575   17000
Vertical (Left power car axle 2)    TrackID -195.7675   -195.7575   17000
Vertical (Left power car axle 3)    TrackID -184.7675   -184.7575   17000
Vertical (Left power car axle 4)    TrackID -181.7675   -181.7575   17000
Vertical (Left end coach axle 1)    TrackID -178.2425   -178.2325   17000
Vertical (Left end coach axle 2)    TrackID -176.2425   -176.2325   17000
Vertical (Left end coach axle 3)    TrackID -163.005    -162.995    17000
Vertical (Int. coach 1 axle 1)  TrackID -161.005    -160.995    17000
Vertical (Int. coach 1 axle 2)  TrackID -145.005    -144.995    17000
Vertical (Int. coach 2 axle 1)  TrackID -143.005    -142.995    17000
Vertical (Int. coach 2 axle 2)  TrackID -127.005    -126.995    17000
Vertical (Int. coach 3 axle 1)  TrackID -125.005    -124.995    17000
Vertical (Int. coach 3 axle 2)  TrackID -109.005    -108.995    17000
```

Normal text file | length : 7615 lines : 126 | Ln : 1 Col : 1 Sel : 0 | 0 | Dos\Windows | ANSI as UTF-8 | INS

F:\V20Manual\HSLM-A1.prm - Notepad++

```
Vertical (Int. coach 18 axle 2) TrackID 160.995 161.005 17000
Vertical (Right end coach axle 1)   TrackID 162.995 163.005 17000
Vertical (Right end coach axle 2)   TrackID 176.2325    176.2425    17000
Vertical (Right end coach axle 3)   TrackID 178.2325    178.2425    17000
Vertical (Right power car axle 1)   TrackID 181.7575    181.7675    17000
Vertical (Right power car axle 2)   TrackID 184.7575    184.7675    17000
Vertical (Right power car axle 3)   TrackID 195.7575    195.7675    17000
Vertical (Right power car axle 4)   TrackID 198.7575    198.7675    17000
Braking TrackID -198.7625   198.7625    15.093390352808

Braking load UDL has been factored as total load over the 397.525 m trainset is 7950.5 kN (> 6000 kN
limit for default UDL)
Braking load UDL reduced to = 15.093390352808 kN/m



ACCELERATING HSLM-A1 TRAIN
Vertical (Left power car axle 1)    TrackID -198.7675   -198.7575   17000
Vertical (Left power car axle 2)    TrackID -195.7675   -195.7575   17000
Vertical (Left power car axle 3)    TrackID -184.7675   -184.7575   17000
Vertical (Left power car axle 4)    TrackID -181.7675   -181.7575   17000
Vertical (Left end coach axle 1)    TrackID -178.2425   -178.2325   17000
Vertical (Left end coach axle 2)    TrackID -176.2425   -176.2325   17000
Vertical (Left end coach axle 3)    TrackID -163.005    -162.995    17000
Vertical (Int. coach 1 axle 1)  TrackID -161.005    -160.995    17000
Vertical (Int. coach 1 axle 2)  TrackID -145.005    -144.995    17000
Vertical (Int. coach 2 axle 1)  TrackID -143.005    -142.995    17000
Vertical (Int. coach 2 axle 2)  TrackID -127.005    -126.995    17000
```

Normal text file | length : 7615 lines : 126 | Ln : 1 Col : 1 Sel : 0 | 0 | Dos\Windows | ANSI as UTF-8 | INS

Figure 164: Output for a HSLM-A1 Trainset Configuration (1 of 2)

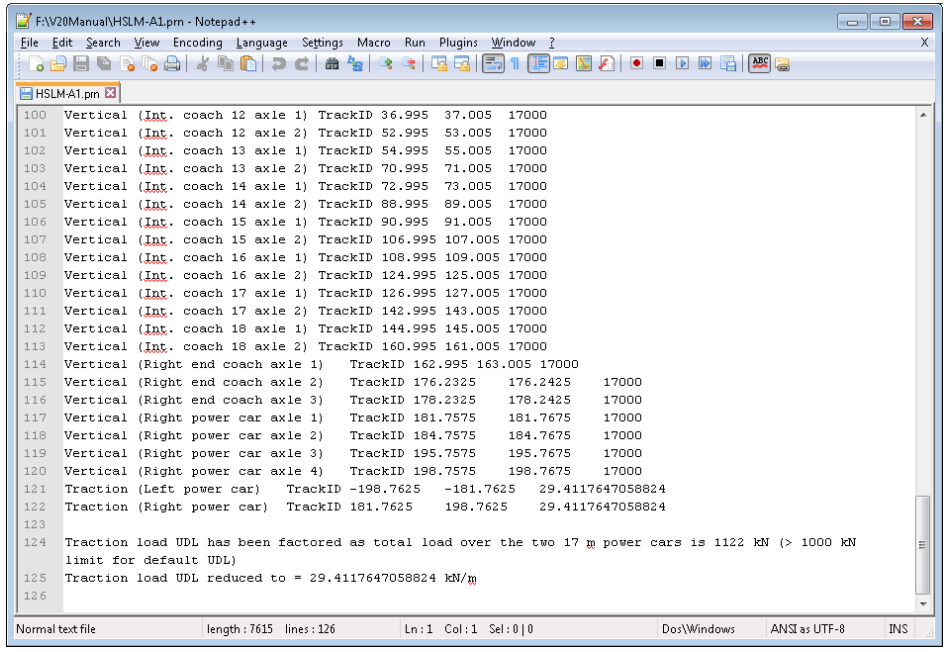


Figure 165: Output for a HSLM-A1 Trainset Configurations (2 of 2)

To use this trainset loading within the **Loading** worksheet of the input XLSX spreadsheet you should initially have the input spreadsheet which has been edited to represent the structure loaded. To transfer this data defined by the VBScript into the worksheet:

1) Import the TAB delimited file generated above into Microsoft Excel (or an equivalent application).

2) Highlight the braking or accelerating/traction loading to be copied (only the rows defining the vertical and braking/traction loading) and choose Copy – below we are copying the braking trainset

A13 | Vertical (Left power car axle 1)

	A	B	C	D	E
1	This TAB delimited file defines the HSLM-A1 train definitions for a braking train travelling in the positive (to the right) direction in the RTA model				
2	and an accelerating train travelling in the negative (to the left) direction in the RTA model.				
3					
4	The vertical and braking loads for the braking train are defined first, followed by the vertical and traction loads for the accelerating train.				
5	After importing into Microsoft Excel the appropriate loads for the analysis being considered can be copied and pasted into the input spreadsheet.				
6					
7	Contact length for point/axle loads = 0.01				
8	Origin for loading is the middle of the trainset.				
9					
10					
11					
12	BRAKING HSLM-A1 TRAIN				
13	Vertical (Left power car axle 1)	TrackID	-198.7675	-198.7575	17000
14	Vertical (Left power car axle 2)	TrackID	-195.7675	-195.7575	17000
15	Vertical (Left power car axle 3)	TrackID	-184.7675	-184.7575	17000
16	Vertical (Left power car axle 4)	TrackID	-181.7675	-181.7575	17000
17	Vertical (Left end coach axle 1)	TrackID	-178.2425	-178.2325	17000
18	Vertical (Left end coach axle 2)	TrackID	-176.2425	-176.2325	17000
19	Vertical (Left end coach axle 3)	TrackID	-163.005	-162.995	17000
20	Vertical (Int. coach 1 axle 1)	TrackID	-161.005	-160.995	17000
21	Vertical (Int. coach 1 axle 2)	TrackID	-145.005	-144.995	17000
22	Vertical (Int. coach 2 axle 1)	TrackID	-143.005	-142.995	17000
23	Vertical (Int. coach 2 axle 2)	TrackID	-127.005	-126.995	17000
24	Vertical (Int. coach 3 axle 1)	TrackID	-125.005	-124.995	17000
25	Vertical (Int. coach 3 axle 2)	TrackID	-109.005	-108.995	17000
26	Vertical (Int. coach 4 axle 1)	TrackID	-107.005	-106.995	17000
27	Vertical (Int. coach 4 axle 2)	TrackID	-91.005	-90.995	17000
28	Vertical (Int. coach 5 axle 1)	TrackID	-89.005	-88.995	17000
29	Vertical (Int. coach 5 axle 2)	TrackID	-73.005	-72.995	17000
30	Vertical (Int. coach 6 axle 1)	TrackID	-71.005	-70.995	17000
31	Vertical (Int. coach 6 axle 2)	TrackID	-55.005	-54.995	17000
32	Vertical (Int. coach 7 axle 1)	TrackID	-53.005	-52.995	17000
33	Vertical (Int. coach 7 axle 2)	TrackID	-37.005	-36.995	17000
34	Vertical (Int. coach 8 axle 1)	TrackID	-35.005	-34.995	17000
35	Vertical (Int. coach 8 axle 2)	TrackID	-19.005	-18.995	17000
36	Vertical (Int. coach 9 axle 1)	TrackID	-17.005	-16.995	17000

HSLM-A1

A13 | Vertical (Left power car axle 1)

	A	B	C	D	E
37	Vertical (Int. coach 9 axle 2)	TrackID	-1.005	-0.995	17000
38	Vertical (Int. coach 10 axle 1)	TrackID	0.995	1.005	17000
39	Vertical (Int. coach 10 axle 2)	TrackID	16.995	17.005	17000
40	Vertical (Int. coach 11 axle 1)	TrackID	18.995	19.005	17000
41	Vertical (Int. coach 11 axle 2)	TrackID	34.995	35.005	17000
42	Vertical (Int. coach 12 axle 1)	TrackID	36.995	37.005	17000
43	Vertical (Int. coach 12 axle 2)	TrackID	52.995	53.005	17000
44	Vertical (Int. coach 13 axle 1)	TrackID	54.995	55.005	17000
45	Vertical (Int. coach 13 axle 2)	TrackID	70.995	71.005	17000
46	Vertical (Int. coach 14 axle 1)	TrackID	72.995	73.005	17000
47	Vertical (Int. coach 14 axle 2)	TrackID	88.995	89.005	17000
48	Vertical (Int. coach 15 axle 1)	TrackID	90.995	91.005	17000
49	Vertical (Int. coach 15 axle 2)	TrackID	106.995	107.005	17000
50	Vertical (Int. coach 16 axle 1)	TrackID	108.995	109.005	17000
51	Vertical (Int. coach 16 axle 2)	TrackID	124.995	125.005	17000
52	Vertical (Int. coach 17 axle 1)	TrackID	126.995	127.005	17000
53	Vertical (Int. coach 17 axle 2)	TrackID	142.995	143.005	17000
54	Vertical (Int. coach 18 axle 1)	TrackID	144.995	145.005	17000
55	Vertical (Int. coach 18 axle 2)	TrackID	160.995	161.005	17000
56	Vertical (Right end coach axle 1)	TrackID	162.995	163.005	17000
57	Vertical (Right end coach axle 2)	TrackID	176.2325	176.2425	17000
58	Vertical (Right end coach axle 3)	TrackID	178.2325	178.2425	17000
59	Vertical (Right power car axle 1)	TrackID	181.7575	181.7675	17000
60	Vertical (Right power car axle 2)	TrackID	184.7575	184.7675	17000
61	Vertical (Right power car axle 3)	TrackID	195.7575	195.7675	17000
62	Vertical (Right power car axle 4)	TrackID	198.7575	198.7675	17000
63	Braking	TrackID	-198.7625	198.7625	15.09339035
64					
65	Braking load UDL has been factored as total load over the 397.525 m trainset is 7950.5 kN (> 6000 kN limit for default UDL)				
66	Braking load UDL reduced to = 15.093390352808 kN/m				
67					
68					
69					
70	ACCELERATING HSLM-A1 TRAIN				
71	Vertical (Left power car axle 1)	TrackID	-198.7675	-198.7575	17000
72	Vertical (Left power car axle 2)	TrackID	-195.7675	-195.7575	17000

HSLM-A1

Figure 166: Select the Braking (or Acceleration) Loading to be Copied

3) Select the first **Loading Type** cell of the Train Loading Group which the HSLM-A1 trainset is to be placed in and choose **Paste Values** to only paste the data and not any formatting.

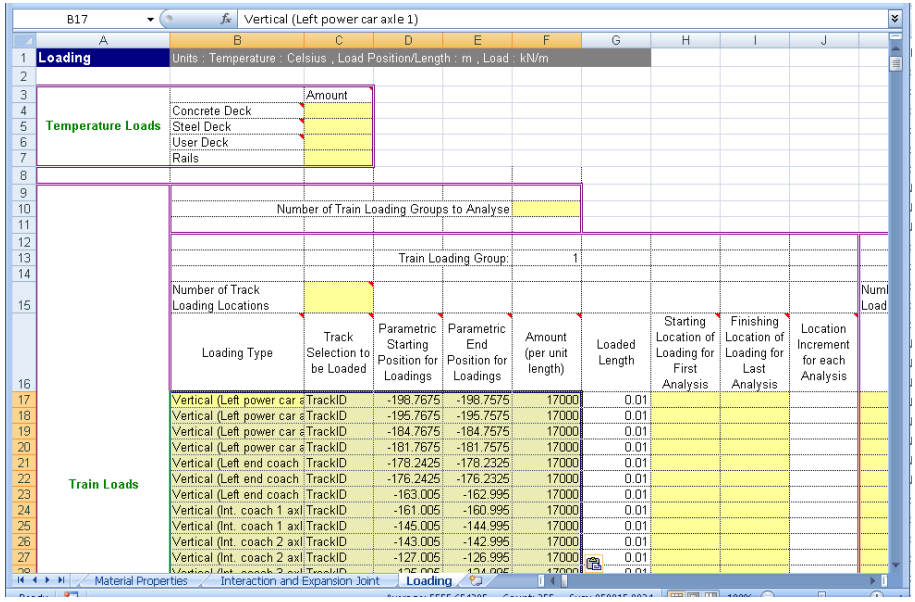


Figure 167: Paste the HSLM-A1 Trainset Definition into the Loading Worksheet

4) Change the **TrackID** in the **Track Selection to be Loaded** column to represent the track that the HSLM-A1 trainset is to be passed along

5) Define the movement of the HSLM-A1 trainset loading across the structure (noting that the origin is at the centre of the loading pattern)

6) If any further trainsets are to be applied another track within the same Train Loading Group then define these below the loading that has just been defined.

Note. The principles applied here for the definition of the HSLM-A trainset loads for the Rail Track Analysis tool can be applied to other trainset configurations that include concentrated loads or can be defined in a parametric way. A single VBScript could be written which defined a range of trainsets by having different subroutines to just the writeHSLMATrain() subroutine or having a single common definition processing subroutine which tabulates the loading using internally defined arrays holding the loading defined by multiple trainset creation subroutines. This is, however, beyond the scope of this demonstration example.

VBScript Source Code for "Define_HSLM-A_for_RTA.vbs"

The following VBScript source code performs the definition of the HSLM-A TAB delimited files containing the loading configuration in accordance with the following assumptions:

- The braking trainset load definition assumes that the HSLM-A train is moving from left to right, the accelerating trainset load definition assumes that the HSLM-A train is moving from right to left (these can be changed by simply reversing the sign of the longitudinal loading values)
- Traction loads are applied as a UDL between the front and back axles of each of the power cars only. If the maximum load of 1000kN stated in Clause 6.5.3 of BS EN 1991-2:2003 is exceeded the loading is factored to ensure only 1000kN is defined
- Braking loads are applied as a UDL over the whole length of the trainset between the first and last axles. If the maximum load of 6000kN stated in Clause 6.5.3 of BS EN 1991-2:2003 is exceeded the loading is factored to ensure only 6000kN is defined
- The point loads are defined as equivalent UDLs using a user defined contact length (default = 0.01m)
- The origin of the HSLM-A trainset is defined at the centre of the trainset configuration when specifying the locations for the trainset across the embankments and structure
- The units are kN and m in accordance with the input requirements of the Rail Track Analysis tool.

This source code is also available from the LUSAS User Area on the website.

```
$ENGINE=VBSCRIPT
'
' Simple VBScript to define the HSLM-A EuroCode train loads for the RTA tool
' using a user-defined contact length for each point load / axle. The braking
' train is travelling in the positive (to right in RTA model) direction and
' the accelerating train is travelling in the negative (to the left in the RTA
' model) direction. To change the directions the signs of the braking and
' traction loads just need to be reversed.
'
' This defines the loads in a TAB delimited file which can be imported into
' a spreadsheet editor and the data then copied and pasted into the Loading
' worksheet of the RTA input spreadsheet.
'
' NOTE: This VBScript is provided AS-IS based on the assumption that the
'       traction loads are applied as a UDL over the length between the first
'       and last axles of the powercars and the braking loads are applied as a
'       UDL over the entire length of the trainset axles (and factored to ensure
'       that the BrakingLoad <= 6000 kN condition is satisfied).
'
'       Vertical point / axle loads for the HSLM-A trainsets are applied as a
'       UDL over the contact length defined by the user and it is up to the user
'       to ensure that this contact length is appropriate. The magnitude of the
```

```
'       UDL is calculated as follows: UDL = PointForce / ContactLength
'
'       The origin of the HSLM-A loading is the middle of the trainset.
'
'       Units assumed are kN and m in accordance with the RTA tool.
'
'       This VBScript is not supported by LUSAS and it is up to the user to
'       decide that the assumptions above are correct.
'
' Dr. G.M.Paice, Project Leader, LUSAS, 14th February 2019
'==============================================================================
' HSLM-A id, 1 to 10
Dim HSLMA_ID
' Contact length for a point load / axle
Dim contactLength
' FileSystemObject
Dim fso
Set fso = CreateObject("Scripting.FileSystemObject")
' Output files
Dim outFile
Dim outFileName
' Dialog text
Const dialogTitle = "EuroCode HSLM-A Train Definition for RTA Tool"
Dim dialogInputText
' Current working directory (folder)
Dim CWD
CWD = getCWD() & "\"
' Flag for continuing
Dim contDefn
contDefn = True
'------------------------------------------------------------------------------
' Get the HSLM-A train ID
errTxt = "The HSLM-A train ID must be an integer between 1 and 10"
dialogInputText = Trim(InputBox("Please enter the HSLM-A train ID (1 to 10):",
dialogTitle, "1"))
If Len(dialogInputText) > 0 Then
    If isNumeric(dialogInputText) Then
        HSLMA_ID = CLng(dialogInputText)
        If HSLMA_ID < 1 Or HSLMA_ID > 10 Then contDefn = False
    Else
        contDefn = False
    End If
Else
    contDefn = False
End If
If Not contDefn Then
    Call MsgBox(errTxt, vbInformation + vbOKOnly, dialogTitle)
Else
    ' Get the contact length for the point/axle loads
    errTxt = "The contact length for the point/axle loads should be a positive
number and small"
    dialogInputText = Trim(InputBox("Please enter the contact length for the
point/axle loads:", dialogTitle, "0.01"))
    If Len(dialogInputText) > 0 Then
        If isNumeric(dialogInputText) Then
            contactLength = CDbl(dialogInputText)
            If Not (contactLength > 0.0) Then contDefn = False
        Else
            contDefn = False
        End If
    Else
        contDefn = False
    End If
    If Not contDefn Then
        Call MsgBox(errTxt, vbInformation + vbOKOnly, dialogTitle)
    Else
```

```
        ' Get the output file (*.prn to match the spreadsheet input)
        errTxt = "The output file should be a valid file with the *.prn extension
for import into the spreadsheet"
        dialogInputText = Trim(InputBox("Please enter the file name for the
generated train loading (with *.prn extension):", dialogTitle, "HSLM-A" &
CStr(HSLMA_ID) & ".prn"))
        If Len(dialogInputText) > 0 Then
            posPrn = InStrRev(dialogInputText, ".prn", -1, 1)
            If posPrn <> (Len(dialogInputText) - 3) Then
                contDefn = False
            Else
                outFileName = dialogInputText
            End If
        Else
            contDefn = False
        End If
        If Not contDefn Then
            Call MsgBox(errTxt, vbInformation + vbOKOnly, dialogTitle)
        Else
            ' Open the output file
            Set outFile = fso.CreateTextFile(CWD & outFileName, True)
            ' Define the HSLM-A train within the file
            Call writeHSLMATrain(outFile, HSLMA_ID, contactLength)
            ' Close the output file
            Call outFile.Close()
            Set outFile = Nothing
        End If
    End If
End If

Sub writeHSLMATrain(fileObj, trainID, contLen)
'*Purpose
' Defines and writes the HSLM-A train data to the file using TAB delimited
' format.
'*Externals
' fileObj -File object
' trainID -HSLM-A train ID (1-10)
' contLen -Contact length to be used for defining the point/axle loads
'*History
' Name Date    Comment
' GP   14Feb19 Initial coding
'*Internals
' axleCoord   -Coordinates for the axles defining the HSLM-A trainset
' axleDesc    -Axle description
' bogieAxle   -Bogie axle spacing for each HSLM-A trainset
' brakLoadLen -Braking loaded length (overall axles for the trainset)
' brakTotLoad -Braking total load
' brakUDL     -Braking load UDL after factoring for the trainset length
' coachLen    -Coach lengths for each HSLM-A trainset
' curAxleID   -Current axle ID being defined
' endCoachSpc -Spacing between the 2nd and 3rd end coach axles
' equivVertUDL-Equivalent vertical UDL for the point / axle load over the contact
length
' nCoaches    -Number of intermediate coaches for each HSLM-A trainset
' pointForce  -Point / axle force for each HSLM-A trainset
' powerCarBog -Spacing between the axles of the power car bogies
' powerCarSpc -Spacing between the 2nd and 3rd power car axles
' powerEndSpc -Spacing between the last power car and the 1st end coach axle
' totNumAxles -Total number of axles for defining the HSLM-A trainset
' tracBack    -Coordinate of the back of the traction loads for the power car
' tracFront   -Coordinate of the front of the traction loads for the power car
' tracLenPwr  -Length of the traction load for each power car
' tracTotLoad -Traction total load
' tracUDL     -Traction load UDL after any factoring for power car length
'-----------------------------------------------------------------------------
    Dim axleCoord
```

```
    Dim axleDesc
    Dim brakLoadLen
    Dim brakUDL
    brakUDL = 20.0
    Dim curAxleID
    Dim endCoachSpc
    Dim equivVertUDL
    Const powerCarBog = 3.0
    Const powerCarSpc = 11.0
    Const powerEndSpc = 3.525
    Dim totNumAxles
    Dim tracBack
    Dim tracFront
    Const tracLenPwr = 17.0
    Dim tracTotLoad
    Dim tracUDL
    tracUDL = 33.0
' NOTE: The N number of intermediate coaches can be odd or even, therefore for
'       simplicity we will initially define the point/axle loads with the origin
'       at the left extent of the trainset before shifting them to be centred.
'
' In the zero-based arrays below, the index is the HSLM-A train ID minus 1
'
' Number of intermediate coaches, N
    Dim nCoaches(9)
    nCoaches(0) = 18
    nCoaches(1) = 17
    nCoaches(2) = 16
    nCoaches(3) = 15
    nCoaches(4) = 14
    nCoaches(5) = 13
    nCoaches(6) = 13
    nCoaches(7) = 12
    nCoaches(8) = 11
    nCoaches(9) = 11
' Coach length, D (m)
    Dim coachLen(9)
    coachLen(0) = 18.0
    coachLen(1) = 19.0
    coachLen(2) = 20.0
    coachLen(3) = 21.0
    coachLen(4) = 22.0
    coachLen(5) = 23.0
    coachLen(6) = 24.0
    coachLen(7) = 25.0
    coachLen(8) = 26.0
    coachLen(9) = 27.0
' Bogie axle spacing, d (m)
    Dim bogieAxle(9)
    bogieAxle(0) = 2.0
    bogieAxle(1) = 3.5
    bogieAxle(2) = 2.0
    bogieAxle(3) = 3.0
    bogieAxle(4) = 2.0
    bogieAxle(5) = 2.0
    bogieAxle(6) = 2.0
    bogieAxle(7) = 2.5
    bogieAxle(8) = 2.0
    bogieAxle(9) = 2.0
' Point force, P (kN)
    Dim pointForce(9)
    pointForce(0) = 170.0
    pointForce(1) = 200.0
    pointForce(2) = 180.0
    pointForce(3) = 190.0
    pointForce(4) = 170.0
```

```
    pointForce(5) = 180.0
    pointForce(6) = 190.0
    pointForce(7) = 190.0
    pointForce(8) = 210.0
    pointForce(9) = 210.0
' Calculate the equivalent UDL for spreading the point/axle load over the contact
length
    equivVertUDL = pointForce(trainID - 1) / contLen
' Determine the number of axles that are required for defining the whole trainset.
' Trainset has 2 powercars + 2 end coaches + N * intermediate coaches
' Power cars have 4 axles each, end coaches have 3 axles each, intermediate coaches
have 2 axles each
    totNumAxles = 2 * (4 + 3) + 2 * nCoaches(trainID - 1)
' Dimension the storage for the axles coordinates and descriptions
    ReDim axleCoord(totNumAxles - 1)
    ReDim axleDesc(totNumAxles - 1)
' Define the left powercar
    axleCoord(0) = 0.0
    axleDesc(0)  = "Left power car axle 1"
    axleCoord(1) = powerCarBog
    axleDesc(1)  = "Left power car axle 2"
    axleCoord(2) = axleCoord(1) + powerCarSpc
    axleDesc(2)  = "Left power car axle 3"
    axleCoord(3) = axleCoord(2) + powerCarBog
    axleDesc(3)  = "Left power car axle 4"
' Define the left end coach
    axleCoord(4) = axleCoord(3) + powerEndSpc
    axleDesc(4)  = "Left end coach axle 1"
    axleCoord(5) = axleCoord(4) + bogieAxle(trainID - 1)
    axleDesc(5)  = "Left end coach axle 2"
    axleCoord(6) = (axleCoord(3) + axleCoord(4)) / 2.0 + coachLen(trainID - 1) -
bogieAxle(trainID - 1) / 2.0
    axleDesc(6)  = "Left end coach axle 3"
    endCoachSpc = axleCoord(6) - axleCoord(5)
' Define the N intermediate coaches
    curAxleID = 7
    For icoach = 1 To nCoaches(trainID - 1)
        curAxleID = curAxleID + 1
        axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + bogieAxle(trainID -
1)
        axleDesc(curAxleID - 1)  = "Int. coach " & CStr(icoach) & " axle 1"
        curAxleID = curAxleID + 1
        axleCoord(curAxleID - 1) = axleCoord(curAxleID - 3) + coachLen(trainID - 1)
        axleDesc(curAxleID - 1)  = "Int. coach " & CStr(icoach) & " axle 2"
    Next
' Define the right end coach
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + bogieAxle(trainID - 1)
    axleDesc(curAxleID - 1)  = "Right end coach axle 1"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + endCoachSpc
    axleDesc(curAxleID - 1)  = "Right end coach axle 2"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + bogieAxle(trainID - 1)
    axleDesc(curAxleID - 1)  = "Right end coach axle 3"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerEndSpc
    axleDesc(curAxleID - 1)  = "Right power car axle 1"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerCarBog
    axleDesc(curAxleID - 1)  = "Right power car axle 2"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerCarSpc
    axleDesc(curAxleID - 1)  = "Right power car axle 3"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerCarBog
```

```
    axleDesc(curAxleID - 1)  = "Right power car axle 4"
' Determine the total length for the braking load and echo the length
    brakLoadLen = axleCoord(totNumAxles - 1)
    Call getTextWindow.writeLine("Braking loads will be defined over a total length
of " & CStr(brakLoadLen) & " (and factored to ensure limit is observed)")
' Determine if the braking load needs to be scaled (most likely)
    brakTotLoad = brakUDL * brakLoadLen
    If brakTotLoad > 6000.0 Then
        brakUDL = brakUDL * 6000.0 / brakTotLoad
        Call getTextWindow.writeLine("Braking load UDL has been factored as " &
CStr(brakTotLoad) & " > 6000 kN for default UDL")
    End If
    Call getTextWindow.writeLine("Braking load UDL = " & CStr(brakUDL) & " kN/m")
' Shift the axles
    Dim shiftAxles
    shiftAxles = axleCoord(totNumAxles - 1) / 2.0
    For iaxle = 0 To totNumAxles - 1
        axleCoord(iaxle) = axleCoord(iaxle) - shiftAxles
    Next
' Determine the coordinates for the power car traction loads and report the lengths
    tracFront = axleCoord(totNumAxles - 1)
    tracBack  = axleCoord(totNumAxles - 4)
    Call getTextWindow.writeLine("Traction loads will be defined for each power car
length of " & CStr(tracLenPwr) & " for both leading and trailing power cars")
' Determine if the traction load for the two power cars needs to be scaled
    tracTotLoad = 2.0 * tracUDL * tracLenPwr
    If tracTotLoad > 1000.0 Then
        tracUDL = tracUDL * 1000.0 / tracTotLoad
        Call getTextWindow.writeLine("Traction load UDL has been factored as " &
CStr(tracTotLoad) & " > 1000 kN for default UDL")
    End If
    Call getTextWindow.writeLine("Traction load UDL = " & CStr(tracUDL) & " kN/m")
' Let us now write out the information to the file
    Call fileObj.writeLine("This TAB delimited file defines the HSLM-A" &
CStr(trainID) & " train definitions for a braking train travelling in the positive
(to the right) direction in the RTA model")
    Call fileObj.writeLine("and an accelerating train travelling in the negative
(to the left) direction in the RTA model.")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("The vertical and braking loads for the braking train
are defined first, followed by the vertical and traction loads for the accelerating
train.")
    Call fileObj.writeLine("After importing into the spreadsheet the appropriate
loads for the analysis being considered can be copied and pasted into the input
spreadsheet.")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("Contact length for point/axle loads = " &
CStr(contLen))
    Call fileObj.writeLine("Origin for loading is the middle of the trainset.")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("BRAKING HSLM-A" & CStr(trainID) & " TRAIN")
    For iaxle = 0 To totNumAxles - 1
        Call fileObj.writeLine("Vertical (" & axleDesc(iaxle) & ")" & Chr(9) &
"TrackID" & Chr(9) & CStr(axleCoord(iaxle) - contLen / 2.0) & Chr(9) &
CStr(axleCoord(iaxle) + contLen / 2.0) & Chr(9) & CStr(equivVertUDL))
    Next
    Call fileObj.writeLine("Braking" & Chr(9) & "TrackID" & Chr(9) &
CStr(axleCoord(0)) & Chr(9) & CStr(axleCoord(totNumAxles - 1)) & Chr(9) &
CStr(brakUDL))
    Call fileObj.writeLine("")
    If brakTotLoad > 6000.0 Then Call fileObj.writeLine("Braking load UDL has been
factored as total load over the " & CStr(brakLoadLen) & " m trainset is " &
CStr(brakTotLoad) & " kN (> 6000 kN limit for default UDL)")
```

```
    Call fileObj.writeLine("Braking load UDL reduced to = " & CStr(brakUDL) & "
kN/m")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("ACCELERATING HSLM-A" & CStr(trainID) & " TRAIN")
    For iaxle = 0 To totNumAxles - 1
        Call fileObj.writeLine("Vertical (" & axleDesc(iaxle) & ")" & Chr(9) &
"TrackID" & Chr(9) & CStr(axleCoord(iaxle) - contLen / 2.0) & Chr(9) &
CStr(axleCoord(iaxle) + contLen / 2.0) & Chr(9) & CStr(equivVertUDL))
    Next
    Call fileObj.writeLine("Traction (Left power car)" & Chr(9) & "TrackID" &
Chr(9) & CStr(-tracFront) & Chr(9) & CStr(-tracBack) & Chr(9) & CStr(tracUDL))
    Call fileObj.writeLine("Traction (Right power car)" & Chr(9) & "TrackID" &
Chr(9) & CStr(tracBack) & Chr(9) & CStr(tracFront) & Chr(9) & CStr(tracUDL))
    Call fileObj.writeLine("")
    If tracTotLoad > 1000.0 Then Call fileObj.writeLine("Traction load UDL has been
factored as total load over the two " & CStr(tracLenPwr) & " m power cars is " &
CStr(tracTotLoad) & " kN (> 1000 kN limit for default UDL)")
    Call fileObj.writeLine("Traction load UDL reduced to = " & CStr(tracUDL) & "
kN/m")
End Sub
```

References

B1 BS EN 1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges

Appendix C: Calculation of Deck Displacements at Alternative Locations to Top of Slab / Deck

Introduction

The finite element modelling of the deck is carried out with the elements / nodal line along the top of the slab / at the location where the track-structure-interaction occurs to ensure that this track-structure-interaction behaviour is modelled correctly in the analyses. The behaviour of the deck itself is modelled through eccentricity in the beam elements with rigid offsets at the support locations to ensure that the support conditions / bearings are at the correct elevations and the overall bending behaviour of the decks is accurate.

As a result of the requirements of the track-structure-interaction the deck displacement results in the post-processing are output at the top of the slab / at the location of the track-structure-interaction. It is however possible to obtain the displacements at other locations such as the neutral axis and the bottom of the slab / section through basic calculation methods which will be highlighted below.

Calculation of Displacements / Rotation at Alternative Locations

The calculations require the following assumptions:

- Plane sections remain plane under bending
- Rotations are small

Considering the behaviour at the end of a deck as illustrated in Figure 168, from the post-processor we have the displacements and rotation (dx_T, dy_T, θz_T) at the top of slab/deck and we will also have its coordinates (x_T, y_T) . The only additional piece of information we need to calculate the alternative displacements and rotation is the location within the section that the calculation is to be performed at. In Figure 168 two locations are illustrated, the neutral axis by a depth D_{NA} from the top and the overall Depth of Section by a depth D.

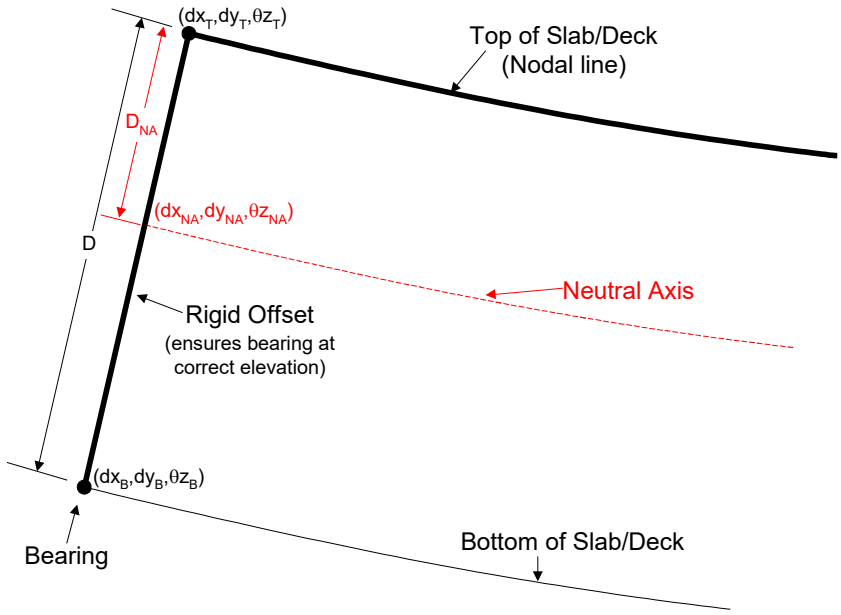


Figure 168: Illustration of Deck at Bearing (Bold Lines Represent Modelling)

Within the rail track analysis tool the rigid support offsets are all built vertically so the coordinates of the location of interest can easily be calculated since the X-coordinate of the location of interest will be identical to the X-coordinate of the top of the slab / deck and the Y-coordinate will just be the required depth from the top of the slab / deck:

$x_{Depth} = x_T$

$y_{Depth} = y_T - Depth$

To calculate the displacements for the location of interest we need to obtain the deformed coordinates of this location. First of all we need to know the deformed coordinates of the top of the slab / deck:

$x_{T(deformed)} = x_T + dx_T$

$y_{T(deformed)} = y_T + dy_T$

We can now calculate the deformed coordinates of the location of interest (noting the assumptions):

$x_{Depth(deformed)} = x_{T(deformed)} + Depth * Sin(\theta z_T)$

$y_{Depth(deformed)} = y_{T(deformed)} - Depth * Cos(\theta z_T)$

We can now calculate the displacements and rotation for the location of interest:

$dx_{Depth} = x_{Depth(deformed)} - x_{Depth}$

$dy_{Depth} = y_{Depth(deformed)} - y_{Depth}$

$\theta z_{Depth} = \theta z_T$

These calculations for the displacements and rotation can be reduced to:

$dx_{Depth} = x_T + dx_T + Depth * Sin(\theta z_T) - x_T$

$= dx_T + Depth * Sin(\theta z_T)$

$dy_{Depth} = y_T + dy_T - Depth * Cos(\theta z_T) - (y_T - Depth)$

$= dy_T + Depth * (1 - Cos(\theta z_T))$

$\theta z_{Depth} = \theta z_T$

From an analysis the following displacements / rotations were obtained:

	DX[m]	DY[m]	THZ[rad]
Top of slab	-1.00273097E-02	-1.21738413E-06	-2.22602390E-04
Bottom of slab	-1.06951168E-02	-1.12373920E-06	-2.22602390E-04

Table 5: Sample Top and Bottom of Slab Displacement Results for 3m Deep Section

The bottom of slab displacements can be calculated from the top of slab using the equations above as follows and utilising the knowledge that the Depth of Section is 3.0m:

$$dx_B = dx_T + D * \mathrm{Sin}(\theta z_T)$$

$$= -1.00273097E\text{-}02 + 3.0 * \mathrm{Sin}(-2.22602390E\text{-}04)$$

$$= -1.06951168E\text{-}02 \text{ m}$$

$$dy_B = dy_T + \mathrm{Depth} * (1 - \mathrm{Cos}(\theta z_T))$$

$$= -1.21738413E\text{-}06 + 3.0 * (1 - \mathrm{Cos}(-2.22602390E\text{-}04))$$

$$= -1.14305640E\text{-}06 \text{ m}$$

$$\theta z_B = \theta z_T = -2.22602390E\text{-}04 \text{ radians}$$

The values for dx_B and θz_B agree exactly with the values in the table, the value for dy_B is within about a percent (it differs very slightly because the 'rigid' offset is not infinitely stiff in the model). It should however be noted that the magnitude of the vertical displacements are of the order of 1.0E-6 m so they are insignificant in terms of the scale of the longitudinal (dx) displacement results in the analysis.

If instead of the bottom of the slab / section, if we wished to calculate the displacements at another location such as the neutral axis of the deck section then all that is needed is to substitute the depth in the calculation with the depth D_{NA}.

Note. The displacements and rotation at the ends of decks / support / bearing locations can also be obtained directly out of Modeller from the results loadcases by manually post-processing the rail track analysis. This can be done by inspecting the displacement results for the **Support Offsets** group in the **Groups** treeview alone for the model. This **Support Offsets** group contains all of the rigid offsets used to ensure that the supports/bearings are at the correct elevations for the decks of the structure and extraction of the displacements (DX, DY) / rotation (THZ) from the model for the bottom node will generally provide the results at the support / bearing elevation.