

A nighttime photograph of a city skyline with a complex multi-level highway interchange in the foreground. The city lights are visible in the background, including several prominent skyscrapers. The highway interchange shows long-exposure light trails from cars, creating a sense of motion. The sky is dark with some clouds.

# LUSAS

## Rail Track Analysis User Manual



# **Rail Track Analysis User Manual**

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**LUSAS Version 18.0 : Issue 1**

LUSAS

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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

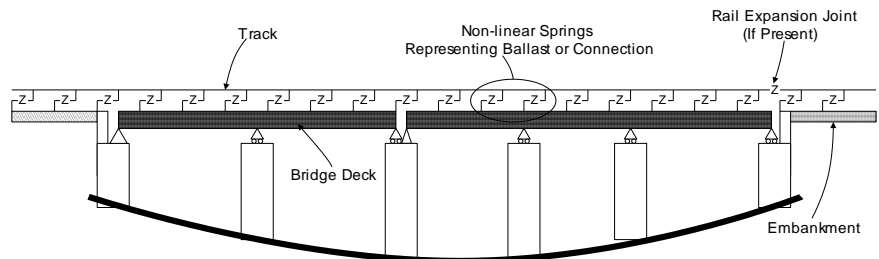
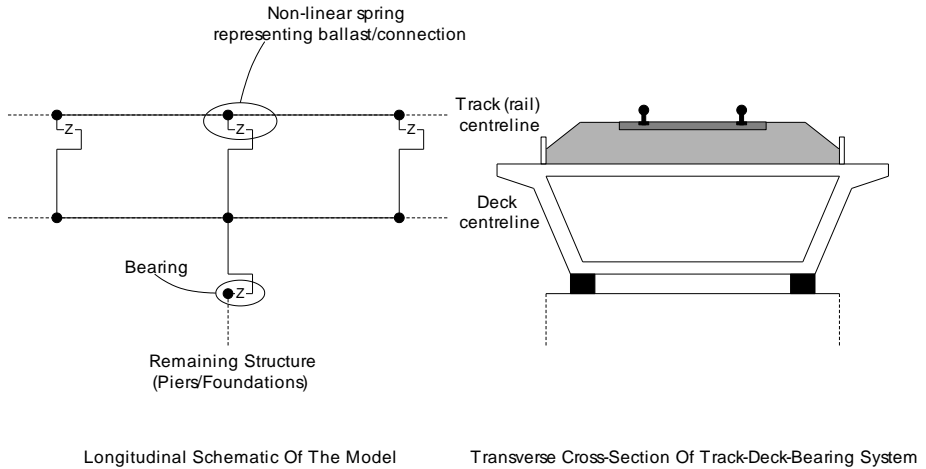


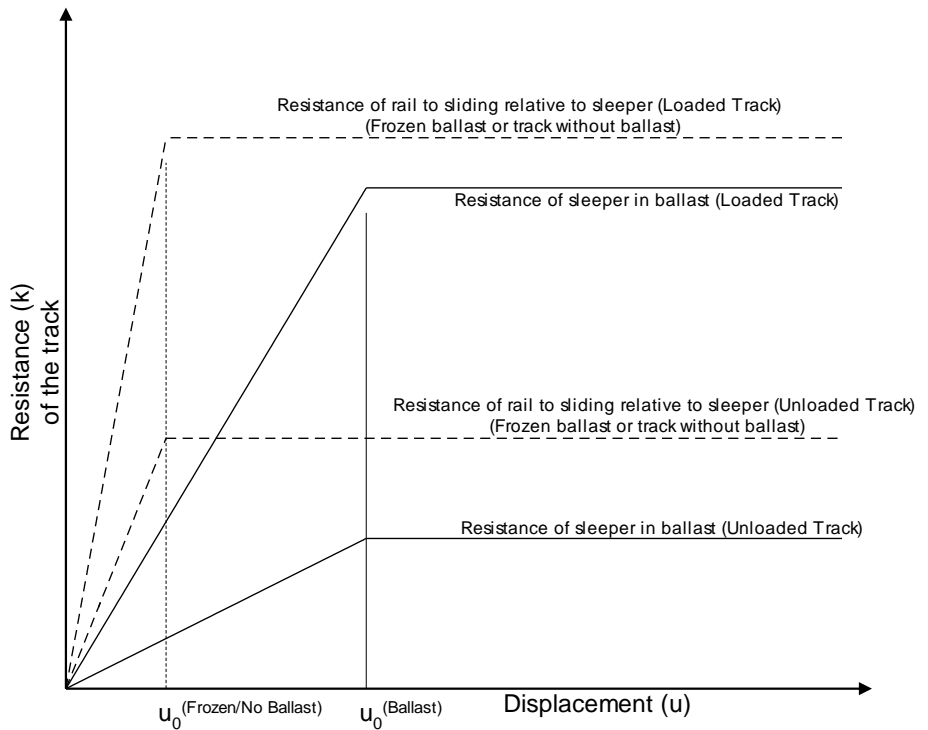
Figure 1: Representation of Structural System for Evaluation of Interaction Effects



**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,  $u_0$ :

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.

## 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 a Microsoft Excel spreadsheet.
- ❑ 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 Microsoft Excel for presentation and further processing

## Worked Example

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.

## The Rail Track Analysis Spreadsheet

A Microsoft Excel spreadsheet is used to define the data from which a LUSAS finite element model is built and a track/bridge interaction analysis 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.



**Note.** All of the data entered into the Microsoft Excel spreadsheet should be in metric 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, all input will be converted to SI units of N, m, kg, C and s.

### Worksheet 1: Decks, Tracks and Embankment Lengths

	A	B	C	D	E	F	G	H	I	J	K
1	<b>Decks, Tracks and Embankment</b>	Units : m									
2											
3	Number of Decks	5									
4	Number of Tracks	2									
5	Left Embankment Length	300									
6	Right Embankment Length	300									
7	Length of Decks Only / Total Length (m)	325	925								
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
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28											
29											
30											
31											
32											
33											
34											
35											
36											

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:

**Number of Decks**

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

Defines the number of railway tracks that pass along the structure and embankments. The number of tracks can be set as either one or two. For two tracks, one track should take the braking load of a trainset and the other the acceleration load of a separate trainset in accordance with the UIC77-3 Code of Practice (Clause 1.4.3). Each track consists of two rails which act together (see the *Geometric Properties* section).

## Left and Right Embankment Length

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 the trainset loading to be placed in the model and, according to the UIC774-3 Code of Practice, should be greater than 100m (Clause 1.7.3).

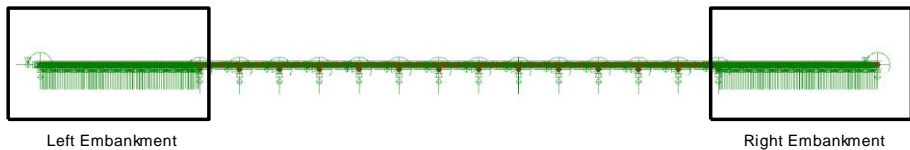


Figure 5: Left and Right Embankments in Model

## Worksheet 2: Structure Definition

A1		Structure Definition												
1		Structure Definition											Units : Pier Height : m ; Bearing springs on top of each pier : kN/mm, Span Length : m	
2														
3		Spring Support for each Abutment/ Pier	Pier Height	Pier Geo Assign.	Pier Mat. Assign.	Bearing Springs on Top of each Pier	Span Length	Geo. Assign.	Mat. Assign.					
Deck 1	4	Left End	R			F								
	5	Span 1	R			307	25	1	1					
	6	Span 2	R			F	25	1	1					
	7	Span 3												
	8	Span 4												
	9	Span 5												
	10	Span 6												
	11	Span 7												
	12	Span 8												
	13	Span 9												
14		Number of Supports for the Deck / Length	3			3	50							
Deck 2	15	Left End	R			F								
	16	Span 1	R			307	25	1	1					
	17	Span 2	R			F	25	1	1					
	18	Span 3												
	19	Span 4												
	20	Span 5												
	21	Span 6												
	22	Span 7												
	23	Span 8												
	24	Span 9												
25		Number of Supports for the Deck / Length	3			3	50							
Deck 3	26	Left End	R			F								
	27	Span 1	R			259	25	1	1					
	28	Span 2	R			F	25	1	1					
	29	Span 3	R			F	25	1	1					
	30	Span 4												
	31	Span 5												

Figure 6: 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 and material 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**

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 6, 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 Microsoft Excel 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:

$$\delta_{\text{total}} = \delta_p + \delta_\phi + \delta_h + \delta_b$$

where

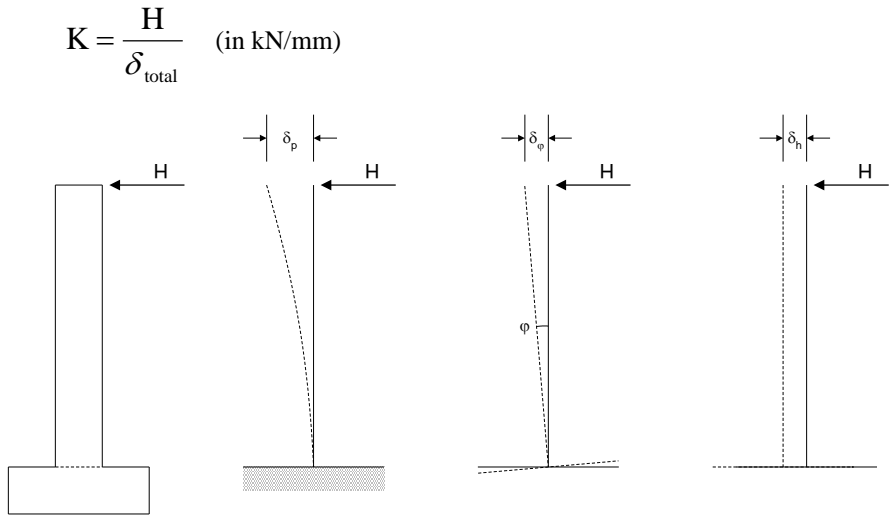
$\delta_p$  = displacement at top of support due to elastic deformation

$\delta_\phi$  = displacement at top of support due to rotation of the foundation

$\delta_h$  = displacement at top of support due to horizontal movement of the foundation

$\delta_b$  = 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:



**Figure 7: 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**

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.

### **Span Length**

Defines the span length between support locations for a deck. Up to nine spans can be defined for each deck. In the example illustrated in Figure 6 the first two decks have two 25m spans each and the third deck has three 25m spans.

### **Geometric Assignment**

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**

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.

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**

Defines the height of the support / pier for the current location in the deck. If the pier height is blank the wizard assumes that the pier behaviour is represented solely by the spring supports and bearing springs.

### **Pier Geometric Assignment**

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**

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 Microsoft Excel 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.

	A	B	C	D	E	F	G	H	K	L	M	N
1	<b>Structure Definition</b>		Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m									
2			Spring Support for each Abutment/Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign.	Bearing Springs on Top of each Pier	Span Length	Geo. Assign.	Mat. Assign.		
3												
1089	Deck 100	Span 7										
1090		Span 8										
1091		Span 9										
1092		Number of Supports for the Deck / Length	0				0	0				
1093		Left End										
1094		Span 1										
1095		Span 2										
1096		Span 3										
1097		Span 4										
1098		Span 5										
1099	Span 6											
1100	Span 7											
1101	Span 8											
1102	Span 9											
1103	Number of Supports for the Deck / Length	0				0	0					
1104												
1105												
1106												
1107												
1108												
1109												
1110												
1111												
1112												
1113												
1114												
1115												
1116												
1117												

**Figure 8: 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 first 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 which can be done under the Review options in Microsoft Excel. 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.



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	Span Length	Geo. Assign.	Mat. Assign.
1089	Span 7								
1090	Span 8								
1091	Span 9								
1092	Number of Supports for the Deck / Length	0				0	0		
1093	Left End								
1094	Span 1								
1095	Span 2								
1096	Span 3								
1097	Span 4								
1098	Span 5								
1099	Span 6								
1100	Span 7								
1101	Span 8								
1102	Span 9								
1103	Number of Supports for the Deck / Length	0				0	0		
1104	Left End								
1105	Span 1								
1106	Span 2								
1107	Span 3								
1108	Span 4								
1109	Span 5								
1110	Span 6								
1111	Span 7								
1112	Span 8								
1113	Span 9								
1114	Number of Supports for the Deck / Length	0				0	0		

Figure 9: Pasting of Additional Decks to Ensure Formatting Maintained

### Worksheet 3: Geometric Properties

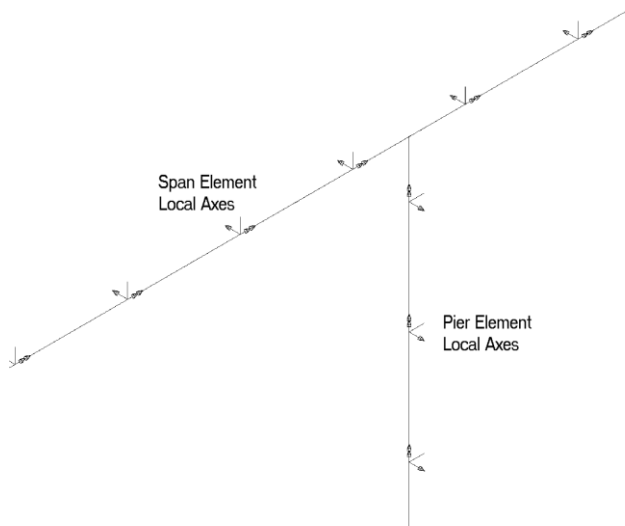
Depth of Section to Support	A	Iyy	Izz	J	Asy	Asz	Eccentricity	Description
Rail	0.0153389	6.079E-05	1.021E-05	4.339E-06	0.0064723	0.0127397	0	Rails
1	2.84	10.57	10.4	115.5	115.5	10570	10570	0.918 Deck Cross-Section

Figure 10: 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 Support** entry that is needed by the model building to ensure the support conditions occur at the correct elevation.

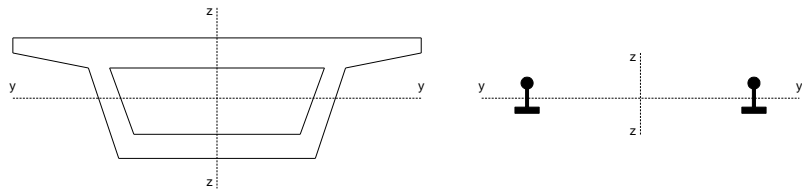
### Element Orientations

The orientations of the sectional properties should obey 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 11: 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 12.



**Figure 12: Section Axes for Deck and Rail Definitions**

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. When analysing a single track structure it is possible to approximate the behaviour of individual rails by choosing to model two tracks and only defining the section properties for a single rail in the *Geometric Properties* worksheet. Caution should be used when considering modelling of this type as the analysis will ignore any connectivity between the two rails that may be provided by the sleeper arrangement.

**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.

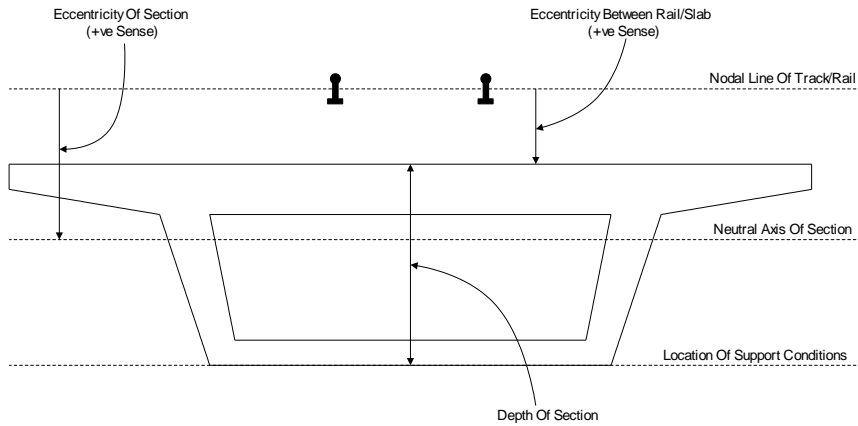


**Notes**

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 13: Eccentricity Definition for Geometric Properties and Depth of Section**

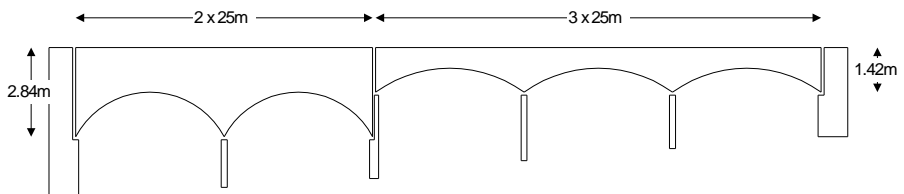
## Varying Section Geometric Properties

Although the Microsoft Excel 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 wizard 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 14: Example Varying Section Structure**

If the structure in Figure 14 was required, the main track-structure interaction model could be set up using a Microsoft Excel Spreadsheet with the *Structure Definition* and *Geometric Properties* indicated in Figure 15 and Figure 16. This would define the base model indicated in Figure 17.

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	Span Length	Geo. Assign.	Mat. Assign.
Deck 1	Left End	R				F			
	Span 1	R				307	25	1	1
	Span 2	R				F	25	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
	Span 2	R				F	25	2	1
	Span 3	R				F	25	2	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								

Figure 15: Structure Definition for Sample Varying Section Structure

Geometric Properties		Units : m						
Depth of section to support	A	lyy	lzz	J	Asy	Asz	Eccentricity/Description	
Rail	2.84	0.0153389	6.0726E-05	1.0209E-05	4.3393E-06	0.0064723	0 Rails	
1	1.42	1	1	1	1	1	0 Deck Cross-Section 1	
2		1	1	1	1	1	0 Deck Cross-Section 2	

Figure 16: Geometric Properties for Sample Varying Section Structure

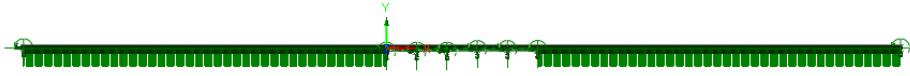


Figure 17: Base Model for Sample Varying Section Structure

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).

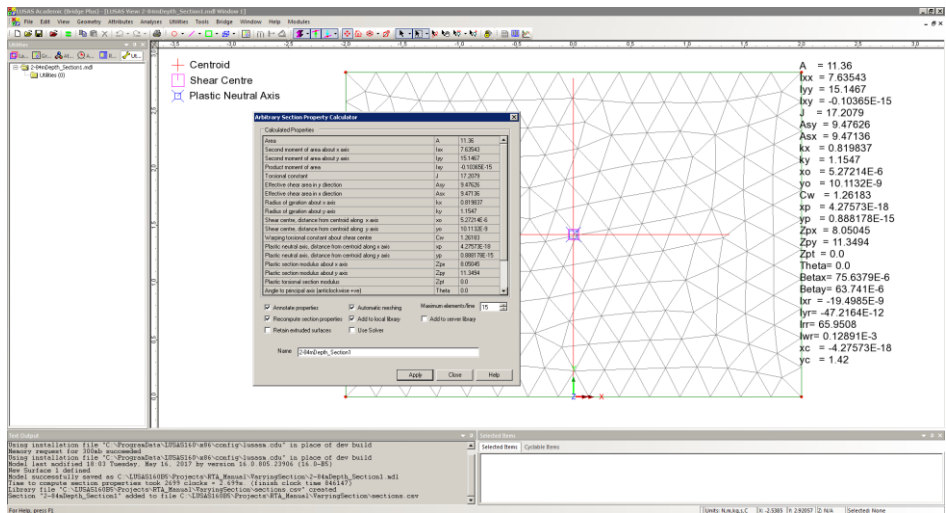


Figure 18: Arbitrary Section Property Calculation for 2.84m Depth of Section Span

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 19 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 20 where each reference path has been offset in the Y direction for visualisation purposes.

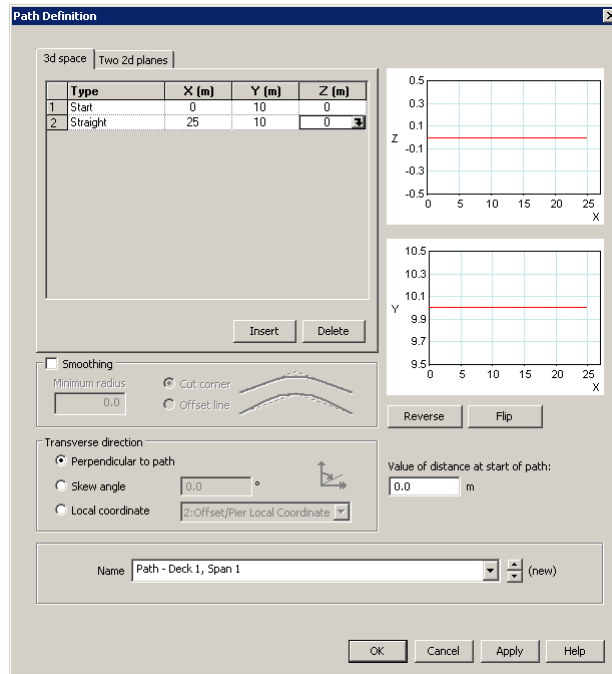


Figure 19: Definition of Reference Path for Deck 1, Span 1

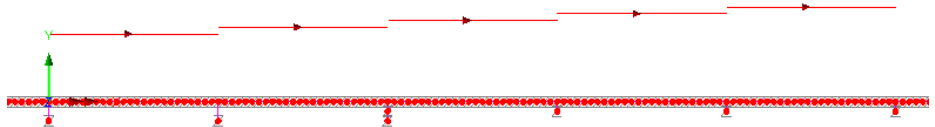
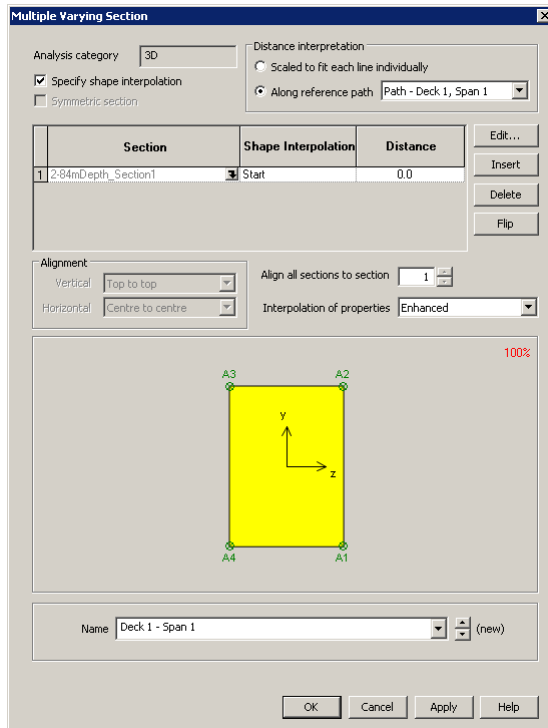


Figure 20: Reference Path for all Decks and Spans (Offset for Visualisation Purposes)

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 19). For the start of the varying section the 2.84m deep section (“2-84mDepth\_Section1” in this case) should be selected from the user library and the section edited. The eccentricity in the z direction (ez) should be set to the required value of 1.42m 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. At this stage the Multiple Varying Section dialog will just have the starting section as illustrated in Figure 21.



**Figure 21: 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**



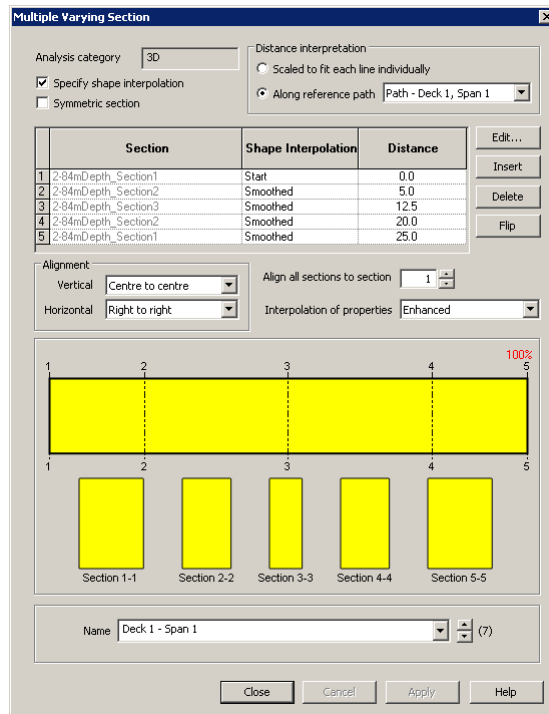
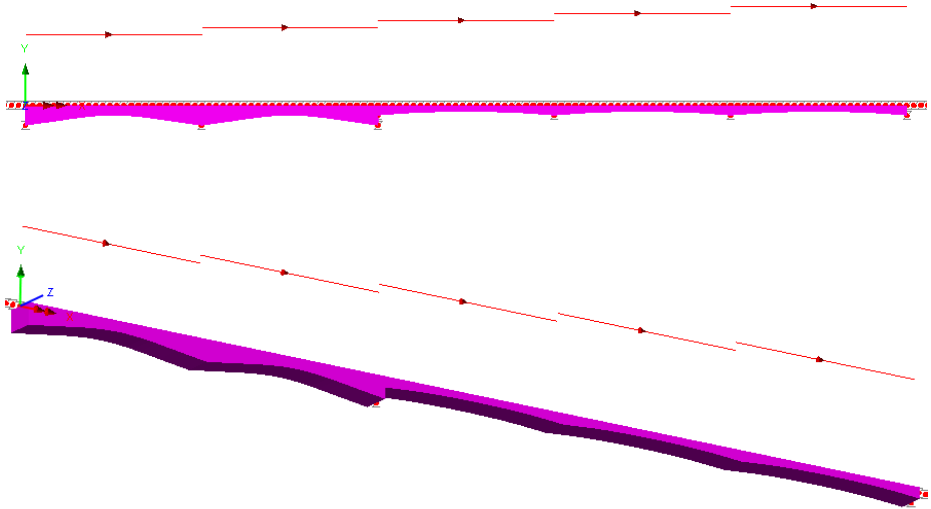


Figure 22: Definition of Multiple Varying Section for Deck 1, Span 1 (2 of 2)

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 wizard. 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 23.



**Figure 23: 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 24. When modelling structures where the sections do not vary smoothly, for example over a pier as indicated in Figure 14, 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 25 and Figure 26 which examine the behaviour at an intermediate pier of a deck when a single path is used for each deck. In Figure 26 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.

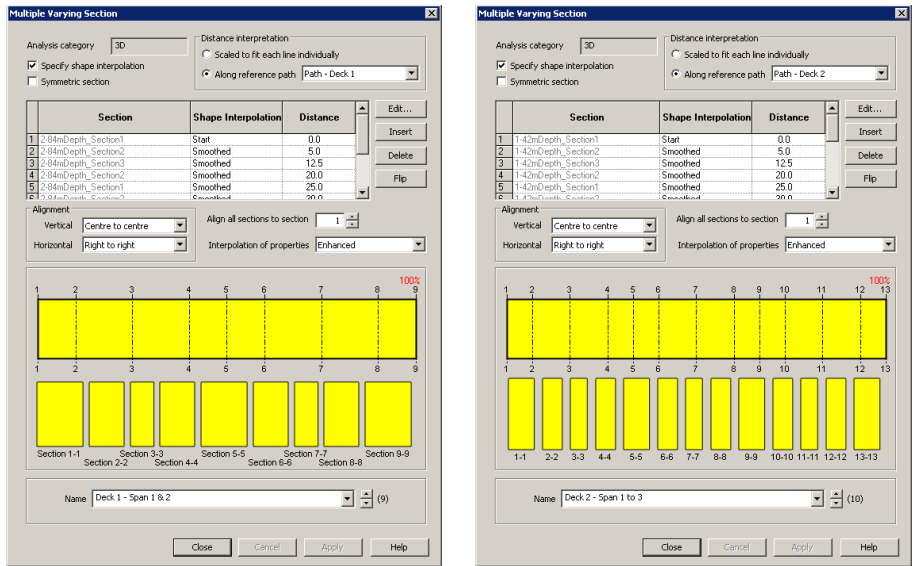


Figure 24: Definition of Multiple Varying Section for Deck 1 and Deck 2 for Two Reference Paths

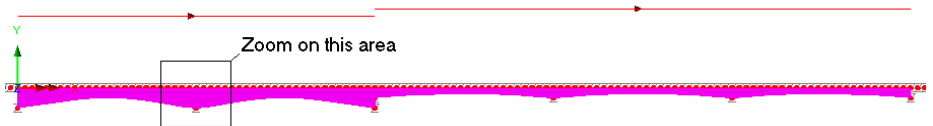


Figure 25: Model after Assignment of Multiple Varying Sections with Two Reference Paths

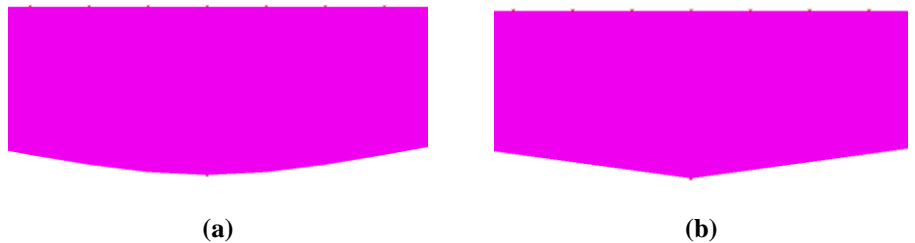


Figure 26: Zoomed Plot of Pier Location between Spans of Deck 1 Showing (a) Smoothed Section for a Multiple Varying Sections with One Reference Path per Deck and (b) Correct Unsmoothed Section for a Multiple Varying Sections with One Reference Path per Span



## Worksheet 5: Interaction and Expansion Joint Properties

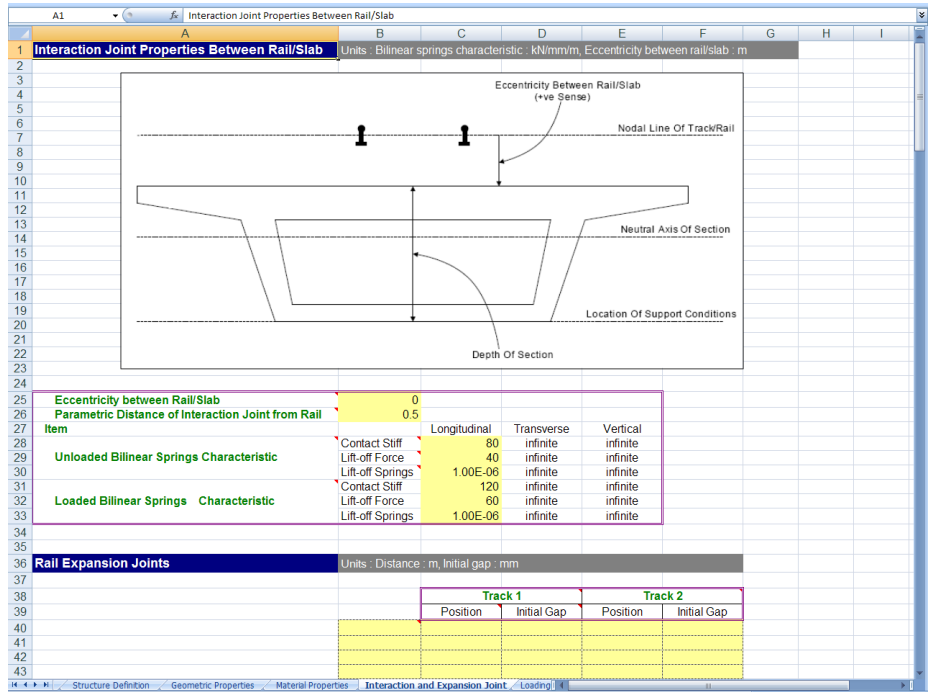


Figure 28: Interaction Properties Between the Track/Bridge and Expansion Joint Definition

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.

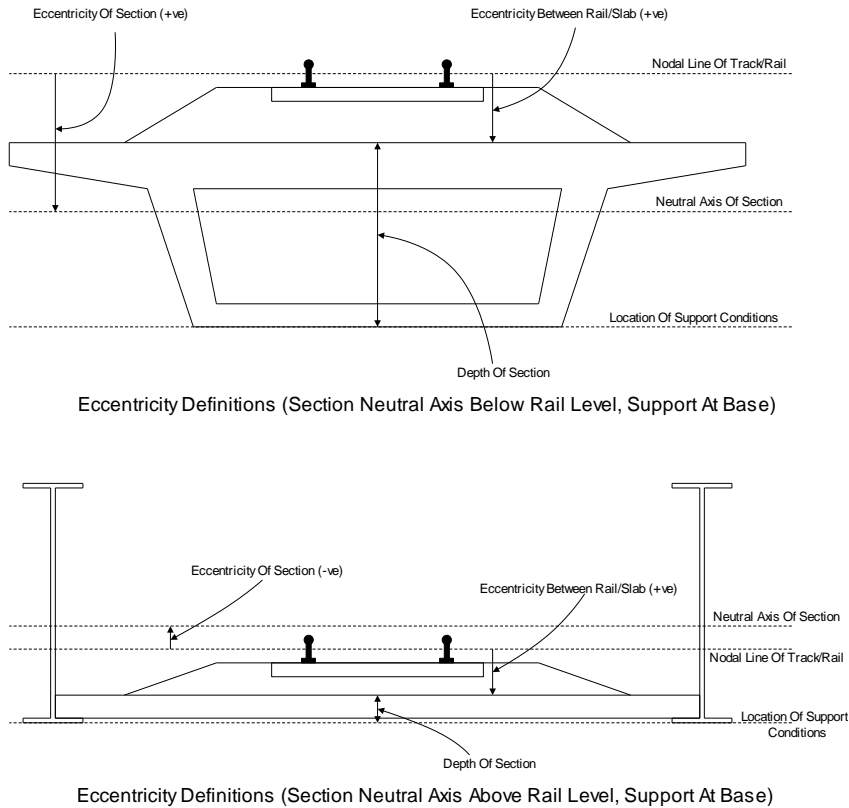
### Eccentricity Between Rail/Slab

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. If the entry is undefined the Rail Track Analysis tool will assume a value of 0.5 to place the interaction joints midway between the rail/track and the bridge slab/deck.



**Figure 29: 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. 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 contact stiffness is defined in kN/mm per metre length of track, the lift-off force

(onset of plastic yield) is defined in kN per metre length and the lift-off stiffness defined as a small value so there is no stiffness once plastic yielding has started. The values in Figure 28 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):

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

The contact stiffness is calculated directly from:

$$\text{Contact Stiffness} = \frac{k}{u_0}$$

giving 80 kN/mm/m for the unloaded and 120 kN/mm/m for the loaded interaction contact stiffness values. The transverse spring properties of the interaction should always be infinite (as the analysis is two-dimensional even though the elements are three-dimensional) but the vertical spring properties can be adjusted from this to include vertical deformation effects of the ballast by building the temperature only model and editing the model before applying the trainset rail loads. If this type of analysis is carried out, care must be taken to ensure that the spring remains in the elastic regime. This is achieved by setting a very high value for the lift-off force (1.0E12 kN/mm per metre length for example) and ensuring that the lift-off springs are set to the same stiffness value as the contact stiffness.



**Note.** If a zero or small lift-off 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.

### Defining Rail Expansion Joints

If rail expansion joints 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 positive ID number that is placed in column B, the positions and initial gaps. The expansion joint data will be read from the spreadsheet until a blank ID entry is detected. For each unique ID number an expansion joint can be defined for either track by entering the position in metres from the start of the left-hand embankment and initial gap in millimetres.

# Rail Track Analysis User Manual

The screenshot displays a software window titled "Interaction Joint Properties Between Rail/Slab". The window is divided into two main sections: a diagram and two data tables.

**Diagram:** A cross-sectional diagram of a rail and slab. The top horizontal line is labeled "Nodal Line Of Track/Rail". Below it, a trapezoidal shape represents the slab cross-section. The bottom horizontal line is labeled "Location Of Support Conditions". The vertical distance between the nodal line and the support location is labeled "Eccentricity Between Rail/Slab (+ve Sense)". The vertical distance from the bottom of the slab to the support location is labeled "Depth Of Section". The horizontal line passing through the center of the slab is labeled "Neutral Axis Of Section".

**Interaction Joint Properties Table:**

Interaction Joint Properties Between Rail/Slab				
Units: Bilinear springs characteristic: kN/mm/m, Eccentricity between rail/slab: m				
Eccentricity between Rail/Slab		0		
Parametric Distance of Interaction Joint from Rail		0.5		
Item		Longitudinal	Transverse	Vertical
Unloaded Bilinear Springs Characteristic	Contact Stiff	80	infinite	infinite
	Lift-off Force	40	infinite	infinite
	Lift-off Springs	1.00E-06	infinite	infinite
Loaded Bilinear Springs Characteristic	Contact Stiff	120	infinite	infinite
	Lift-off Force	60	infinite	infinite
	Lift-off Springs	1.00E-06	infinite	infinite

**Rail Expansion Joints Table:**

Rail Expansion Joints				
Units: Distance: m, Initial gap: mm				
	Track 1		Track 2	
	Position	Initial Gap	Position	Initial Gap
1	300	5		
2	475	5	475	5
3			625	5

Figure 30: Sample Expansion Joint Definitions



## Worksheet 6: Thermal and Train Loading

Loading		Units: Temperature: Celsius	Load Position/Length: m	Load: kN/m						
<b>For Deck</b>		Amount	20							
		Temperature	0							
		Number of Track Loading Locations	5							
<b>For Rails</b>		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
	Braking	1	0	300	20	300	0	325	81.25	
	Vertical1	1	0	300	80	300	0	325	81.25	
	Vertical2	2	0	300	80	300	270	595	81.25	
	Acceleration	2	0	30	33.3	30	270	595	81.25	
	Acceleration	2	30	300	0	270	270	595	81.25	

Figure 31: 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 locations using the parametric loading facility which is 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). 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.



**Note.** For structures where more than one temperature loading may need to be entered for the deck (e.g. mixed steel and concrete bridges) the model should be defined with a single deck temperature and then a temperature only model built. This model can then have its temperature loading for the deck adjusted before the **Apply Rail Loads** dialog is then used to include the trainset loading to the railtracks.

## Trainset Loading to Rails of Tracks

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 a single spreadsheet and all of these positions to be analysed on one go by the wizard. All of the trainset loading must fit within the length of the tracks of the model with the left-hand end of the left embankment at a position of 0.0m and the right-hand end of the right embankment at a position equal to the total length of the model reported in the *Decks, Tracks And Embankment* worksheet.

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 the accelerating trainset loading illustrated in Figure 32. To extend the bottom of the table extra rows can be inserted (making sure to copy the formulae in columns G and J) or the last rows copied and pasted as many times as required.



**Note.** This may require the worksheet to be unprotected first which can be done under the Review options in Microsoft Excel. 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.

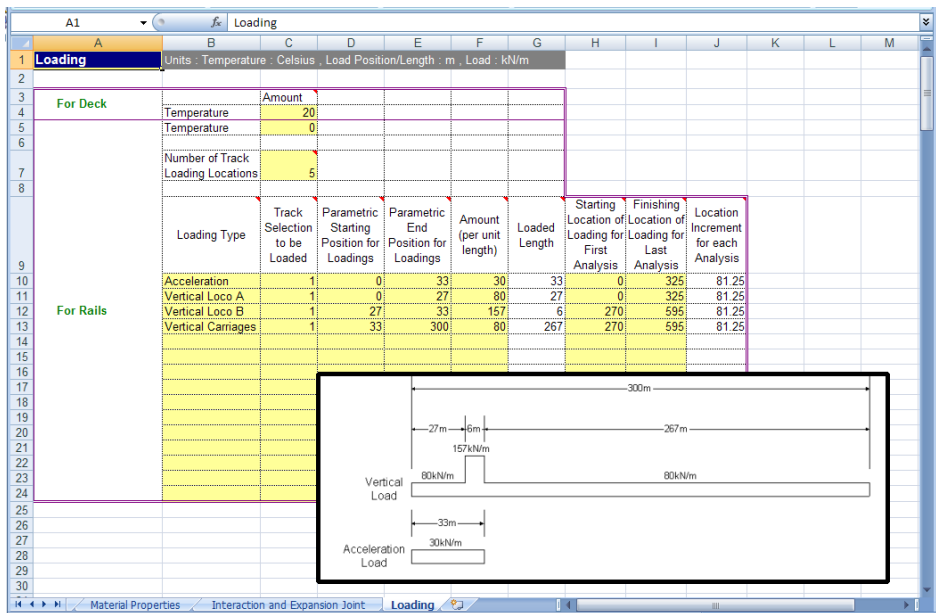


Figure 32: More Complex Train Loading Definition in Spreadsheet

The inputs to the worksheet are:

**Number of track loading locations**

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

**Loading type**

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, **B**raking and **V**ertical. A more descriptive definition of the loading type may be entered if required as illustrated in Figure 32 so long as the first character is set to either A, B or V.

**Track selection to be loaded**

Defines the track that the loading will be assigned to and can be either 1 or 2 (only if the structure is a two track structure). For two tracks the UIC774-3 Code of Practice (Clause 1.4.3) states that the accelerating and braking forces from trainsets should be applied to different tracks.

**Parametric starting position for loadings**

Defines the start of the loading of the trainset. 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**

Defines the end of the loading of the trainset. 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.

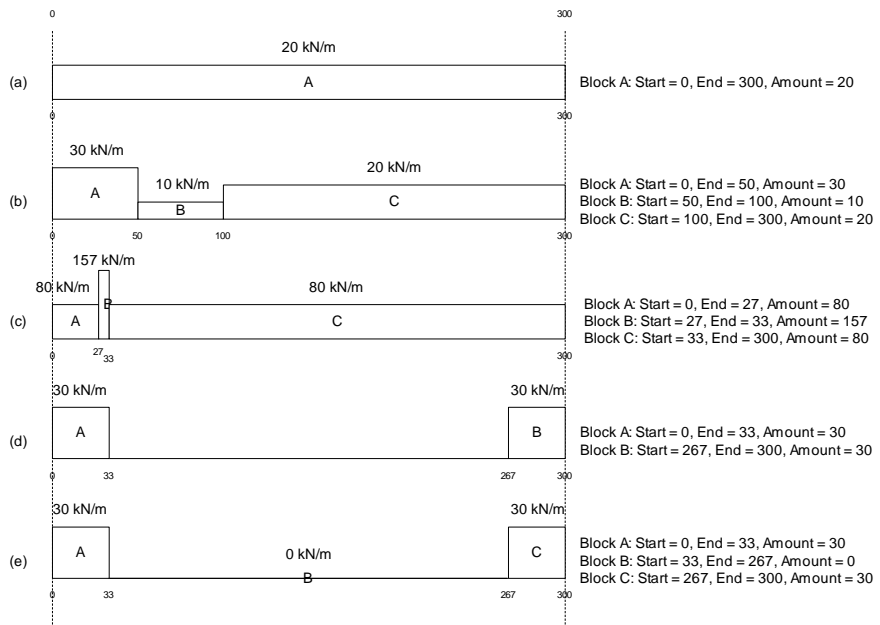
**Amount (per unit length)**

Defines the magnitude of the trainset loading in units of kN per metre length. For longitudinal loads such as acceleration 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 33 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.



**Figure 33: Sample Trainset Loading Position Definitions**

## Starting location of loading for first analysis

Defines the starting location of the reference position of the parametric trainset loading on the track for the first analysis and should be defined from the left-most end of the left-hand embankment which is at a location of 0.0m. The starting position should allow for the inclusion of any load that is to the left of this position on the track (defined with a negative position in the parametric loading position) or to the right of this position (defined with a positive position in the parametric loading position). For example, if the parametric trainset loading has been defined from -150m to 150m representing a 300m long trainset centred on the reference position the minimum location for the loading would be +150m relative to the left-most end of the left-hand embankment. Any value less than 150m would mean that it would be impossible to fit the whole of the trainset loading onto the track. Similarly, the maximum location for

the loading would be  $(\text{TotalLengthTrack} - 150)\text{m}$  relative to the left-most end of the left-hand embankment.

### **Finishing location of loading for last analysis**

Defines the finishing location of the reference position of the parametric trainset loading on the track for the last analysis and should be defined from the left-most end of the left-hand embankment which is at a location of 0.0m. The finishing position should allow for the inclusion of any load that is to the left of this position on the track (defined with a negative position in the parametric loading position) or to the right of this position (defined with a positive position in the parametric loading position). The limits of the finishing location are identical to those for the starting location discussed above.

### **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 must be set to 1. For a two track structure, one of the trainsets on one of the tracks may be stationary but an error will result if both of the trainsets loading the track are stationary if the number of track loading locations is greater than 1. To analyse two stationary trainsets on a two track structure the number of track loading locations must be set to 1.

## Rail Track Analysis Menu Options

The Rail Track Analysis option is accessed through the Bridge menu by selecting the Rail Track Analysis UIC774-3 entry. This menu entry provides the following three options:

- Build Model...**
- Apply Rail Loads...**
- Extract Results To Excel...**

## Build Model Dialog

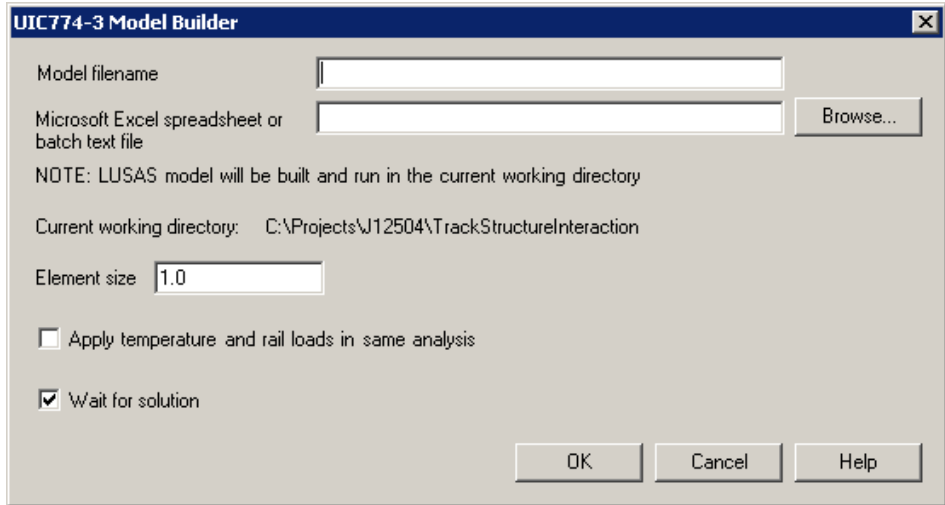


Figure 34: UIC774-3 Model Builder Dialog

- ❑ **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.
- ❑ **Microsoft Excel spreadsheet or batch text file** If batch processing is not being used and a single model is being created, the filename of the Microsoft Excel 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 Microsoft Excel 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.

The format of the batch text file is indicated below and simply contains a TAB delimited list of the Microsoft Excel files to build the models from and an optional LUSAS model name (if no model name is supplied the basename of the Microsoft Excel spreadsheet will be used) with one model entry per line. If no folder structure is defined for the Microsoft Excel files then the current working folder will be assumed to contain the spreadsheet files, 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 Microsoft Excel 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 35: 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  $0 < \text{Element Size} \leq 2.0\text{m}$  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.



**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 model to be updated prior to applying the rail loading. A situation where this may be needed is the case of a mixed bridge type (for example, one having concrete and steel sections) where the temperature loading of the bridge/deck cannot be classified by the single temperature change available in the Microsoft Excel spreadsheet. If only the temperature model is

built, additional temperature loading attributes can be defined and assigned to the temperature loadcase prior to the rail load application.

Solving only the temperature effects will also allow the support conditions to be modified for pier foundations that require rotational stiffness rather than rigidity (see the discussion of Structure Definition section of the Microsoft Excel spreadsheet) or the addition of varying sections to the decks and spans of the structure.



**Note.** Models created from spreadsheet data contain named groups that are used in the creation of results worksheets. Care should be taken to avoid making major changes to the layout of the model and the loadcases, otherwise the application of the rail loading may fail.

- 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 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

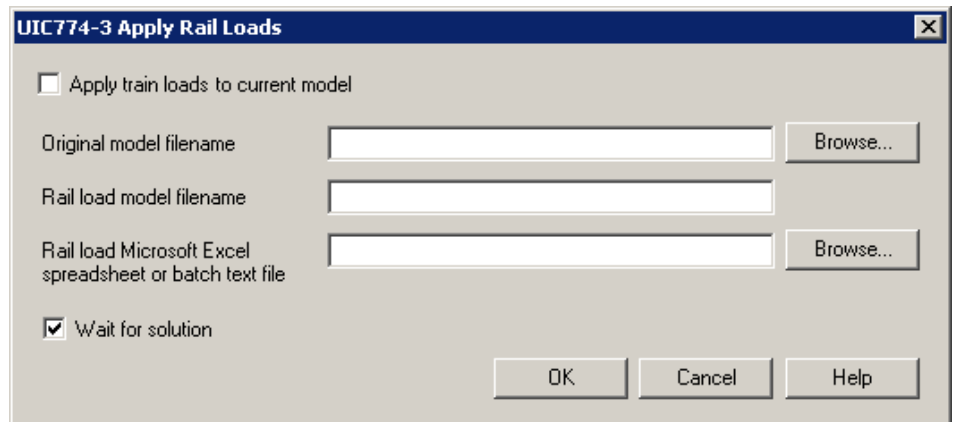


Figure 36: UIC774-3 Apply Rail Loads Dialog

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 Microsoft Excel spreadsheet or batch text file** If a single rail load configuration is to be analysed for the specified bridge model the filename of the Microsoft Excel 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.

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 Microsoft Excel 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.xls
Bridge1.mdl	Bridge1_RailConfig2.mdl	Bridge1_RailConfig2.xls
Bridge1.mdl	Bridge1_RailConfig3.mdl	Bridge1_RailConfig3.xls
Bridge1.mdl	Bridge1_RailConfig4.mdl	Bridge1_RailConfig4.xls
Bridge2.mdl	Bridge2_RailConfig1.mdl	Bridge2_RailConfig1.xls
Bridge2.mdl	Bridge2_RailConfig2.mdl	Bridge2_RailConfig2.xls
Bridge3.mdl	Bridge3_RailConfig1.mdl	Bridge3_RailConfig1.xls

**Figure 37: 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 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 Microsoft Excel Dialog

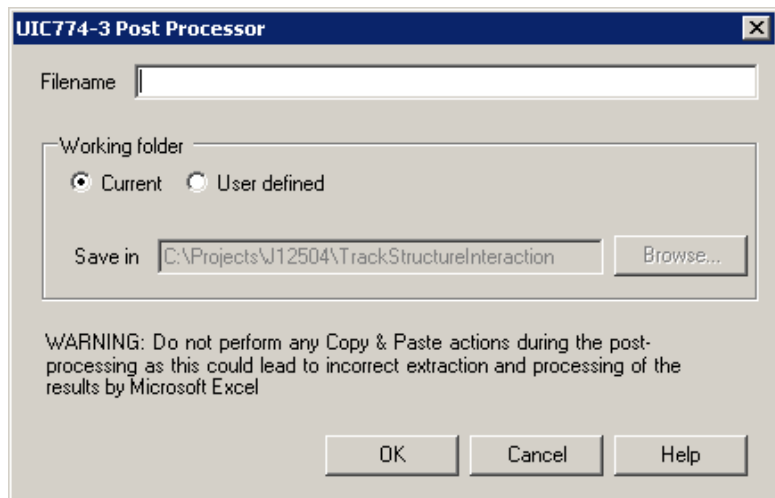


Figure 38: UIC774-3 Post Processor Dialog

A dedicated post-processing dialog is provided that allows the automatic extraction of the results from the track/bridge interaction analysis to a Microsoft Excel 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 1”, “Track 2”, “Decks” and interaction joint groups should not be modified or renamed.

- ❑ **Filename** The filename for the Microsoft Excel 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.
- ❑ After clicking **OK** the option to carry out enveloping of results within Excel is available.



**Note.** When large models and / or large numbers of results files are being post-processed then the time required for the post-processing can become significant due to the amount of data that is transferred between Modeller and Microsoft Excel. During the post-processing it will not be possible to perform any other tasks in Modeller.



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

## 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.

In 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**

### Results worksheets created

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

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

### 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 in Microsoft Excel 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 in Microsoft Excel 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). LUSAS envelopes will not be included in the Microsoft Excel enveloping.



**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.

### 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 39 to Figure 41. 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 42 to Figure 44.

Figure 45 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.

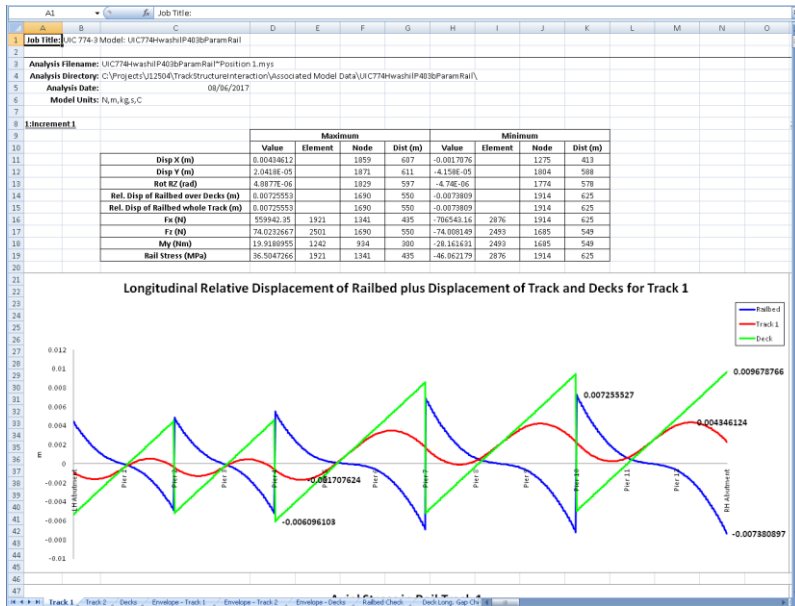


Figure 39: Track Worksheet Summary and Railbed Graph for Temperature Only Results of Analysis, Increment 1 (1 of 3)

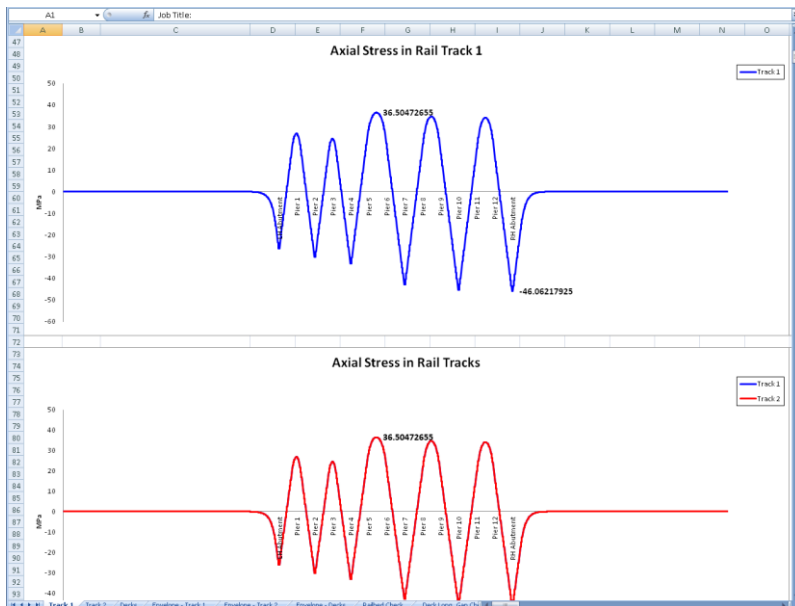


Figure 40: Track Worksheet Rail Stress Graphs for Temperature Only Results of Analysis, Increment 1 (2 of 3)

# Rail Track Analysis Results Spreadsheet

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 (kN)	Fy (kN)	My (kNm)	Rail Stress (MPa)
100	39	33	0	-900	0	0	0	0	0	0	-3.034E-15	1.212E-209	2.886E-210	-1.978E-19
101	39	38	1	-299	0	0	-9.40E-25	3.17E-219	1.113E-216	-9.42E-25	-3.034E-15	1.212E-209	2.886E-210	-1.978E-19
102	44	38	1	-299	0	0	-9.42E-25	3.17E-219	1.113E-216	-9.42E-25	-3.11E-15	-4.49E-209	-1.95E-209	-2.027E-19
103	44	39	2	-298	0	0	-1.907E-24	-2.43E-210	-4.63E-216	-1.907E-24	-3.11E-15	-4.49E-209	-1.95E-209	-2.027E-19
104	48	39	2	-298	0	0	-1.907E-24	-2.43E-210	-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	-2.93E-24	3.11E-210	1.81E-215	-2.92E-24	-2.622E-15	1.76E-208	5.203E-209	-2.127E-19
106	51	43	3	-297	0	0	-2.93E-24	3.11E-210	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	3.901E-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	3.901E-216	2.746E-214	-5.19E-24	4.232E-15	-1.04E-206	-3.07E-207	-2.795E-19
111	59	52	6	-294	0	0	-6.504E-24	-3.8E-216	-1.07E-213	-6.504E-24	4.232E-15	-1.04E-206	-3.07E-207	-2.795E-19
112	63	52	6	-294	0	0	-6.504E-24	-3.8E-216	-1.07E-213	-6.504E-24	4.723E-15	4.048E-206	1.197E-206	-3.096E-19
113	63	55	7	-293	0	0	-7.979E-24	2.094E-215	4.65E-213	-7.979E-24	-4.723E-15	4.048E-206	1.197E-206	-3.096E-19
114	67	55	7	-293	0	0	-7.979E-24	2.094E-215	4.65E-213	-7.979E-24	-5.39E-15	-1.58E-205	-4.66E-206	-3.514E-19
115	67	58	8	-292	0	0	-8.653E-24	-8.16E-215	-1.62E-212	-8.653E-24	-5.39E-15	-1.58E-205	-4.66E-206	-3.514E-19
116	71	58	8	-292	0	0	-8.653E-24	-8.16E-215	-1.62E-212	-8.653E-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	6.91E-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	6.91E-212	-1.157E-23	-7.080E-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	-7.080E-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	-8.109E-15	9.31E-204	2.754E-204	-5.399E-19
121	79	66	11	-289	0	0	-1.631E-23	4.019E-213	9.89E-211	-1.631E-23	-8.109E-15	9.31E-204	2.754E-204	-5.399E-19
122	83	66	11	-289	0	0	-1.631E-23	4.019E-213	9.89E-211	-1.631E-23	-9.494E-15	-3.63E-203	-1.07E-203	-6.109E-19
123	83	69	12	-288	0	0	-1.924E-23	-1.88E-212	-3.79E-210	-1.924E-23	-9.494E-15	-3.63E-203	-1.07E-203	-6.109E-19
124	87	71	12	-288	0	0	-1.924E-23	-1.88E-212	-3.79E-210	-1.924E-23	-1.103E-14	1.419E-202	4.177E-202	-7.193E-19
125	87	72	13	-287	0	0	-2.268E-23	2.399E-212	1.854E-209	-2.268E-23	-1.103E-14	1.419E-202	4.177E-202	-7.193E-19
126	91	72	13	-287	0	0	-2.268E-23	2.399E-212	1.854E-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	-1.490E-14	1.148E-201	6.39E-201	-9.767E-19
129	95	79	15	-285	0	0	-3.132E-23	1.198E-210	2.205E-208	-3.132E-23	-1.490E-14	1.148E-201	6.39E-201	-9.767E-19
130	99	79	15	-285	0	0	-3.132E-23	1.198E-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	-2.040E-14	3.25E-200	9.61E-200	-1.322E-18
133	104	84	17	-283	0	0	-4.309E-23	1.682E-209	3.844E-207	-4.309E-23	-2.040E-14	3.25E-200	9.61E-200	-1.322E-18
134	107	84	17	-283	0	0	-4.309E-23	1.682E-209	3.844E-207	-4.309E-23	-2.388E-14	-1.27E-199	-3.74E-200	-1.557E-18
135	107	88	18	-282	0	0	-5.05E-23	-6.59E-209	-1.3E-206	-5.05E-23	-2.388E-14	-1.27E-199	-3.74E-200	-1.557E-18
136	112	88	18	-282	0	0	-5.05E-23	-6.59E-209	-1.3E-206	-5.05E-23	-2.726E-14	4.93E-199	1.408E-199	-1.82E-18
137	112	92	19	-281	0	0	-5.917E-23	2.951E-208	5.872E-206	-5.917E-23	-2.726E-14	4.93E-199	1.408E-199	-1.82E-18
138	116	92	19	-281	0	0	-5.917E-23	2.951E-208	5.872E-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	4.477E-198	2.211E-198	-2.40E-18
141	119	96	21	-279	0	0	-8.116E-23	3.868E-207	7.949E-205	-8.116E-23	-3.819E-14	4.477E-198	2.211E-198	-2.40E-18
142	123	96	21	-279	0	0	-8.116E-23	3.868E-207	7.949E-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

Figure 41: Track Worksheet Tabulated Output for Temperature Only Results of Analysis, Increment 1 (3 of 3)

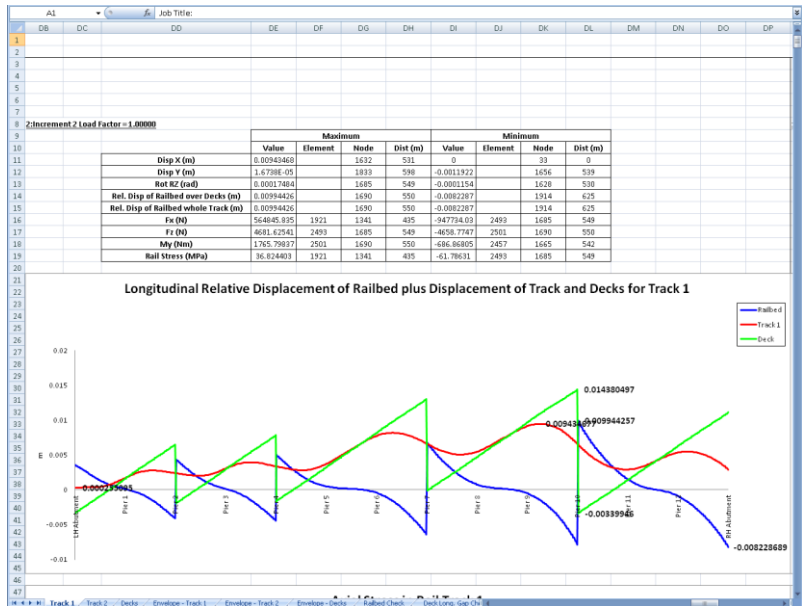


Figure 42: Track Worksheet Summary and Railbed Graph for Temperature and Trainset Results of Analysis, Increment 2 (1 of 3)

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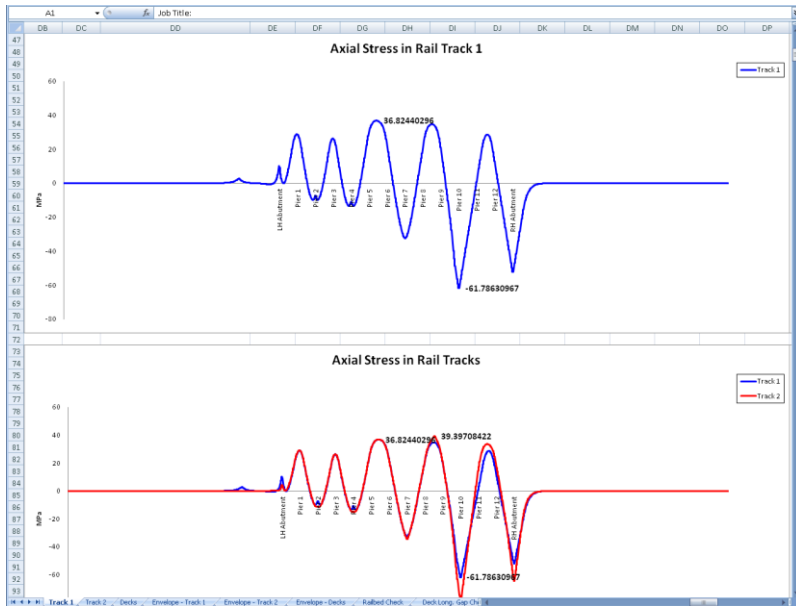
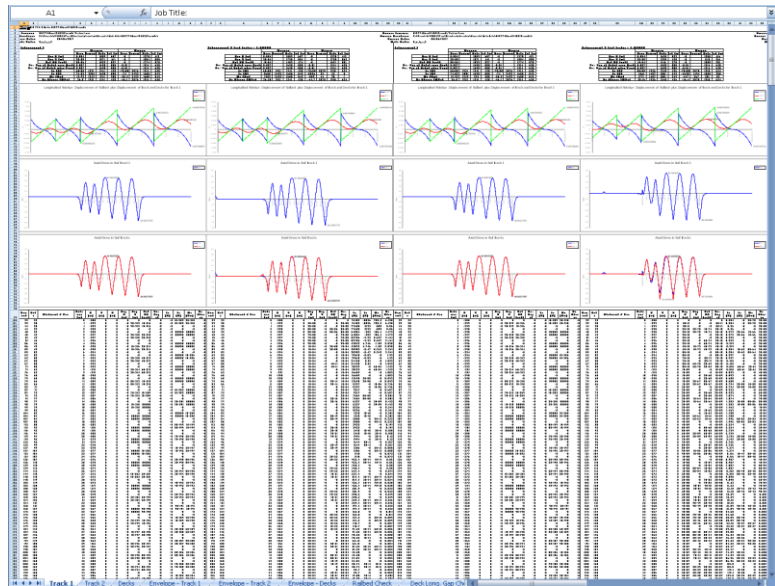


Figure 43: Track Worksheet Rail Stress Graphs for Temperature and Trainset Results of Analysis, Increment 2 (2 of 3)

Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Rot. Disp of Railhead (m)	Fx (N)	Fy (N)	Mx (Nm)	Rail Stress (MPa)
100	39	33	0	-300	0	0	0	0	0	0	1.9998E-12	-9.02E-175	-2.34E-175	1.3037E-16
101	39	38	1	-299	0	0	6.2088E-22	-7.43E-184	-9.02E-182	6.2088E-22	1.9998E-12	-9.02E-175	-2.34E-175	1.3037E-16
102	44	38	1	-299	0	0	6.2088E-22	-7.43E-184	-9.02E-182	6.2088E-22	1.0495E-12	3.641E-174	1.095E-174	1.3361E-16
103	44	39	2	-298	0	0	1.2571E-21	1.971E-183	3.75E-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	3.75E-181	1.2571E-21	2.15E-12	-1.43E-173	-4.22E-174	1.4017E-16
105	48	39	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	3.39E-12	5.553E-173	1.642E-173	1.5021E-16
107	51	46	4	-296	0	0	2.6398E-21	2.078E-182	5.71E-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	2.078E-182	5.71E-180	2.6398E-21	2.5152E-12	-2.14E-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	-2.14E-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	2.7898E-12	8.422E-172	2.49E-173	1.831E-16
111	59	52	6	-294	0	0	4.2864E-21	4.357E-181	6.66E-179	4.2864E-21	2.7898E-12	8.422E-172	2.49E-173	1.831E-16
112	63	52	6	-294	0	0	4.2864E-21	4.357E-181	6.66E-179	4.2864E-21	3.1218E-12	-3.28E-171	-9.7E-172	2.0417E-16
113	63	55	7	-293	0	0	5.2387E-21	-1.7E-180	-3.37E-178	5.2387E-21	3.1218E-12	-3.28E-171	-9.7E-172	2.0417E-16
114	67	55	7	-293	0	0	5.2387E-21	-1.7E-180	-3.37E-178	5.2387E-21	3.5524E-12	1.277E-170	3.777E-171	2.316E-16
115	67	58	8	-292	0	0	6.3615E-21	6.60E-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	6.60E-180	1.314E-177	6.3615E-21	4.0614E-12	-4.98E-170	-1.47E-170	2.6470E-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	2.6470E-16
118	76	62	9	-291	0	0	7.6224E-21	-2.57E-179	-5.12E-177	7.6224E-21	4.672E-12	1.939E-169	5.729E-170	3.0493E-16
119	76	65	10	-290	0	0	9.0725E-21	1.002E-178	1.994E-176	9.0725E-21	4.672E-12	1.939E-169	5.729E-170	3.0493E-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	-8.9E-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	-8.9E-178	-7.76E-176	1.0748E-20	6.2568E-12	2.939E-168	8.69E-169	4.379E-16
123	83	81	12	-288	0	0	1.265E-20	1.521E-177	3.024E-175	1.265E-20	6.2568E-12	2.939E-168	8.69E-169	4.379E-16
124	87	71	12	-288	0	0	1.265E-20	1.521E-177	3.024E-175	1.265E-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	2.304E-176	4.58E-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	2.304E-176	4.58E-174	1.7577E-20	9.874E-12	-1.74E-166	-5.18E-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	-5.18E-167	6.4372E-16
130	99	79	15	-285	0	0	2.0642E-20	-8.98E-176	-1.79E-173	2.0642E-20	1.155E-11	6.761E-166	1.999E-166	7.510E-16
131	99	83	16	-284	0	0	2.422E-20	3.498E-175	6.95E-173	2.422E-20	1.155E-11	6.761E-166	1.999E-166	7.510E-16
132	104	83	16	-284	0	0	2.422E-20	3.498E-175	6.95E-173	2.422E-20	1.346E-11	-2.63E-165	-7.79E-166	8.777E-16
133	104	84	17	-283	0	0	2.84E-20	-1.34E-174	-2.71E-172	2.84E-20	1.346E-11	-2.63E-165	-7.79E-166	8.777E-16
134	107	84	17	-283	0	0	3.0465E-20	-8.98E-176	-1.79E-173	3.0465E-20	1.575E-11	1.193E-166	3.033E-165	1.0209E-15
135	107	88	18	-282	0	0	3.3284E-20	5.306E-174	1.095E-171	3.3284E-20	1.575E-11	1.026E-164	3.033E-165	1.0209E-15
136	112	88	18	-282	0	0	3.3284E-20	5.306E-174	1.095E-171	3.3284E-20	1.8998E-11	-3.99E-164	-1.18E-164	1.1948E-15
137	112	92	19	-281	0	0	3.8996E-20	-2.07E-173	-4.11E-171	3.8996E-20	1.8998E-11	-3.99E-164	-1.18E-164	1.1948E-15
138	116	92	19	-281	0	0	3.8996E-20	-2.07E-173	-4.11E-171	3.8996E-20	2.1517E-11	1.595E-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	1.595E-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	-6.04E-163	-1.79E-163	1.641E-15
141	119	96	21	-279	0	0	5.348E-20	-3.13E-172	-6.23E-170	5.348E-20	2.5171E-11	-6.04E-163	-1.79E-163	1.641E-15
142	123	96	21	-279	0	0	5.348E-20	-3.13E-172	-6.23E-170	5.348E-20	2.9451E-11	2.959E-162	6.977E-163	1.92E-15
143	123	99	22	-278	0	0	6.2638E-20	1.221E-171	2.428E-169	6.2638E-20	2.9451E-11	2.959E-162	6.977E-163	1.92E-15

Figure 44: Track Worksheet Tabulated Output for Temperature and Trainset Results of Analysis, Increment 2 (3 of 3)



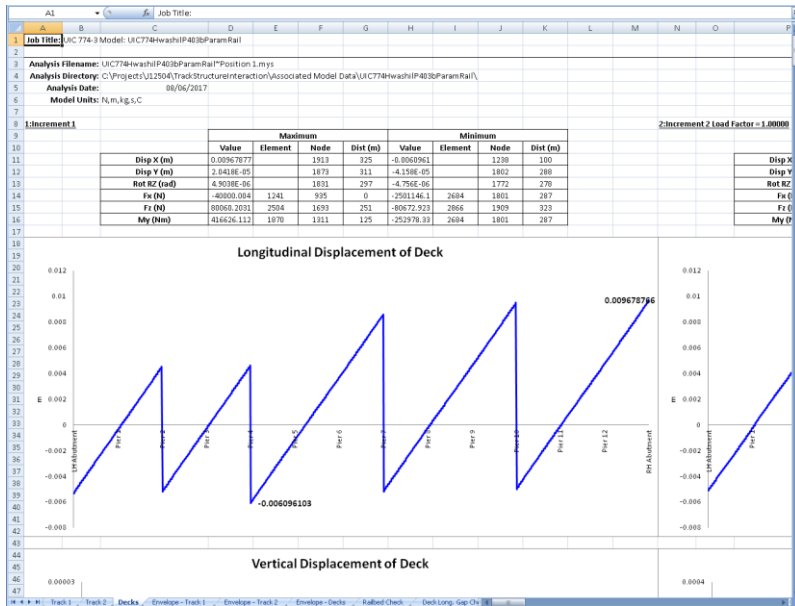


**Figure 45: Track Worksheet for Multiple Results Files**

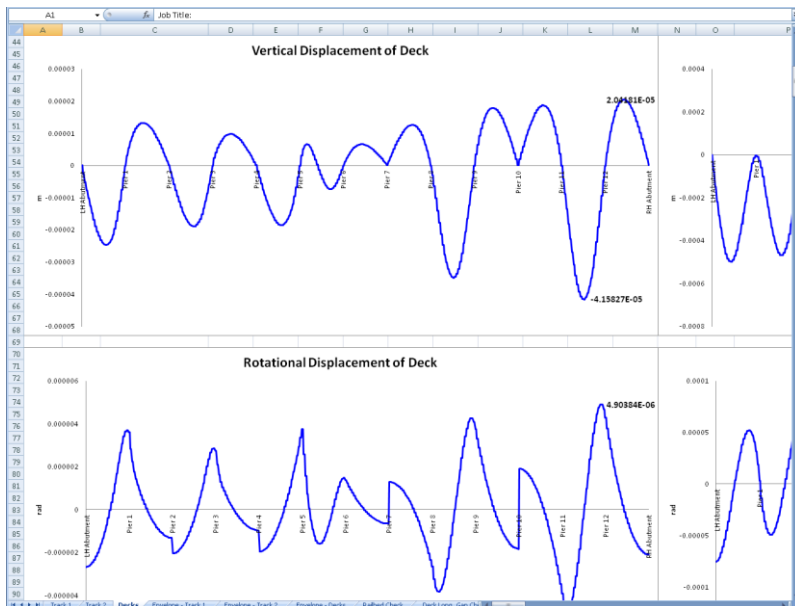
If valid basic combinations or envelopes that match the criteria described in **Post-processing of automatically defined groups** (page 38) are present in the model then additional results for these will be tabulated into the Microsoft Excel worksheets for the tracks. For basic combinations a warning will be added at the top of the extracted results indicating that basic combinations of nonlinear results are not strictly valid. For envelopes all quantities other than the railbed displacements will be calculated for the tracks but the results from LUSAS envelopes will be excluded from any enveloping carried out in Microsoft Excel.

### **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 46 to Figure 49 show the tabulated and graph output generated for the deck for all of the loading conditions included in the analyses. Figure 50 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.



**Figure 46: Deck Worksheet Summary and Longitudinal Displacement Graph for Results of Analysis (1 of 4)**



**Figure 47: Deck Worksheet Vertical and Rotational Displacement Graphs for Results of Analysis (2 of 4)**

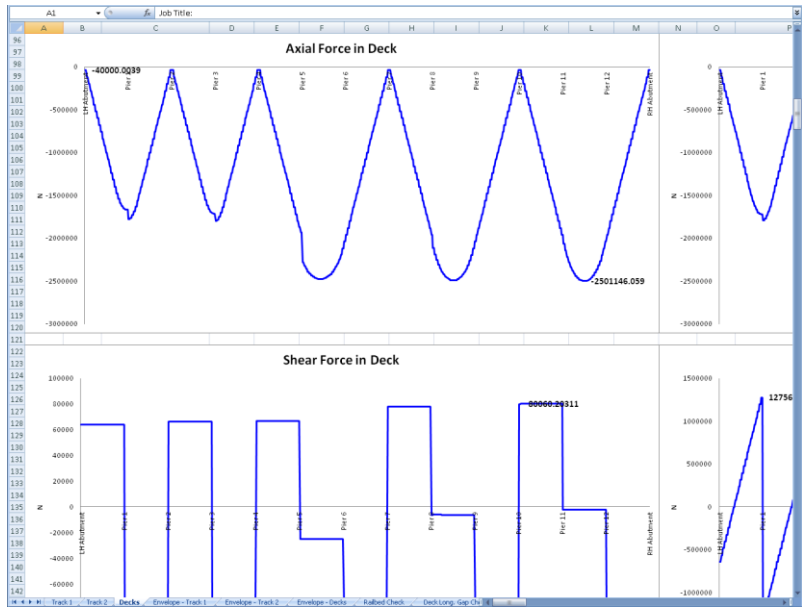


Figure 48: Deck Worksheet Axial and Shear Force Graphs for Results of Analysis (3 of 4)

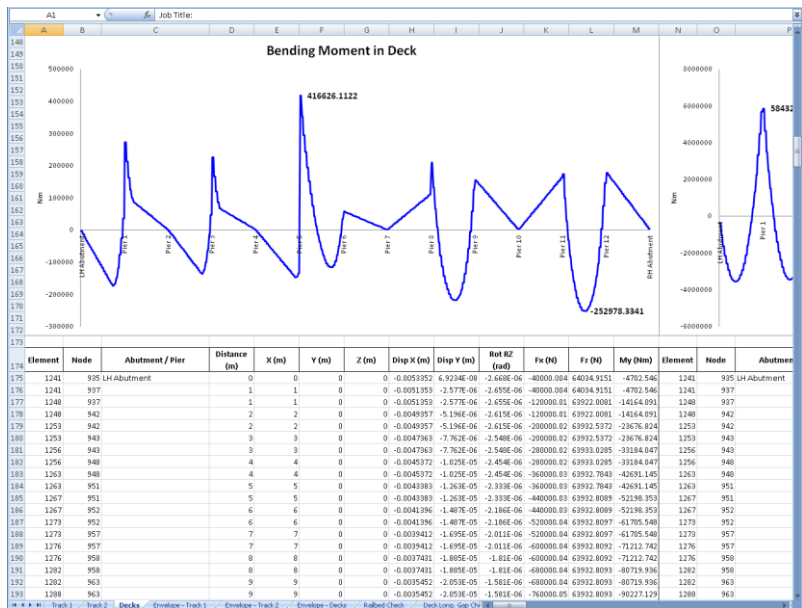
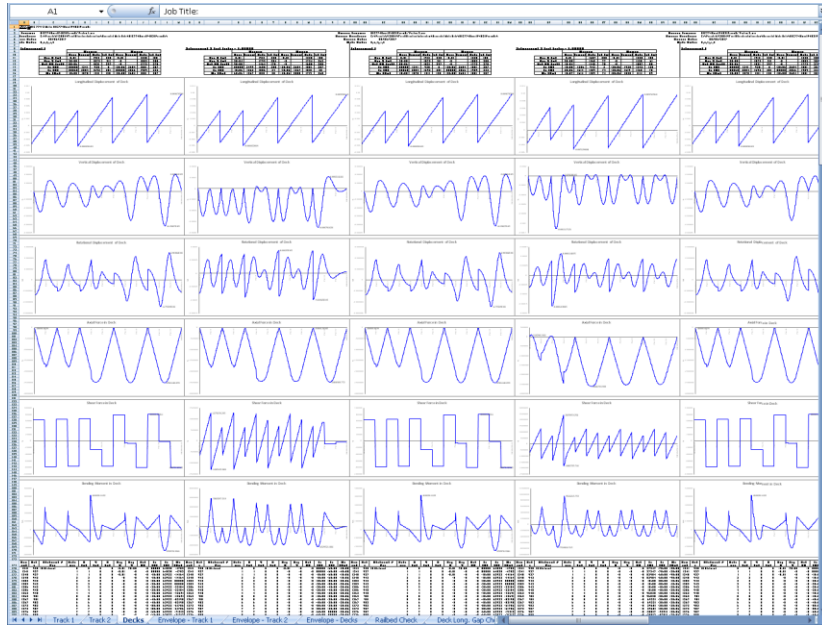


Figure 49: Deck Worksheet Bending Moment Graph and Tabulated Output for Results of Analysis (4 of 4)



**Figure 50: 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 38) are present in the model then additional results for these will be tabulated into the Microsoft Excel 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. For envelopes all quantities will be calculated for the decks but the results from the LUSAS envelopes will be excluded from any enveloping carried out in Microsoft Excel.

## **Additional Results from Enveloping in Microsoft Excel**

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 38) and enveloping in Microsoft Excel has been selected then additional envelope results output is generated by the post-processor in separate worksheets in Microsoft Excel. 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)**

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.

# Rail Track Analysis User Manual

Analysis ID	Results Filename	Track 1		Track 2		Peak Relative Longitudinal Displacement Between Rail and Deck	Track Number with Peak Displacement	Distance from Left End of the Model to the Peak Displacement	Description of Peak Location
		Loading Type	Distance from Left End of the Model to the Starting Position	Distance from Left End of the Model to the Finish	Loading Type				
1	UC7FH4shRP01am-Position Temp	Temperature Only	0	300	Temperature Only	300	600	0.00738007	320 Pea Abotment
2	UC7FH4shRP01am-Position Temp	Braking	0	300	Accelerating	300	600	0.00737926	320 Pea Abotment
3	UC7FH4shRP01am-Position Temp	Braking	15	324	Accelerating	300	600	0.00737328	320 Pea Abotment
4	UC7FH4shRP01am-Position Temp	Braking	30	348	Accelerating	300	600	0.00736730	320 Pea Abotment
5	UC7FH4shRP01am-Position Temp	Braking	45	372	Accelerating	300	600	0.00736132	320 Pea Abotment
6	UC7FH4shRP01am-Position Temp	Braking	60	396	Accelerating	300	600	0.00735534	320 Pea Abotment
7	UC7FH4shRP01am-Position Temp	Braking	75	420	Accelerating	300	600	0.00734936	320 Pea Abotment
8	UC7FH4shRP01am-Position Temp	Braking	90	444	Accelerating	300	600	0.00734338	320 Pea Abotment
9	UC7FH4shRP01am-Position Temp	Braking	105	468	Accelerating	300	600	0.00733740	320 Pea Abotment
10	UC7FH4shRP01am-Position Temp	Braking	120	492	Accelerating	300	600	0.00733142	320 Pea Abotment
11	UC7FH4shRP01am-Position Temp	Braking	135	516	Accelerating	300	600	0.00732544	320 Pea Abotment
12	UC7FH4shRP01am-Position Temp	Braking	150	540	Accelerating	300	600	0.00731946	320 Pea Abotment
13	UC7FH4shRP01am-Position Temp	Braking	165	564	Accelerating	300	600	0.00731348	320 Pea Abotment
14	UC7FH4shRP01am-Position Temp	Braking	180	588	Accelerating	300	600	0.00730750	320 Pea Abotment
15	UC7FH4shRP01am-Position Temp	Braking	195	612	Accelerating	300	600	0.00730152	320 Pea Abotment
16	UC7FH4shRP01am-Position Temp	Braking	210	636	Accelerating	300	600	0.00729554	320 Pea Abotment
17	UC7FH4shRP01am-Position Temp	Braking	225	660	Accelerating	300	600	0.00728956	320 Pea Abotment
18	UC7FH4shRP01am-Position Temp	Braking	240	684	Accelerating	300	600	0.00728358	320 Pea Abotment
19	UC7FH4shRP01am-Position Temp	Braking	255	708	Accelerating	300	600	0.00727760	320 Pea Abotment
20	UC7FH4shRP01am-Position Temp	Braking	270	732	Accelerating	300	600	0.00727162	320 Pea Abotment
21	UC7FH4shRP01am-Position Temp	Braking	285	756	Accelerating	300	600	0.00726564	320 Pea Abotment
22	UC7FH4shRP01am-Position Temp	Braking	300	780	Accelerating	300	600	0.00725966	320 Pea Abotment
23	UC7FH4shRP01am-Position Temp	Braking	315	804	Accelerating	300	600	0.00725368	320 Pea Abotment
24	UC7FH4shRP01am-Position Temp	Braking	330	828	Accelerating	300	600	0.00724770	320 Pea Abotment
25	UC7FH4shRP01am-Position Temp	Braking	345	852	Accelerating	300	600	0.00724172	320 Pea Abotment
26	UC7FH4shRP01am-Position Temp	Braking	360	876	Accelerating	300	600	0.00723574	320 Pea Abotment
27	UC7FH4shRP01am-Position Temp	Braking	375	900	Accelerating	300	600	0.00722976	320 Pea Abotment
28	UC7FH4shRP01am-Position Temp	Braking	390	924	Accelerating	300	600	0.00722378	320 Pea Abotment
29	UC7FH4shRP01am-Position Temp	Braking	405	948	Accelerating	300	600	0.00721780	320 Pea Abotment
30	UC7FH4shRP01am-Position Temp	Braking	420	972	Accelerating	300	600	0.00721182	320 Pea Abotment
31	UC7FH4shRP01am-Position Temp	Braking	435	996	Accelerating	300	600	0.00720584	320 Pea Abotment
32	UC7FH4shRP01am-Position Temp	Braking	450	1020	Accelerating	300	600	0.00719986	320 Pea Abotment
33	UC7FH4shRP01am-Position Temp	Braking	465	1044	Accelerating	300	600	0.00719388	320 Pea Abotment
34	UC7FH4shRP01am-Position Temp	Braking	480	1068	Accelerating	300	600	0.00718790	320 Pea Abotment
35	UC7FH4shRP01am-Position Temp	Braking	495	1092	Accelerating	300	600	0.00718192	320 Pea Abotment
36	UC7FH4shRP01am-Position Temp	Braking	510	1116	Accelerating	300	600	0.00717594	320 Pea Abotment
37	UC7FH4shRP01am-Position Temp	Braking	525	1140	Accelerating	300	600	0.00716996	320 Pea Abotment
38	UC7FH4shRP01am-Position Temp	Braking	540	1164	Accelerating	300	600	0.00716398	320 Pea Abotment
39	UC7FH4shRP01am-Position Temp	Braking	555	1188	Accelerating	300	600	0.00715800	320 Pea Abotment
40	UC7FH4shRP01am-Position Temp	Braking	570	1212	Accelerating	300	600	0.00715202	320 Pea Abotment
41	UC7FH4shRP01am-Position Temp	Braking	585	1236	Accelerating	300	600	0.00714604	320 Pea Abotment
42	UC7FH4shRP01am-Position Temp	Braking	600	1260	Accelerating	300	600	0.00714006	320 Pea Abotment
43	UC7FH4shRP01am-Position Temp	Braking	615	1284	Accelerating	300	600	0.00713408	320 Pea Abotment
44	UC7FH4shRP01am-Position Temp	Braking	630	1308	Accelerating	300	600	0.00712810	320 Pea Abotment
45	UC7FH4shRP01am-Position Temp	Braking	645	1332	Accelerating	300	600	0.00712212	320 Pea Abotment
46	UC7FH4shRP01am-Position Temp	Braking	660	1356	Accelerating	300	600	0.00711614	320 Pea Abotment
47	UC7FH4shRP01am-Position Temp	Braking	675	1380	Accelerating	300	600	0.00711016	320 Pea Abotment
48	UC7FH4shRP01am-Position Temp	Braking	690	1404	Accelerating	300	600	0.00710418	320 Pea Abotment
49	UC7FH4shRP01am-Position Temp	Braking	705	1428	Accelerating	300	600	0.00709820	320 Pea Abotment
50	UC7FH4shRP01am-Position Temp	Braking	720	1452	Accelerating	300	600	0.00709222	320 Pea Abotment
51	UC7FH4shRP01am-Position Temp	Braking	735	1476	Accelerating	300	600	0.00708624	320 Pea Abotment
52	UC7FH4shRP01am-Position Temp	Braking	750	1500	Accelerating	300	600	0.00708026	320 Pea Abotment
53	UC7FH4shRP01am-Position Temp	Braking	765	1524	Accelerating	300	600	0.00707428	320 Pea Abotment
54	UC7FH4shRP01am-Position Temp	Braking	780	1548	Accelerating	300	600	0.00706830	320 Pea Abotment
55	UC7FH4shRP01am-Position Temp	Braking	795	1572	Accelerating	300	600	0.00706232	320 Pea Abotment
56	UC7FH4shRP01am-Position Temp	Braking	810	1596	Accelerating	300	600	0.00705634	320 Pea Abotment
57	UC7FH4shRP01am-Position Temp	Braking	825	1620	Accelerating	300	600	0.00705036	320 Pea Abotment
58	UC7FH4shRP01am-Position Temp	Braking	840	1644	Accelerating	300	600	0.00704438	320 Pea Abotment
59	UC7FH4shRP01am-Position Temp	Braking	855	1668	Accelerating	300	600	0.00703840	320 Pea Abotment
60	UC7FH4shRP01am-Position Temp	Braking	870	1692	Accelerating	300	600	0.00703242	320 Pea Abotment
61	UC7FH4shRP01am-Position Temp	Braking	885	1716	Accelerating	300	600	0.00702644	320 Pea Abotment
62	UC7FH4shRP01am-Position Temp	Braking	900	1740	Accelerating	300	600	0.00702046	320 Pea Abotment
63	UC7FH4shRP01am-Position Temp	Braking	915	1764	Accelerating	300	600	0.00701448	320 Pea Abotment
64	UC7FH4shRP01am-Position Temp	Braking	930	1788	Accelerating	300	600	0.00700850	320 Pea Abotment
65	UC7FH4shRP01am-Position Temp	Braking	945	1812	Accelerating	300	600	0.00700252	320 Pea Abotment
66	UC7FH4shRP01am-Position Temp	Braking	960	1836	Accelerating	300	600	0.00699654	320 Pea Abotment
67	UC7FH4shRP01am-Position Temp	Braking	975	1860	Accelerating	300	600	0.00699056	320 Pea Abotment
68	UC7FH4shRP01am-Position Temp	Braking	990	1884	Accelerating	300	600	0.00698458	320 Pea Abotment
69	UC7FH4shRP01am-Position Temp	Braking	1005	1908	Accelerating	300	600	0.00697860	320 Pea Abotment
70	UC7FH4shRP01am-Position Temp	Braking	1020	1932	Accelerating	300	600	0.00697262	320 Pea Abotment
71	UC7FH4shRP01am-Position Temp	Braking	1035	1956	Accelerating	300	600	0.00696664	320 Pea Abotment
72	UC7FH4shRP01am-Position Temp	Braking	1050	1980	Accelerating	300	600	0.00696066	320 Pea Abotment
73	UC7FH4shRP01am-Position Temp	Braking	1065	2004	Accelerating	300	600	0.00695468	320 Pea Abotment
74	UC7FH4shRP01am-Position Temp	Braking	1080	2028	Accelerating	300	600	0.00694870	320 Pea Abotment
75	UC7FH4shRP01am-Position Temp	Braking	1095	2052	Accelerating	300	600	0.00694272	320 Pea Abotment
76	UC7FH4shRP01am-Position Temp	Braking	1110	2076	Accelerating	300	600	0.00693674	320 Pea Abotment
77	UC7FH4shRP01am-Position Temp	Braking	1125	2100	Accelerating	300	600	0.00693076	320 Pea Abotment
78	UC7FH4shRP01am-Position Temp	Braking	1140	2124	Accelerating	300	600	0.00692478	320 Pea Abotment
79	UC7FH4shRP01am-Position Temp	Braking	1155	2148	Accelerating	300	600	0.00691880	320 Pea Abotment
80	UC7FH4shRP01am-Position Temp	Braking	1170	2172	Accelerating	300	600	0.00691282	320 Pea Abotment
81	UC7FH4shRP01am-Position Temp	Braking	1185	2196	Accelerating	300	600	0.00690684	320 Pea Abotment
82	UC7FH4shRP01am-Position Temp	Braking	1200	2220	Accelerating	300	600	0.00690086	320 Pea Abotment
83	UC7FH4shRP01am-Position Temp	Braking	1215	2244	Accelerating	300	600	0.00689488	320 Pea Abotment
84	UC7FH4shRP01am-Position Temp	Braking	1230	2268	Accelerating	300	600	0.00688890	320 Pea Abotment
85	UC7FH4shRP01am-Position Temp	Braking	1245	2292	Accelerating	300	600	0.00688292	320 Pea Abotment
86	UC7FH4shRP01am-Position Temp	Braking	1260	2316	Accelerating	300	600	0.00687694	320 Pea Abotment
87	UC7FH4shRP01am-Position Temp	Braking	1275	2340	Accelerating	300	600	0.00687096	320 Pea Abotment
88	UC7FH4shRP01am-Position Temp	Braking	1290	2364	Accelerating	300	600	0.00686498	320 Pea Abotment
89	UC7FH4shRP01am-Position Temp	Braking	1305	2388	Accelerating	300	600	0.00685900	320 Pea Abotment
90	UC7FH4shRP01am-Position Temp	Braking	1320	2412	Accelerating	300	600	0.00685302	320 Pea Abotment
91	UC7FH4shRP01am-Position Temp	Braking	1335	2436	Accelerating	300	600	0.00684704	320 Pea Abotment
92	UC7FH4shRP01am-Position Temp	Braking	1350	2460	Accelerating	300	600	0.00684106	320 Pea Abotment
93	UC7FH4shRP01am-Position Temp	Braking	1365	2484	Accelerating	300	600	0.00683508	320 Pea Abotment
94	UC7FH4shRP01am-Position Temp	Braking	1380	2508	Accelerating	300	600	0.00682910	320 Pea Abotment
95	UC7FH4shRP01am-Position Temp	Braking	1395	2532	Accelerating	300	600	0.00682312	320 Pea Abotment
96	UC7FH4shRP01am-Position Temp	Braking	1410	2556	Accelerating	300	600	0.00681714	320 Pea Abotment
97	UC7FH4shRP01am-Position Temp	Braking	1425	2580	Accelerating	300	600	0.00681116	320 Pea Abotment
98	UC7FH4shRP01am-Position Temp	Braking	1440	2604	Accelerating	300	600	0.00680518	320 Pea Abotment
99	UC7FH4shRP01am-Position Temp	Braking	1455	2628	Accelerating	300	600	0.00679920	320 Pea Abotment
100	UC7FH4shRP01am-Position Temp	Braking	1470	2652	Accelerating	300	600	0.00679322	320 Pea Abotment
101	UC7FH4shRP01am-Position Temp	Braking	1485	2676	Accelerating	300	600	0.00678724	320 Pea Abotment
102	UC7FH4shRP01am-Position Temp	Braking	1500	2700	Accelerating	300	600	0.00678126	320 Pea Abotment
103	UC7FH4shRP01am-Position Temp	Braking	1515	2724	Accelerating	300	600	0.00677528	320 Pea Abotment
104	UC7FH4shRP01am-Position Temp	Braking	1530	2748	Accelerating	300	600	0.00676930	320 Pea Abotment
105	UC7FH4shRP01am-Position Temp	Braking	1545	2772	Accelerating	300	600	0.00676332	320 Pea Abotment
106	UC7FH4shRP01am-Position Temp	Braking	1560	2796	Accelerating	300	600	0.00675734	320 Pea Abotment
107	UC7FH4shRP01am-Position Temp	Braking	1575	2820	Accelerating	300	600	0.00675136	320 Pea Abotment
108	UC7FH4shRP01am-Position Temp	Braking	1590	2844	Accelerating	300	600	0.00674538	320 Pea Abotment
109	UC7FH4shRP01am-Position Temp	Braking	1605	2868	Accelerating	300	600	0.00673940	320 Pea Abotment
110	UC7FH4shRP01am-Position Temp	Braking	1620	2892	Accelerating	300	600	0.00673342	320 Pea Abotment
111	UC7FH4shRP01am-Position Temp	Braking	1635	2916	Accelerating	300	600	0.00672744	320 Pea Abotment
112	UC7FH4shRP01am-Position Temp	Braking	1650	2940	Accelerating	300	600	0.00672146	320 Pea Abotment
113	UC7FH4shRP01am-Position Temp	Braking	1665	2964	Accelerating	300	600	0.00671548	320 Pea Abotment
114	UC7FH4shRP01am-Position Temp	Braking	1680	2988	Accelerating	300	600	0.00670950	320 Pea Abotment
115	UC7FH4shRP01am-Position Temp	Braking	1695	3012	Accelerating	300	600	0.00670352	320 Pea Abotment
116	UC7FH4shRP01am-Position Temp	Braking	1710	3036	Accelerating	300	600	0.00669754	320 Pea Abotment
117	UC7FH4shRP01am-Position Temp								

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

**Job Title:** UC 774-3 Model UC774ash0P0eam  
**Analysis Filename:** UC774ash0P0eamPosition1 - UC774ash0P0eamPosition10  
**Model Name:** UC774ash0P0eamPosition10  
**Analysis Date:** 09/06/2017 - 09/06/2017  
**Model User:** A.C.

Analysis ID	Results Filename	Track 1		Track 2		Pier Number	Supporting Deck with Peak Displacement
		Loading Type	Distance from Left End of the Model to the Starting	Distance from Left End of the Model to the Finishing	Loading Type		
1	UC774ash0P0eamPosition1.mst	Temperature Only	0	300	Accelerating Only	300	600
2	UC774ash0P0eamPosition2.mst	Dwelling	1.25	300	Accelerating	303.25	603.25
3	UC774ash0P0eamPosition3.mst	Dwelling	0.25	37.5	Accelerating	300.5	600.5
4	UC774ash0P0eamPosition4.mst	Dwelling	18.75	37.5	Accelerating	309.75	609.75
5	UC774ash0P0eamPosition5.mst	Dwelling	25	37.5	Accelerating	313	613
6	UC774ash0P0eamPosition6.mst	Dwelling	31.25	37.5	Accelerating	316.25	616.25
7	UC774ash0P0eamPosition7.mst	Dwelling	37.5	37.5	Accelerating	319.5	619.5
8	UC774ash0P0eamPosition8.mst	Dwelling	43.75	37.5	Accelerating	322.75	622.75
9	UC774ash0P0eamPosition9.mst	Dwelling	50	37.5	Accelerating	326	626
10	UC774ash0P0eamPosition10.mst	Dwelling	56.25	37.5	Accelerating	329.25	629.25
11	UC774ash0P0eamPosition11.mst	Dwelling	62.5	37.5	Accelerating	332.5	632.5
12	UC774ash0P0eamPosition12.mst	Dwelling	68.75	37.5	Accelerating	335.75	635.75
13	UC774ash0P0eamPosition13.mst	Dwelling	75	37.5	Accelerating	339	639
14	UC774ash0P0eamPosition14.mst	Dwelling	81.25	37.5	Accelerating	342.25	642.25
15	UC774ash0P0eamPosition15.mst	Dwelling	87.5	37.5	Accelerating	345.5	645.5
16	UC774ash0P0eamPosition16.mst	Dwelling	93.75	37.5	Accelerating	348.75	648.75
17	UC774ash0P0eamPosition17.mst	Dwelling	100	37.5	Accelerating	352	652
18	UC774ash0P0eamPosition18.mst	Dwelling	106.25	37.5	Accelerating	355.25	655.25
19	UC774ash0P0eamPosition19.mst	Dwelling	112.5	41.25	Accelerating	358.5	658.5
20	UC774ash0P0eamPosition20.mst	Dwelling	118.75	41.25	Accelerating	361.75	661.75
21	UC774ash0P0eamPosition 21.mst	Dwelling	125	41.25	Accelerating	365	665
22	UC774ash0P0eamPosition22.mst	Dwelling	131.25	41.25	Accelerating	368.25	668.25
23	UC774ash0P0eamPosition23.mst	Dwelling	137.5	41.25	Accelerating	371.5	671.5
24	UC774ash0P0eamPosition24.mst	Dwelling	143.75	41.25	Accelerating	374.75	674.75
25	UC774ash0P0eamPosition25.mst	Dwelling	150	45	Accelerating	378	678
26	UC774ash0P0eamPosition26.mst	Dwelling	156.25	45	Accelerating	381.25	681.25
27	UC774ash0P0eamPosition27.mst	Dwelling	162.5	45	Accelerating	384.5	684.5
28	UC774ash0P0eamPosition28.mst	Dwelling	168.75	45	Accelerating	387.75	687.75
29	UC774ash0P0eamPosition29.mst	Dwelling	175	48.75	Accelerating	391	691
30	UC774ash0P0eamPosition30.mst	Dwelling	181.25	48.75	Accelerating	394.25	694.25
31	UC774ash0P0eamPosition31.mst	Dwelling	187.5	48.75	Accelerating	397.5	697.5
32	UC774ash0P0eamPosition32.mst	Dwelling	193.75	48.75	Accelerating	400.75	700.75
33	UC774ash0P0eamPosition33.mst	Dwelling	200	52.5	Accelerating	404	704
34	UC774ash0P0eamPosition34.mst	Dwelling	206.25	52.5	Accelerating	407.25	707.25
35	UC774ash0P0eamPosition35.mst	Dwelling	212.5	52.5	Accelerating	410.5	710.5
36	UC774ash0P0eamPosition36.mst	Dwelling	218.75	56.25	Accelerating	413.75	713.75
37	UC774ash0P0eamPosition37.mst	Dwelling	225	56.25	Accelerating	417	717
38	UC774ash0P0eamPosition38.mst	Dwelling	231.25	56.25	Accelerating	420.25	720.25
39	UC774ash0P0eamPosition39.mst	Dwelling	237.5	56.25	Accelerating	423.5	723.5
40	UC774ash0P0eamPosition40.mst	Dwelling	243.75	54.75	Accelerating	426.75	726.75
41	UC774ash0P0eamPosition41.mst	Dwelling	250	54.75	Accelerating	430	730
42	UC774ash0P0eamPosition42.mst	Dwelling	256.25	58.25	Accelerating	433.25	733.25
43	UC774ash0P0eamPosition43.mst	Dwelling	262.5	58.25	Accelerating	436.5	736.5
44	UC774ash0P0eamPosition44.mst	Dwelling	268.75	58.25	Accelerating	439.75	739.75
45	UC774ash0P0eamPosition45.mst	Dwelling	275	61.75	Accelerating	443	743
46	UC774ash0P0eamPosition46.mst	Dwelling	281.25	61.75	Accelerating	446.25	746.25
47	UC774ash0P0eamPosition47.mst	Dwelling	287.5	61.75	Accelerating	449.5	749.5
48	UC774ash0P0eamPosition48.mst	Dwelling	293.75	65.25	Accelerating	452.75	752.75
49	UC774ash0P0eamPosition49.mst	Dwelling	300	65.25	Accelerating	456	756
50	UC774ash0P0eamPosition50.mst	Dwelling	306.25	65.25	Accelerating	459.25	759.25
51	UC774ash0P0eamPosition51.mst	Dwelling	312.5	62.5	Accelerating	462.5	762.5
52	UC774ash0P0eamPosition52.mst	Dwelling	318.75	62.5	Accelerating	465.75	765.75
53	UC774ash0P0eamPosition53.mst	Dwelling	325	62.5	Accelerating	469	769
54	UC774ash0P0eamPosition54.mst	Dwelling	331.25	62.5	Accelerating	472.25	772.25
55	UC774ash0P0eamPosition55.mst	Dwelling	337.5	63.75	Accelerating	475.5	775.5
56	UC774ash0P0eamPosition56.mst	Dwelling	343.75	63.75	Accelerating	478.75	778.75
57	UC774ash0P0eamPosition57.mst	Dwelling	350	60	Accelerating	482	782
58	UC774ash0P0eamPosition58.mst	Dwelling	356.25	60	Accelerating	485.25	785.25
59	UC774ash0P0eamPosition59.mst	Dwelling	362.5	60	Accelerating	488.5	788.5
60	UC774ash0P0eamPosition60.mst	Dwelling	368.75	60	Accelerating	491.75	791.75

**Figure 53: 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:** UC 774-3 Model UC774ash0P0eam  
**Analysis Filename:** UC774ash0P0eamPosition1 - UC774ash0P0eamPosition10  
**Model Name:** UC774ash0P0eamPosition10  
**Analysis Date:** 09/06/2017 - 09/06/2017  
**Model User:** A.C.

Analysis ID	Results Filename	Track 1		Track 2		Pier Number	Supporting Deck with Peak Displacement
		Loading Type	Distance from Left End of the Model to the Starting	Distance from Left End of the Model to the Finishing	Loading Type		
1	UC774ash0P0eamPosition1.mst	Temperature Only	0	300	Accelerating Only	300	600
2	UC774ash0P0eamPosition2.mst	Dwelling	1.25	300	Accelerating	303.25	603.25
3	UC774ash0P0eamPosition3.mst	Dwelling	0.25	37.5	Accelerating	300.5	600.5
4	UC774ash0P0eamPosition4.mst	Dwelling	18.75	37.5	Accelerating	309.75	609.75
5	UC774ash0P0eamPosition5.mst	Dwelling	25	37.5	Accelerating	313	613
6	UC774ash0P0eamPosition6.mst	Dwelling	31.25	37.5	Accelerating	316.25	616.25
7	UC774ash0P0eamPosition7.mst	Dwelling	37.5	37.5	Accelerating	319.5	619.5
8	UC774ash0P0eamPosition8.mst	Dwelling	43.75	37.5	Accelerating	322.75	622.75
9	UC774ash0P0eamPosition9.mst	Dwelling	50	37.5	Accelerating	326	626
10	UC774ash0P0eamPosition10.mst	Dwelling	56.25	37.5	Accelerating	329.25	629.25
11	UC774ash0P0eamPosition11.mst	Dwelling	62.5	37.5	Accelerating	332.5	632.5
12	UC774ash0P0eamPosition12.mst	Dwelling	68.75	37.5	Accelerating	335.75	635.75
13	UC774ash0P0eamPosition13.mst	Dwelling	75	37.5	Accelerating	339	639
14	UC774ash0P0eamPosition14.mst	Dwelling	81.25	37.5	Accelerating	342.25	642.25
15	UC774ash0P0eamPosition15.mst	Dwelling	87.5	37.5	Accelerating	345.5	645.5
16	UC774ash0P0eamPosition16.mst	Dwelling	93.75	37.5	Accelerating	348.75	648.75
17	UC774ash0P0eamPosition17.mst	Dwelling	100	37.5	Accelerating	352	652
18	UC774ash0P0eamPosition18.mst	Dwelling	106.25	37.5	Accelerating	355.25	655.25
19	UC774ash0P0eamPosition19.mst	Dwelling	112.5	41.25	Accelerating	358.5	658.5
20	UC774ash0P0eamPosition20.mst	Dwelling	118.75	41.25	Accelerating	361.75	661.75
21	UC774ash0P0eamPosition 21.mst	Dwelling	125	41.25	Accelerating	365	665
22	UC774ash0P0eamPosition22.mst	Dwelling	131.25	41.25	Accelerating	368.25	668.25
23	UC774ash0P0eamPosition23.mst	Dwelling	137.5	41.25	Accelerating	371.5	671.5
24	UC774ash0P0eamPosition24.mst	Dwelling	143.75	41.25	Accelerating	374.75	674.75
25	UC774ash0P0eamPosition25.mst	Dwelling	150	45	Accelerating	378	678
26	UC774ash0P0eamPosition26.mst	Dwelling	156.25	45	Accelerating	381.25	681.25
27	UC774ash0P0eamPosition27.mst	Dwelling	162.5	45	Accelerating	384.5	684.5
28	UC774ash0P0eamPosition28.mst	Dwelling	168.75	45	Accelerating	387.75	687.75
29	UC774ash0P0eamPosition29.mst	Dwelling	175	48.75	Accelerating	391	691
30	UC774ash0P0eamPosition30.mst	Dwelling	181.25	48.75	Accelerating	394.25	694.25
31	UC774ash0P0eamPosition31.mst	Dwelling	187.5	48.75	Accelerating	397.5	697.5
32	UC774ash0P0eamPosition32.mst	Dwelling	193.75	48.75	Accelerating	400.75	700.75
33	UC774ash0P0eamPosition33.mst	Dwelling	200	52.5	Accelerating	404	704
34	UC774ash0P0eamPosition34.mst	Dwelling	206.25	52.5	Accelerating	407.25	707.25
35	UC774ash0P0eamPosition35.mst	Dwelling	212.5	52.5	Accelerating	410.5	710.5
36	UC774ash0P0eamPosition36.mst	Dwelling	218.75	56.25	Accelerating	413.75	713.75
37	UC774ash0P0eamPosition37.mst	Dwelling	225	56.25	Accelerating	417	717
38	UC774ash0P0eamPosition38.mst	Dwelling	231.25	56.25	Accelerating	420.25	720.25
39	UC774ash0P0eamPosition39.mst	Dwelling	237.5	56.25	Accelerating	423.5	723.5
40	UC774ash0P0eamPosition40.mst	Dwelling	243.75	54.75	Accelerating	426.75	726.75
41	UC774ash0P0eamPosition41.mst	Dwelling	250	54.75	Accelerating	430	730
42	UC774ash0P0eamPosition42.mst	Dwelling	256.25	58.25	Accelerating	433.25	733.25
43	UC774ash0P0eamPosition43.mst	Dwelling	262.5	58.25	Accelerating	436.5	736.5
44	UC774ash0P0eamPosition44.mst	Dwelling	268.75	58.25	Accelerating	439.75	739.75
45	UC774ash0P0eamPosition45.mst	Dwelling	275	61.75	Accelerating	443	743
46	UC774ash0P0eamPosition46.mst	Dwelling	281.25	61.75	Accelerating	446.25	746.25
47	UC774ash0P0eamPosition47.mst	Dwelling	287.5	61.75	Accelerating	449.5	749.5
48	UC774ash0P0eamPosition48.mst	Dwelling	293.75	65.25	Accelerating	452.75	752.75
49	UC774ash0P0eamPosition49.mst	Dwelling	300	65.25	Accelerating	456	756
50	UC774ash0P0eamPosition50.mst	Dwelling	306.25	65.25	Accelerating	459.25	759.25
51	UC774ash0P0eamPosition51.mst	Dwelling	312.5	62.5	Accelerating	462.5	762.5
52	UC774ash0P0eamPosition52.mst	Dwelling	318.75	62.5	Accelerating	465.75	765.75
53	UC774ash0P0eamPosition53.mst	Dwelling	325	62.5	Accelerating	469	769
54	UC774ash0P0eamPosition54.mst	Dwelling	331.25	62.5	Accelerating	472.25	772.25
55	UC774ash0P0eamPosition55.mst	Dwelling	337.5	63.75	Accelerating	475.5	775.5
56	UC774ash0P0eamPosition56.mst	Dwelling	343.75	63.75	Accelerating	478.75	778.75
57	UC774ash0P0eamPosition57.mst	Dwelling	350	60	Accelerating	482	782
58	UC774ash0P0eamPosition58.mst	Dwelling	356.25	60	Accelerating	485.25	785.25
59	UC774ash0P0eamPosition59.mst	Dwelling	362.5	60	Accelerating	488.5	788.5
60	UC774ash0P0eamPosition60.mst	Dwelling	368.75	60	Accelerating	491.75	791.75

**Figure 54: Longitudinal Deck End Displacement due to Total Effects Check Worksheet for Multiple Results Files**

# Rail Track Analysis User Manual

Check of Vertical Relative Displacement between Ends of Decks										
Job Title: UC-774-35Model UC774a.tbl#9Param										
Analysis Filename: UC774a.tbl#9ParamPosition 1 - UC774a.tbl#9ParamPosition 01										
Model Director: C:\ProgramData\RailSoft\Exec\userman										
Analysis Date: 09/06/2017 -> 09/06/2017										
Model User: N.Najjar,C										
Analysis ID	Results Filename	Loading Type	Track 1		Track 2		Peak Relative Vertical Displacement between Ends of Decks. Positive = Near deck 1 failure and Negative = Near deck 2 failure. Higher than previous. Near deck 2 displacement lower than that	Vertical Displacement	Peak Number	Number of Supporting Decks with Peak Displacement
			Distance from Left End of the Model to the Seating Position of the Loading (m)	Distance from Left End of the Model to the Fastening Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Seating Position of the Loading (m)				
1	UC774a.tbl#9ParamPosition 1.mtr	Temperature Only								
14	UC774a.tbl#9ParamPosition 1.mtr	Beating	0	300	Accelerating	300	600	-7.2553E-07	14	1
15	UC774a.tbl#9ParamPosition 1.mtr	Beating	6.25	300	Accelerating	300.5	600.5	-1.5448E-07	14	1
16	UC774a.tbl#9ParamPosition 1.mtr	Beating	12.5	312	Accelerating	306.5	606.5	-1.6033E-06	14	1
17	UC774a.tbl#9ParamPosition 1.mtr	Beating	18.75	318	Accelerating	309.75	609.75	-9.9202E-07	14	1
18	UC774a.tbl#9ParamPosition 1.mtr	Beating	25	325	Accelerating	313	613	-9.8955E-07	14	1
19	UC774a.tbl#9ParamPosition 1.mtr	Beating	31.25	332	Accelerating	316.25	616.25	-1.3737E-06	14	1
20	UC774a.tbl#9ParamPosition 1.mtr	Beating	37.5	337.5	Accelerating	319.5	619.5	-8.5236E-07	14	1
21	UC774a.tbl#9ParamPosition 1.mtr	Beating	43.75	343	Accelerating	322.75	622.75	-6.2448E-07	14	1
22	UC774a.tbl#9ParamPosition 1.mtr	Beating	50	350	Accelerating	326	626	9.6599E-07	14	2
23	UC774a.tbl#9ParamPosition 1.mtr	Beating	56.25	356.25	Accelerating	329.25	629.25	7.7957E-07	14	2
24	UC774a.tbl#9ParamPosition 1.mtr	Beating	62.5	362.5	Accelerating	332.5	632.5	7.7959E-07	14	2
25	UC774a.tbl#9ParamPosition 1.mtr	Beating	68.75	368.75	Accelerating	335.75	635.75	6.0678E-07	14	2
26	UC774a.tbl#9ParamPosition 1.mtr	Beating	75	375	Accelerating	339	639	7.7939E-07	14	2
27	UC774a.tbl#9ParamPosition 1.mtr	Beating	81.25	381.25	Accelerating	342.25	642.25	7.7937E-07	14	2
28	UC774a.tbl#9ParamPosition 1.mtr	Beating	87.5	387.5	Accelerating	345.5	645.5	7.7936E-07	14	2
29	UC774a.tbl#9ParamPosition 1.mtr	Beating	93.75	393.75	Accelerating	348.75	648.75	7.7935E-07	14	2
30	UC774a.tbl#9ParamPosition 1.mtr	Beating	100	400	Accelerating	352	652	7.79439E-07	14	2
31	UC774a.tbl#9ParamPosition 1.mtr	Beating	106.25	406.25	Accelerating	355.25	655.25	7.7927E-07	14	2
32	UC774a.tbl#9ParamPosition 1.mtr	Beating	112.5	412.5	Accelerating	358.5	658.5	7.7937E-07	14	2
33	UC774a.tbl#9ParamPosition 1.mtr	Beating	118.75	418.75	Accelerating	361.75	661.75	7.7937E-07	14	2
34	UC774a.tbl#9ParamPosition 1.mtr	Beating	125	425	Accelerating	365	665	7.7937E-07	14	2
35	UC774a.tbl#9ParamPosition 1.mtr	Beating	131.25	431.25	Accelerating	368.25	668.25	7.7937E-07	14	2
36	UC774a.tbl#9ParamPosition 1.mtr	Beating	137.5	437.5	Accelerating	371.5	671.5	7.7934E-07	14	2
37	UC774a.tbl#9ParamPosition 1.mtr	Beating	143.75	443.75	Accelerating	374.75	674.75	7.7934E-07	14	2
38	UC774a.tbl#9ParamPosition 1.mtr	Beating	150	450	Accelerating	378	678	7.7934E-07	14	2
39	UC774a.tbl#9ParamPosition 1.mtr	Beating	156.25	456.25	Accelerating	381.25	681.25	7.7932E-07	14	2
40	UC774a.tbl#9ParamPosition 1.mtr	Beating	162.5	462.5	Accelerating	384.5	684.5	7.7932E-07	14	2
41	UC774a.tbl#9ParamPosition 1.mtr	Beating	168.75	468.75	Accelerating	387.75	687.75	7.7932E-07	14	2
42	UC774a.tbl#9ParamPosition 1.mtr	Beating	175	475	Accelerating	391	691	8.5526E-07	14	2
43	UC774a.tbl#9ParamPosition 1.mtr	Beating	181.25	481.25	Accelerating	394.25	694.25	1.7793E-06	14	2
44	UC774a.tbl#9ParamPosition 1.mtr	Beating	187.5	487.5	Accelerating	397.5	697.5	7.7938E-07	14	2
45	UC774a.tbl#9ParamPosition 1.mtr	Beating	193.75	493.75	Accelerating	400.75	700.75	7.7937E-07	14	2
46	UC774a.tbl#9ParamPosition 1.mtr	Beating	200	500	Accelerating	404	704	7.6232E-07	14	2
47	UC774a.tbl#9ParamPosition 1.mtr	Beating	206.25	506.25	Accelerating	407.25	707.25	7.6232E-07	14	2
48	UC774a.tbl#9ParamPosition 1.mtr	Beating	212.5	512.5	Accelerating	410.5	710.5	7.6232E-07	14	2
49	UC774a.tbl#9ParamPosition 1.mtr	Beating	218.75	518.75	Accelerating	413.75	713.75	7.6232E-07	14	2
50	UC774a.tbl#9ParamPosition 1.mtr	Beating	225	525	Accelerating	417	717	7.6232E-07	14	2
51	UC774a.tbl#9ParamPosition 1.mtr	Beating	231.25	531.25	Accelerating	420.25	720.25	7.6232E-07	14	2
52	UC774a.tbl#9ParamPosition 1.mtr	Beating	237.5	537.5	Accelerating	423.5	723.5	7.6232E-07	14	2
53	UC774a.tbl#9ParamPosition 1.mtr	Beating	243.75	543.75	Accelerating	426.75	726.75	7.6232E-07	14	2
54	UC774a.tbl#9ParamPosition 1.mtr	Beating	250	550	Accelerating	430	730	8.2034E-07	14	2
55	UC774a.tbl#9ParamPosition 1.mtr	Beating	256.25	556.25	Accelerating	433.25	733.25	7.6232E-07	14	2
56	UC774a.tbl#9ParamPosition 1.mtr	Beating	262.5	562.5	Accelerating	436.5	736.5	7.6232E-07	14	2
57	UC774a.tbl#9ParamPosition 1.mtr	Beating	268.75	568.75	Accelerating	439.75	739.75	7.6232E-07	14	2
58	UC774a.tbl#9ParamPosition 1.mtr	Beating	275	575	Accelerating	443	743	7.5229E-07	14	2
59	UC774a.tbl#9ParamPosition 1.mtr	Beating	281.25	581.25	Accelerating	446.25	746.25	7.5229E-07	14	2
60	UC774a.tbl#9ParamPosition 1.mtr	Beating	287.5	587.5	Accelerating	449.5	749.5	7.5229E-07	14	2
61	UC774a.tbl#9ParamPosition 1.mtr	Beating	293.75	593.75	Accelerating	452.75	752.75	7.5229E-07	14	2
62	UC774a.tbl#9ParamPosition 1.mtr	Beating	300	600	Accelerating	456	756	7.5229E-07	14	2
63	UC774a.tbl#9ParamPosition 1.mtr	Beating	306.25	606.25	Accelerating	459.25	759.25	7.5229E-07	14	2
64	UC774a.tbl#9ParamPosition 1.mtr	Beating	312.5	612.5	Accelerating	462.5	762.5	8.6532E-07	14	2
65	UC774a.tbl#9ParamPosition 1.mtr	Beating	318.75	618.75	Accelerating	465.75	765.75	8.6532E-07	14	2
66	UC774a.tbl#9ParamPosition 1.mtr	Beating	325	625	Accelerating	469	769	1.5359E-06	14	2
67	UC774a.tbl#9ParamPosition 1.mtr	Beating	331.25	631.25	Accelerating	472.25	772.25	1.8327E-06	14	2
68	UC774a.tbl#9ParamPosition 1.mtr	Beating	337.5	637.5	Accelerating	475.5	775.5	1.8327E-06	14	2
69	UC774a.tbl#9ParamPosition 1.mtr	Beating	343.75	643.75	Accelerating	478.75	778.75	1.8327E-06	14	2
70	UC774a.tbl#9ParamPosition 1.mtr	Beating	350	650	Accelerating	482	782	1.8327E-06	14	2
71	UC774a.tbl#9ParamPosition 1.mtr	Beating	356.25	656.25	Accelerating	485.25	785.25	1.8327E-06	14	2

Figure 55: Vertical Deck End Displacement Check Worksheet for Multiple Results Files

Check of Longitudinal Reactions										
Job Title: UC-774-35Model UC774a.tbl#9Param										
Analysis Filename: UC774a.tbl#9ParamPosition 1 - UC774a.tbl#9ParamPosition 01										
Model Director: C:\ProgramData\RailSoft\Exec\userman										
Analysis Date: 09/06/2017 -> 09/06/2017										
Model User: N.Najjar,C										
Analysis ID	Results Filename	Loading Type	Track 1		Track 2		Peak Longitudinal Reaction (N)	Abandon # if Peak Reaction	Peak Reaction	Number of Supporting Decks with Peak Reaction
			Distance from Left End of the Model to the Seating Position of the Loading (m)	Distance from Left End of the Model to the Fastening Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Seating Position of the Loading (m)				
1	UC774a.tbl#9ParamPosition 1.mtr	Temperature Only								
14	UC774a.tbl#9ParamPosition 1.mtr	Beating	0	300	Accelerating	300	600	240325.1743	14	5
15	UC774a.tbl#9ParamPosition 1.mtr	Beating	6.25	300	Accelerating	300.5	600.5	240325.1743	14	5
16	UC774a.tbl#9ParamPosition 1.mtr	Beating	12.5	312	Accelerating	306.5	606.5	23993.3946	14	5
17	UC774a.tbl#9ParamPosition 1.mtr	Beating	18.75	318	Accelerating	309.75	609.75	-28172.8408	14	5
18	UC774a.tbl#9ParamPosition 1.mtr	Beating	25	325	Accelerating	313	613	-38729.3681	14	5
19	UC774a.tbl#9ParamPosition 1.mtr	Beating	31.25	332	Accelerating	316.25	616.25	-50112.7952	14	5
20	UC774a.tbl#9ParamPosition 1.mtr	Beating	37.5	337.5	Accelerating	319.5	619.5	-56395.3031	14	5
21	UC774a.tbl#9ParamPosition 1.mtr	Beating	43.75	343	Accelerating	322.75	622.75	-57678.8444	14	5
22	UC774a.tbl#9ParamPosition 1.mtr	Beating	50	350	Accelerating	326	626	-58395.9711	14	5
23	UC774a.tbl#9ParamPosition 1.mtr	Beating	56.25	356.25	Accelerating	329.25	629.25	-59059.4261	14	5
24	UC774a.tbl#9ParamPosition 1.mtr	Beating	62.5	362.5	Accelerating	332.5	632.5	-59700.4391	14	5
25	UC774a.tbl#9ParamPosition 1.mtr	Beating	68.75	368.75	Accelerating	335.75	635.75	-60321.8171	14	5
26	UC774a.tbl#9ParamPosition 1.mtr	Beating	75	375	Accelerating	339	639	-60929.0391	14	5
27	UC774a.tbl#9ParamPosition 1.mtr	Beating	81.25	381.25	Accelerating	342.25	642.25	-61522.8171	14	5
28	UC774a.tbl#9ParamPosition 1.mtr	Beating	87.5	387.5	Accelerating	345.5	645.5	-62104.5331	14	5
29	UC774a.tbl#9ParamPosition 1.mtr	Beating	93.75	393.75	Accelerating	348.75	648.75	-62674.6911	14	5
30	UC774a.tbl#9ParamPosition 1.mtr	Beating	100	400	Accelerating	352	652	-63234.0331	14	5
31	UC774a.tbl#9ParamPosition 1.mtr	Beating	106.25	406.25	Accelerating	355.25	655.25	-63783.1711	14	5
32	UC774a.tbl#9ParamPosition 1.mtr	Beating	112.5	412.5	Accelerating	358.5	658.5	-64322.6911	14	5
33	UC774a.tbl#9ParamPosition 1.mtr	Beating	118.75	418.75	Accelerating	361.75	661.75	-64862.8911	14	5
34	UC774a.tbl#9ParamPosition 1.mtr	Beating	125	425	Accelerating	365	665	-65403.2911	14	5
35	UC774a.tbl#9ParamPosition 1.mtr	Beating	131.25	431.25	Accelerating	368.25	668.25	-65944.2911	14	5
36	UC774a.tbl#9ParamPosition 1.mtr	Beating	137.5	437.5	Accelerating	371.5	671.5	-66485.4911	14	5
37	UC774a.tbl#9ParamPosition 1.mtr	Beating	143.75	443.75	Accelerating	374.75	674.75	-67027.2911	14	5
38	UC774a.tbl#9ParamPosition 1.mtr	Beating	150	450	Accelerating	378	678	-67569.2911	14	5
39	UC774a.tbl#9ParamPosition 1.mtr	Beating	156.25	456.25	Accelerating	381.25	681.25	-68111.9911	14	5
40	UC774a.tbl#9ParamPosition 1.mtr	Beating	162.5	462.5	Accelerating	384.5	684.5	-68654.9911	14	5
41	UC774a.tbl#9ParamPosition 1.mtr	Beating	168.75	468.75	Accelerating	387.75	687.75	-69197.6911	14	5
42	UC774a.tbl#9ParamPosition 1.mtr	Beating	175	475	Accelerating	391	691	-69740.6911	14	5
43	UC774a.tbl#9ParamPosition 1.mtr	Beating	181.25	481.25	Accelerating	394.25	694.25	-70283.4911	14	5
44	UC774a.tbl#9ParamPosition 1.mtr	Beating	187.5	487.5	Accelerating	397.5	697.5			





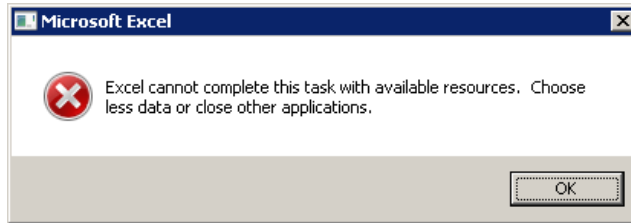
Check of Longitudinal Reactions										
Analysis ID	Results Filename / Combination Name	Loading Type	Track 1		Track 2		Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction		
			Distance from Left End of the Model to the Starting Position	Distance from Left End of the Model to the Finishing	Distance from Left End of the Model to the Starting Position	Distance from Left End of the Model to the Finishing				
1	UIC774-3 Model UIC774-3.tbl	Temperature Only								
2	UIC774-3.tbl	Braking	0	300	Temperature Only	270	570	30045.4475 Pier 5		
3	UIC774-3.tbl	Braking	81.25	391.25	Accelerating	351.25	693.25	-446077.2753 Pier 3		
4	UIC774-3.tbl	Braking	162.5	482.5	Accelerating	432.5	732.5	-87959.4475 Pier 3		
5	UIC774-3.tbl	Braking	243.75	563.75	Accelerating	513.75	813.75	-1201042.37 Pier 8		
6	UIC774-3.tbl	Braking	325	645	Accelerating	595	895	-193932.026 Pier 8		
7	Basic Combination	Position Including Self Weight						262974.6646 Pier 5		
8	Basic Combination	Position 2 including Self Weight						-843693.0266 Pier 3		
9	Basic Combination	Position 3 including Self Weight						-836174.0266 Pier 3		
10	Basic Combination	Position 4 including Self Weight						-1214172.798 Pier 8		
11	Basic Combination	Position 5 including Self Weight						-193932.026 Pier 8		

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

**Figure 59: Longitudinal Reaction Check Worksheet for Rail Track Analysis Results and Basic Combinations of these Results**

## Microsoft Excel Fails with Insufficient Resources when Enveloping

If Microsoft Excel fails to complete the post-processing successfully with a complaint of insufficient resources (with messages similar to the one in the following figure) when performing the enveloping within Microsoft Excel the post-processing will need to be carried out using a different method. These memory limitations with Microsoft Excel are dependent upon both the size of the rail track model being post-processed and the number of results files loaded.



**Figure 60: Insufficient Resources for Microsoft Excel to Complete the Post-Processing**



**Note.** After the failure of a post-processing the Microsoft Excel application may still be dormant on the computer and may need to be terminated by ending the process in Windows Task Manager. The Rail Track module is also likely to have been disabled in LUSAS Modeller and a message reported such as “An error occurred in LUSAS Module UIC774-3. Error LateGet: The remote procedure call failed. Please contact LUSAS technical support. Module Controller has caught an unhandled exception in debug module UIC774-3.” This is caused by the failure of Microsoft Excel and there is no need to contact LUSAS technical support but the Rail Track module will remain disabled until LUSAS Modeller is closed down and restarted.

If there are insufficient resources for Microsoft Excel to carry out the enveloping of the analyses and it is not appropriate to increase the size of the elements used for the modelling of the analysis or reduce the number of trainset positions then two automatic post-processing options are generally available. The first option is to post-process the results files in smaller groups to minimise the amount of memory that Microsoft Excel needs for holding the data. The number of results files loaded can be altered by choosing the File>Manage Results Files... option. Disable the 'Let LUSAS manage results files (recommended)' option (a warning will be issued but this can be ignored so long as the model is not saved). Deselect the analysis results to exclude by unticking the checkboxes in the 'Open' column and click the OK button. This will close those results chosen and allow the post-processing to be performed only on the results that remain loaded.



**Caution.** Do not save the model with the 'Let LUSAS manage results files (recommended)' option disabled. If it has been turned off then it should be turned back on if the model is saved.

The advantage of this first option is that it still allows the creation of the additional summary tables of derived quantities such as the relative railbed displacements. The second option is to perform the enveloping in Modeller itself which is illustrated below. The disadvantage of this method is the inability to envelope derived quantities such as the relative railbed displacements. Calculation of the relative railbed displacement from enveloped values of the displacement of the structure and the track will result in the incorrect value being reported and is therefore disabled.

The envelopes can be defined manually but for the number of results files that are generally used for the rail track analyses for analysing different trainset positions it is easier to define the envelopes using VBScript. Figure 61 shows an example of a VBScript file that will automatically generate the equivalent envelopes for 101 separate results files loaded on top of the model. If a different number of results files are to be considered then the line that reads `numResFile = 101` can be changed to the number required. Alternatively if enveloping is always going to be performed over all of the results files loaded then this line can be replaced with `numResFile = database.countResultsFiles ()` .

```
$ENGINE=VBScript
' Sample VBScript to define envelopes in Modeller equivalent to those carried out
' in Microsoft Excel
'
' The number of results files loaded on top of the model
numResFile = 101
' Define the envelope objects
Set envTempOnly = database.createEnvelope("Envelope of Temperature Only")
Set envTempTrain = database.createEnvelope("Envelope of Temperature and Train Loads")
Set envAllConfig = database.createEnvelope("Envelope of All Configurations")
' Loop over the results files
For ires = 1 To numResFile
' Add the temperature only results to the appropriate envelopes
  Call envTempOnly.addEntry(1, ires, -1, -1)
  Call envAllConfig.addEntry(1, ires, -1, -1)
' Add the temperature and train results to the appropriate envelopes
  Call envTempTrain.addEntry(2, ires, -1, -1)
  Call envAllConfig.addEntry(2, ires, -1, -1)
Next
' Release envelope objects
Set envTempOnly = Nothing
Set envTempTrain = Nothing
Set envAllConfig = Nothing
```

**Figure 61: Example VBScript to Define Equivalent Envelopes in Modeller**

If the envelopes in Modeller have been defined correctly then identical results will be obtained from the post-processor for the Modeller and Microsoft Excel enveloping methods. Generation of the envelopes in Modeller through VBScripting removes the potential for errors in the generation of these envelopes and is therefore recommended, particularly for large numbers of results files.

Figure 62 and Figure 63 show the results from the enveloping of the combined temperature and trainset loading for the track of a model. Comparison of the tables and graphs shows that the results are identical for both enveloping methods. In Figure 63 which shows the results for the track from enveloping in Modeller both the summary tables and the graphs have omitted the relative railbed displacement results because these cannot be calculated from the enveloping in Modeller.

Figure 64 and Figure 65 show the results from the enveloping of the combined temperature and trainset loading for the deck of a model. Comparison of the tables and graphs shows that the results are identical for both enveloping methods.

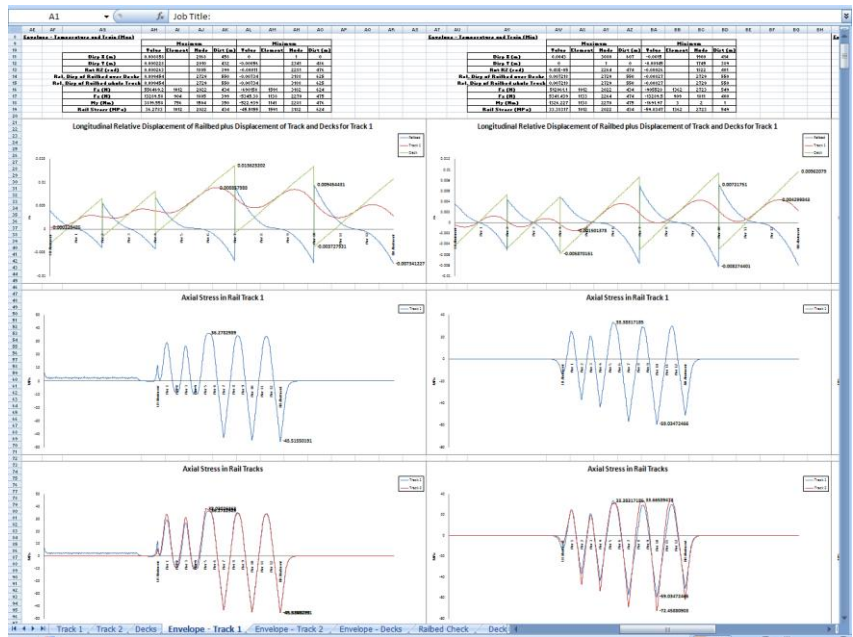


Figure 62: Track Envelopes Performed in Microsoft Excel

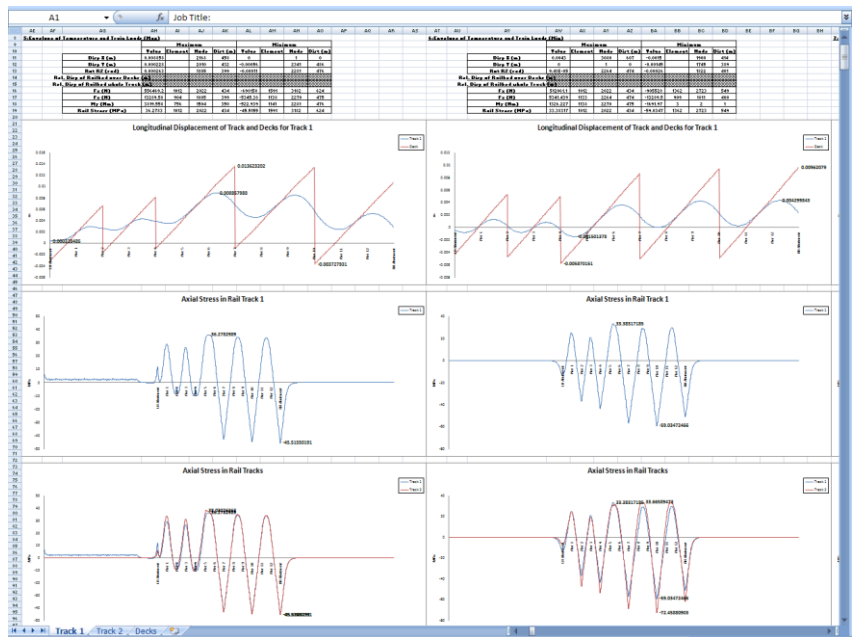


Figure 63: Track Envelopes Performed in Modeller

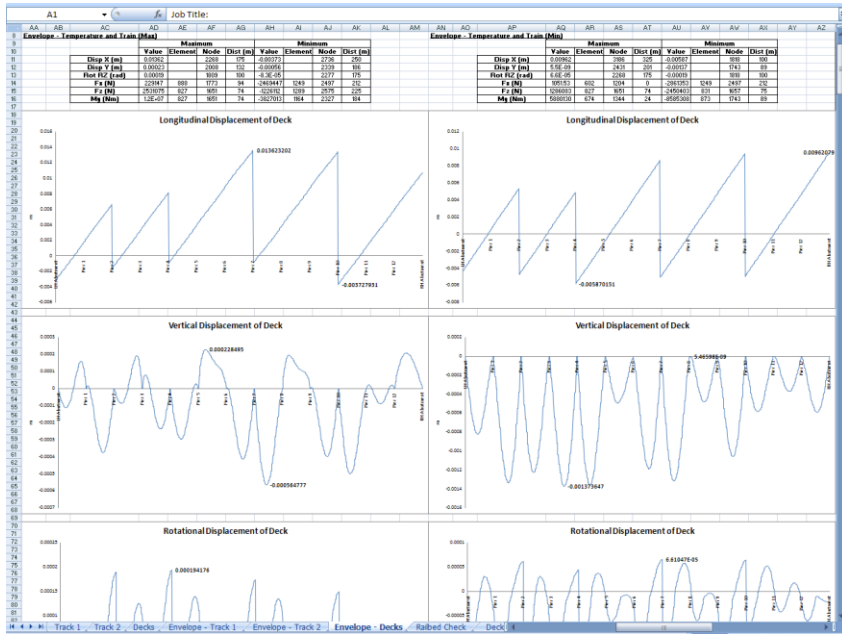


Figure 64: Deck Envelopes Performed in Microsoft Excel

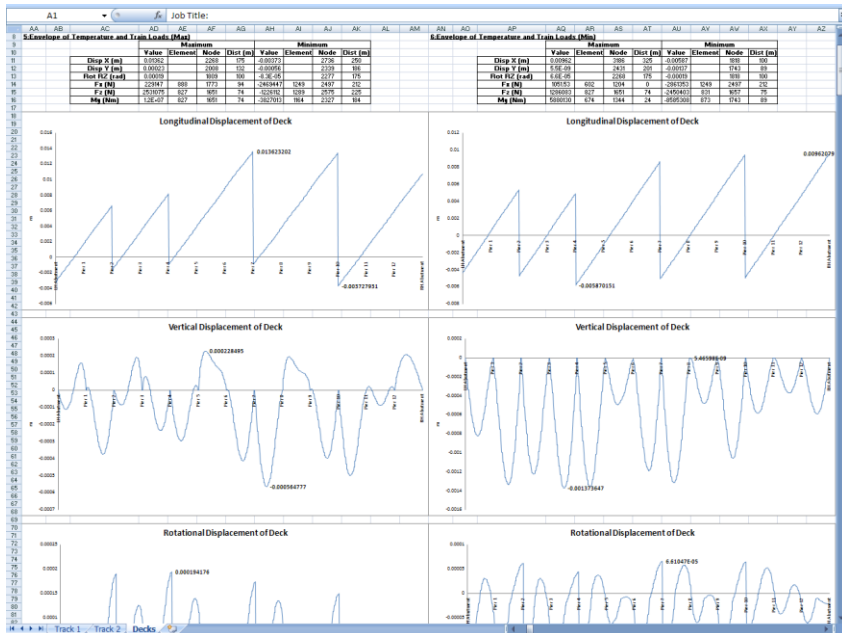

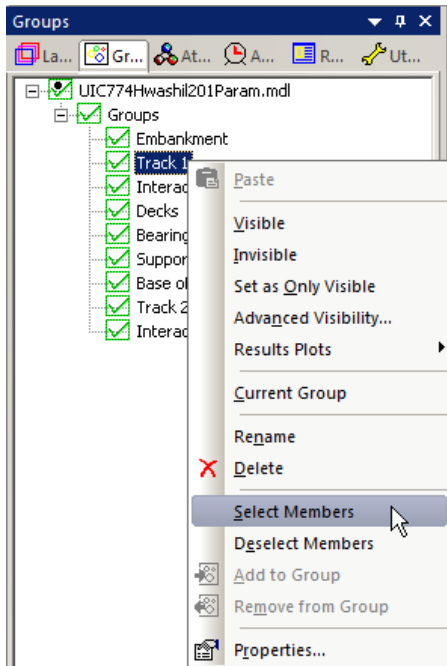



Figure 65: Deck Envelopes Performed in Modeller

One final option available (that should be used with caution, particularly if there is a possibility for the peak behaviours in the track / railbed being observed over any part of the embankments rather than over the structure) is the reduction of the track/rail groups in the model so that they contain the bare minimum of features/mesh over the embankments plus all of the track/rail over the structure. Any modifications of this sort should be done after first making a backup copy of the original model in case the editing corrupts the model.

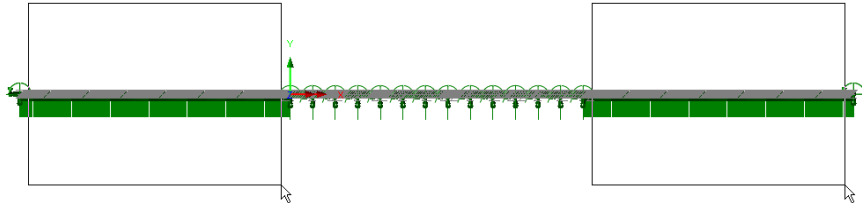
In the rail track analysis model:

- Ensure the whole model is visible and that the selection allows the selection of any geometry and mesh features with the **Select Any** cursor ,
- In the **Groups Treeview** select all of the members in the **Track 1** group by right-clicking on the **Track 1** group and choosing the **Select Members** option as illustrated below,

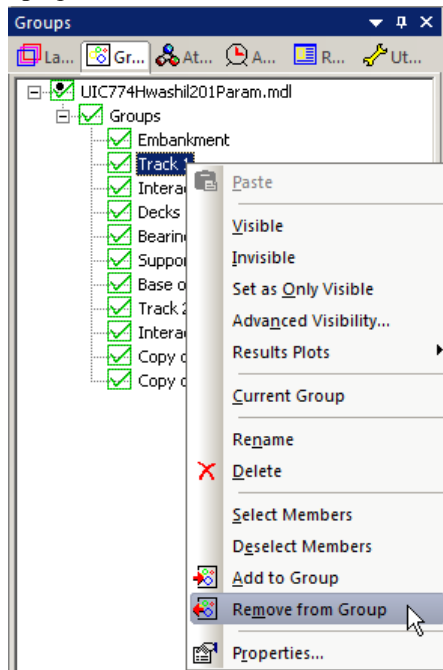


- Create a copy of the **Track 1** group by clicking on the  button to create a new group and give it the name **Copy of Track 1** ,
- If there is more than one track, repeat the two steps above to create a copy of each of the track groups in the model (ensuring that the features from the previous tracks are deselected first before selecting those from other tracks),
- Clear the selection and then select the track features and mesh to be removed from the post-processing as illustrated below ensuring that the extremes of the

embankments are not selected (far left and right along with embankment next to the structure **must** not be selected),



- ❑ Remove the selected features and mesh from the **Track 1** group by right-clicking on the **Track 1** group in the **Groups Treeview** and choosing the **Remove from Group** option as illustrated below,



- ❑ If there is more than one track, repeat the removing of the features and mesh from all of the remaining track groups,
- ❑ Save the model,
- ❑ Post-process the model as before.

In the example below the post-processing of the 201 parametric trainset positions initially failed due to insufficient resources in Microsoft Excel. On removing most of each of the two embankments the full 201 parametric trainset positions could be post-processed successfully in Microsoft Excel.





**Note.** This approach may not always work and is generally more applicable when the lengths of the embankments are similar to the length of the structure. If the embankment lengths are significantly smaller than the length of the structure minimal change in the computer memory usage by Microsoft Excel will be observed.



**Caution.** The extremes of the track/rail over the embankments must be left within the track groups to ensure that the post-processing is carried out correctly. Errors may be observed and inaccurate results obtained if this is not the case.



**Caution.** Excluding the embankments from the track could give misleading results if the peak behaviours actually occur over the embankments, especially close to the transition between the embankment and the structure, rather than over the structure itself. Judgement should be exercised before accepting the results after exclusion of the embankments.

# Rail Track Analysis User Manual

The screenshot displays a Microsoft Excel spreadsheet with the following structure:

- Table Title:** Check of Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)
- Columns:**
  - Track 1:** Railbed from Left End of the Loading Position, Railbed from Right End of the Loading Position
  - Track 2:** Railbed from Left End of the Loading Position, Railbed from Right End of the Loading Position
  - Peak Displacement:** Peak Displacement
  - Track Number with Peak Displacement:** Track Number with Peak Displacement
  - Distance from Left End of the Loading Position:** Distance from Left End of the Loading Position
  - Distance from Right End of the Loading Position:** Distance from Right End of the Loading Position
  - Direction of Peak Displacement:** Direction of Peak Displacement
  - Direction of Peak Displacement:** Direction of Peak Displacement
- Rows:** Multiple rows representing different railbed positions and trainset configurations, including details like 'Railbed from Left End of the Loading Position', 'Railbed from Right End of the Loading Position', and 'Peak Displacement'.

Figure 66: Railbed Enveloped Results for 201 Parametric Trainset Positions in Microsoft Excel

## 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 67 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.

Analysis ID	Results Filename	Loading Type	Track 1		Track 2		Axial Stress of rail for Track 1, Node 1031 (MPa)
			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)	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)	
11	UIC774washIP403BParamRail*Position 1.mys	Temperature Only					15.40232404
12	UIC774washIP403BParamRail*Position 1.mys	Braking	0	300	270	570	14.97805062
13	UIC774washIP403BParamRail*Position 1.mys	Braking	81.25	381.25	351.25	631.25	16.10847752
14	UIC774washIP403BParamRail*Position 3.mys	Braking	162.5	462.5	421.25	732.5	16.53934959
15	UIC774washIP403BParamRail*Position 4.mys	Braking	243.75	543.75	502.5	813.75	16.62340317
16	UIC774washIP403BParamRail*Position 5.mys	Braking	325	625	583.75	895	16.72830257

Figure 67: 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 is 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” 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 68 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.

Job Title: UIC 774-3 Model: UIC774+twashIP403bParamRail													
Analysis Filename: UIC774+twashIP403bParamRail*Position 1.mys													
Analysis Directory: C:\Project\A\1254\TrackStructureInteraction\Associated Model Data\UIC774+twashIP403bParamRail\													
Analysis Date: 08/06/2017													
Model Units: N,m,kg,s,C													
Increment 1													
2:Increment 2 Load Factor = 1.0000													
		Maximum				Minimum							
		Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)				
11	Disp X (m)	0.00452787		1084	50	-0.0053352		935	0				Disp X (m)
12	Disp Y (m)	1.3238E-05		1041	35	-2.197E-05		964	10				Disp Y (m)
13	Rot RZ (rad)	6.8171E-07		1030	32	-2.668E-06		935	0				Rot RZ (rad)
14	Fx (N)	-40000.004	1241	935	0	-1400000.1	1402	1030	32				Fx (N)
15	Fy (N)	65299.5917	1405	1087	50	-77840.038	1486	1083	49				Fy (N)
16	Fz (N)	75564.7728	1402	1030	32	-90227.129	1288	963	9				Fz (N)
17	My (Nm)												My (Nm)

Element	Node	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Fx (N)	Fy (N)	My (Nm)	Element	Node	Distance (m)
19	1241	935	0	0	0	-0.0053352	6.9234E-08	-2.668E-06	-40000.004	64034.9151	-4702.546	1241	935	
20	1241	937	1	1	0	-0.0051353	-2.577E-06	-2.655E-06	-40000.004	64034.9151	-4702.546	1241	937	
21	1248	937	1	1	0	-0.0051353	-2.577E-06	-2.655E-06	-120000.01	63922.0061	-14164.091	1248	937	
22	1248	942	2	2	0	-0.0049357	-5.196E-06	-2.615E-06	-120000.01	63922.0061	-14164.091	1248	942	
23	1253	942	2	2	0	-0.0049357	-5.196E-06	-2.615E-06	-200000.02	63922.5372	-23676.824	1253	942	
24	1253	943	3	3	0	-0.0047363	-7.762E-06	-2.548E-06	-200000.02	63922.5372	-23676.824	1253	943	
25	1256	943	3	3	0	-0.0047363	-7.762E-06	-2.548E-06	-280000.02	63933.0285	-33184.047	1256	943	
26	1256	948	4	4	0	-0.0045372	-1.025E-05	-2.454E-06	-280000.02	63933.0285	-33184.047	1256	948	
27	1263	948	4	4	0	-0.0045372	-1.025E-05	-2.454E-06	-860000.03	63922.7843	-42691.145	1263	948	
28	1263	951	5	5	0	-0.0043383	-1.263E-05	-2.339E-06	-860000.03	63922.7843	-42691.145	1263	951	
29	1267	951	5	5	0	-0.0043383	-1.263E-05	-2.339E-06	-440000.03	63922.8089	-52198.353	1267	951	
30	1267	952	6	6	0	-0.0041396	-1.487E-05	-2.186E-06	-440000.03	63922.8089	-52198.353	1267	952	
31	1273	952	6	6	0	-0.0041396	-1.487E-05	-2.186E-06	-520000.04	63922.8097	-61705.548	1273	952	
32	1273	957	7	7	0	-0.0039412	-1.695E-05	-2.011E-06	-520000.04	63922.8097	-61705.548	1273	957	
33	1276	957	7	7	0	-0.0039412	-1.695E-05	-2.011E-06	-600000.04	63922.8092	-71212.742	1276	957	
34	1276	958	8	8	0	-0.0037421	-1.895E-05	-1.81E-06	-600000.04	63922.8092	-71212.742	1276	958	
35	1282	958	8	8	0	-0.0037421	-1.895E-05	-1.81E-06	-680000.04	63922.8093	-80719.936	1282	958	
36	1282	963	9	9	0	-0.0035452	-2.053E-05	-1.581E-06	-680000.04	63922.8093	-80719.936	1282	963	
37	1288	963	9	9	0	-0.0035452	-2.053E-05	-1.581E-06	-760000.05	63922.8093	-90227.129	1288	963	
38	1288	964	10	10	0	-0.0033475	-2.197E-05	-1.326E-06	-760000.05	63922.8093	-90227.129	1288	964	
39	1402	1030	32	32	0	0.00096209	1.2191E-05	6.8171E-07	-1400000.1	-77813.796	76564.7728	1402	1030	
40	1402	1035	33	33	0	0.00115839	1.2746E-05	4.6518E-07	-1400000.1	-77813.796	76564.7728	1402	1035	
41	1407	1035	33	33	0	0.00115839	1.2746E-05	4.6518E-07	-1320000.1	-77813.798	72190.9763	1407	1035	
42	1407	1036	34	34	0	0.00135491	1.309E-05	2.6102E-07	-1320000.1	-77813.798	72190.9763	1407	1036	

**Figure 68: 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 38) and enveloping in Microsoft Excel has been selected then the Microsoft Excel 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)**

## 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.
- ❑ Only up to two tracks can be considered in accordance with UIC774-3.
- ❑ Thermal loading for mixed steel and concrete bridges in the same model cannot be generated through the input spreadsheet. The model can however be modified to include these different thermal loads if no rail loading is applied when the model is built and the resulting LUSAS model modified manually. Care should be taken carrying this out and generally only additional temperature loading attributes should be defined and assigned to the model.

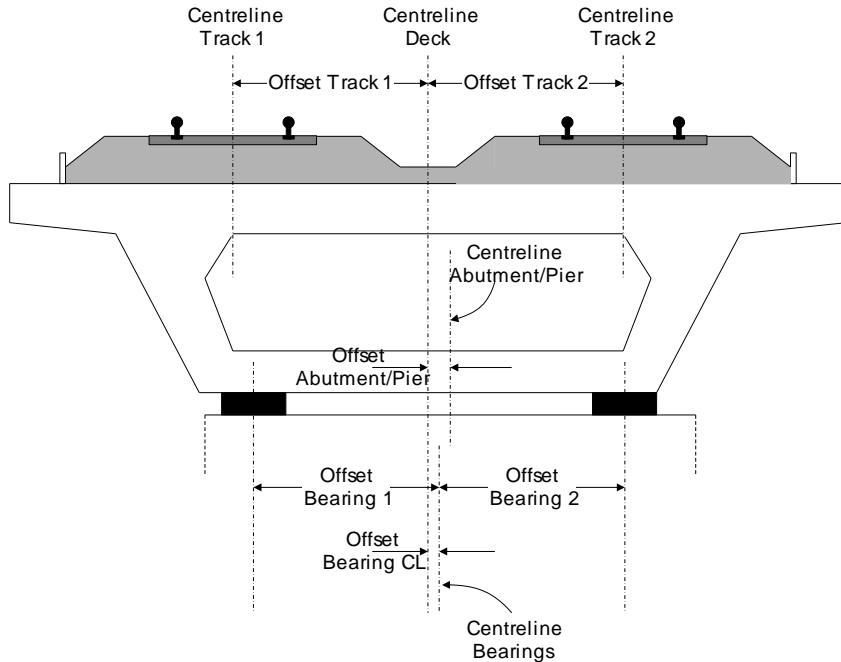


Figure 69: Offsets of Tracks/Bearings/Piers from Centreline Of Deck



# 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**

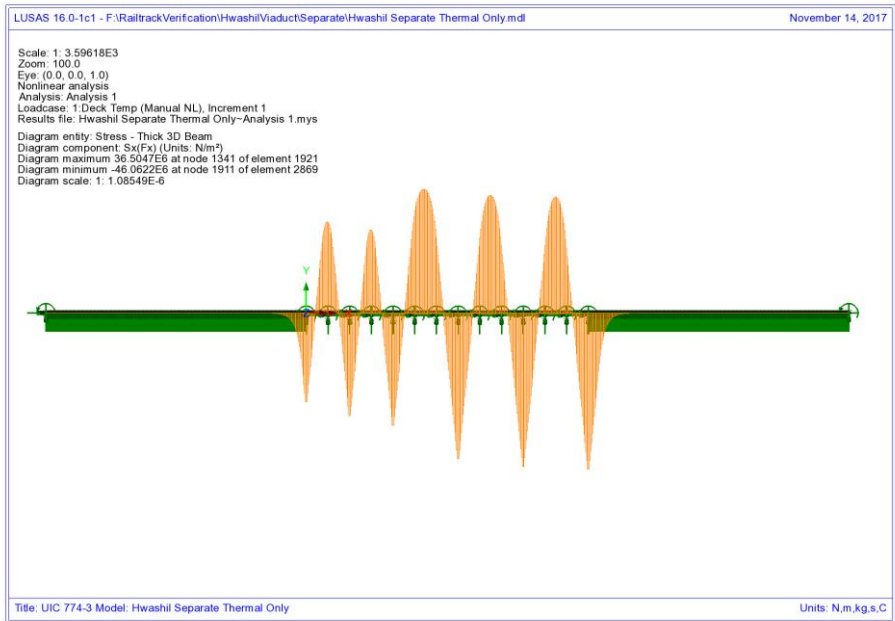
In addition, two of the UIC standard test cases have also been reinvestigated to demonstrate that these results can be matched even if the analysis type is potentially invalid prior to providing guidance and conclusions on this type of analysis. These analyses were:

- 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

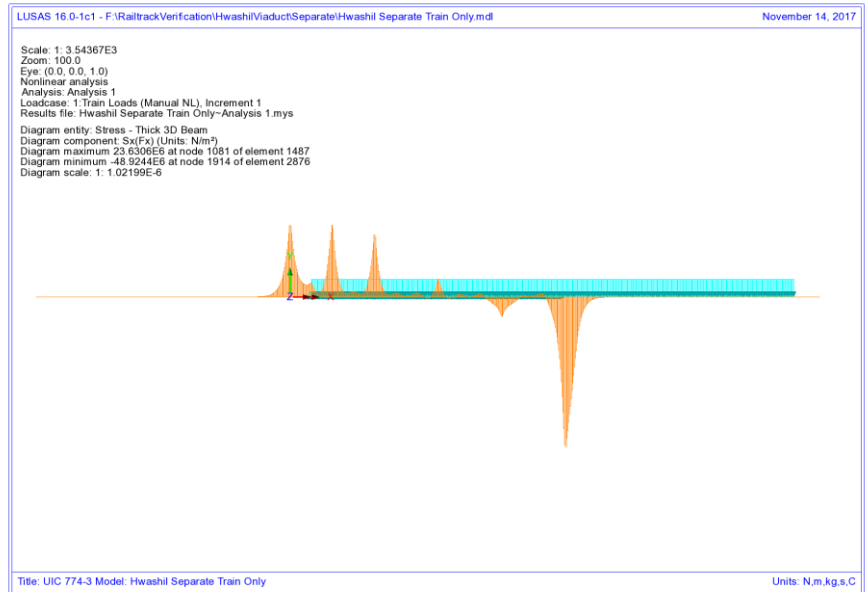
In this form of analysis two or more separate analyses are carried out with each analysis considering a different loading regime to the structure. This is the simplest form of analysis of the track/bridge interaction as it assumes that superposition is valid for a nonlinear system and, according to the 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.

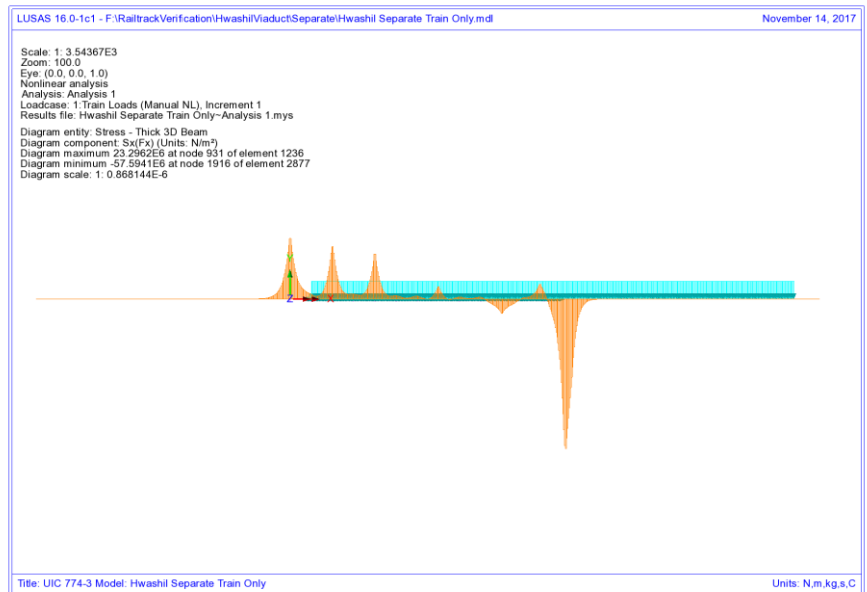


**Figure 70: Axial Stress In Rails Due To Thermal Effects Only**

These thermal effects give a peak compressive rail stress of  $46.06 \text{ N/mm}^2$ . 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 71: Axial Stress In Rails Due To Braking Train Loads On Track 1**



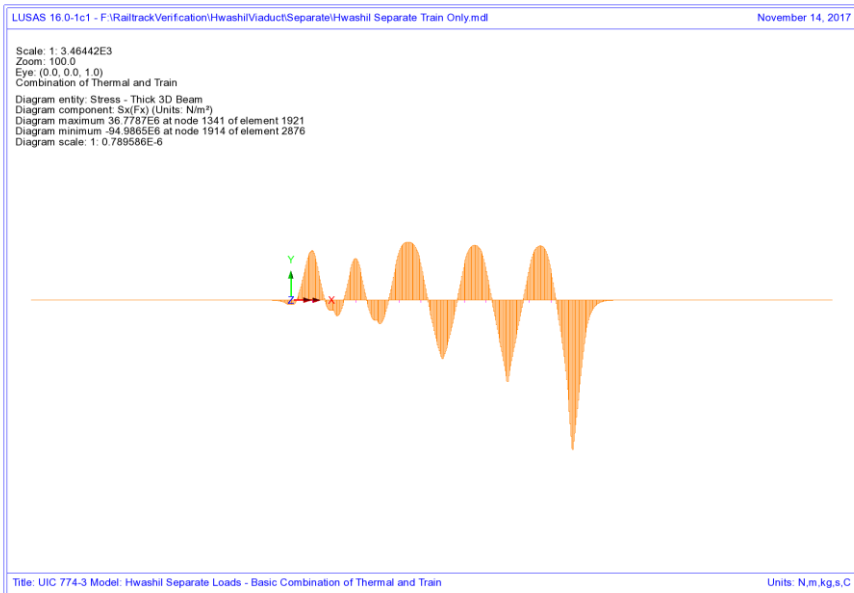
**Figure 72: Axial Stress In Rails Due To Accelerating Train Loads On Track 2**

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

<b>Track 1:</b>	<b>48.92 N/mm<sup>2</sup></b>
<b>Track 2:</b>	<b>57.59 N/mm<sup>2</sup></b>

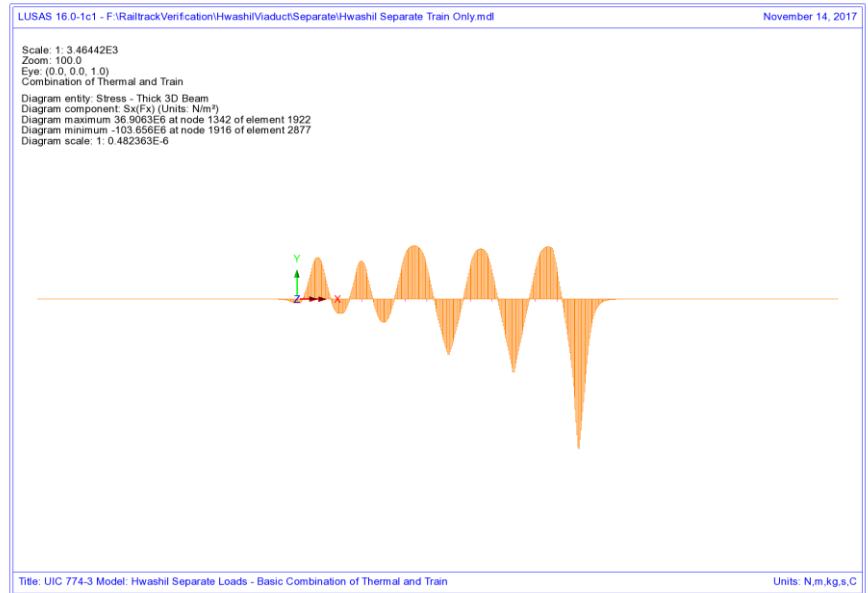
A basic combination of the loading can be defined to add the results from the thermal and rail loading analyses together which gives the following track peak compressive stresses (see following figures):

<b>Track 1:</b>	<b>94.99 N/mm<sup>2</sup></b>
<b>Track 2:</b>	<b>103.66 N/mm<sup>2</sup></b>



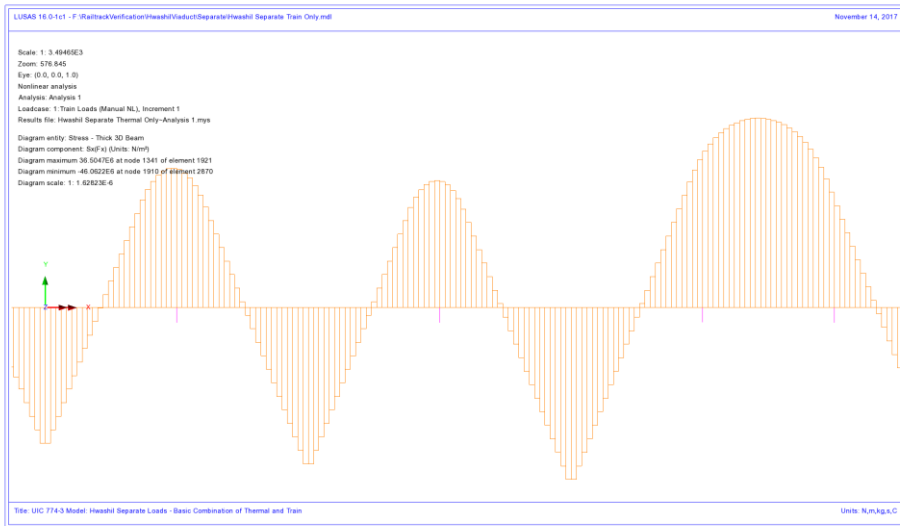
**Figure 73: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track**

1

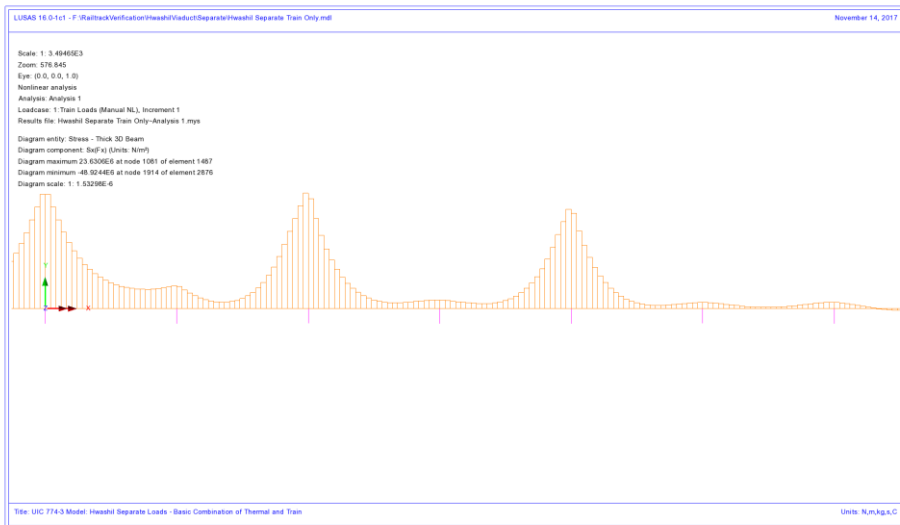


**Figure 74: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 2**

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 76, 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 (2<sup>nd</sup> 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<sup>2</sup> while the axial stress over the start of the second deck is equal to a tensile stress of 22.47 N/mm<sup>2</sup>. 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.



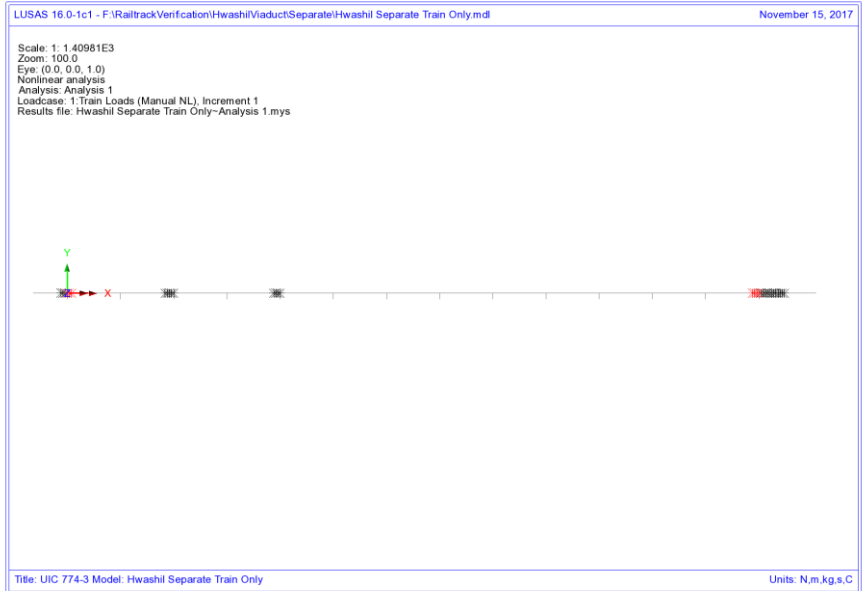
**Figure 75: Zoomed Axial Stress In Rails Due To Thermal Effects Only**



**Figure 76: Zoomed Axial Stress In Rails Due To Braking Train Loads On Track 1**

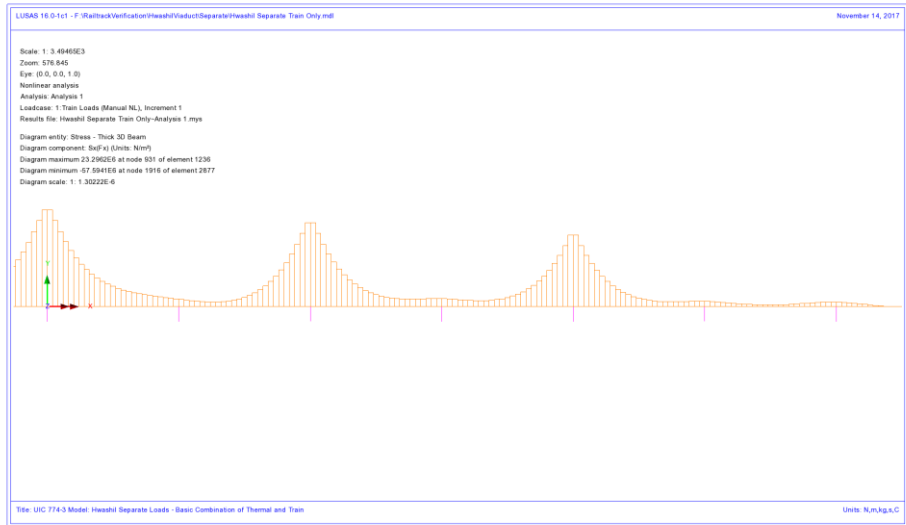
**NOTE:** When viewing this axial force diagram it should be recognised that while the first two decks (2\*25m each) have identical geometry and pier/bearing properties, the first span segment of the first deck does not carry any of the braking train load and this is contributing to the difference in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

Looking at the yield in the track/bridge interaction for this track, Figure 77, 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 77: Yield In Track/Bridge Interaction Due To Train Braking Load On Track 1**

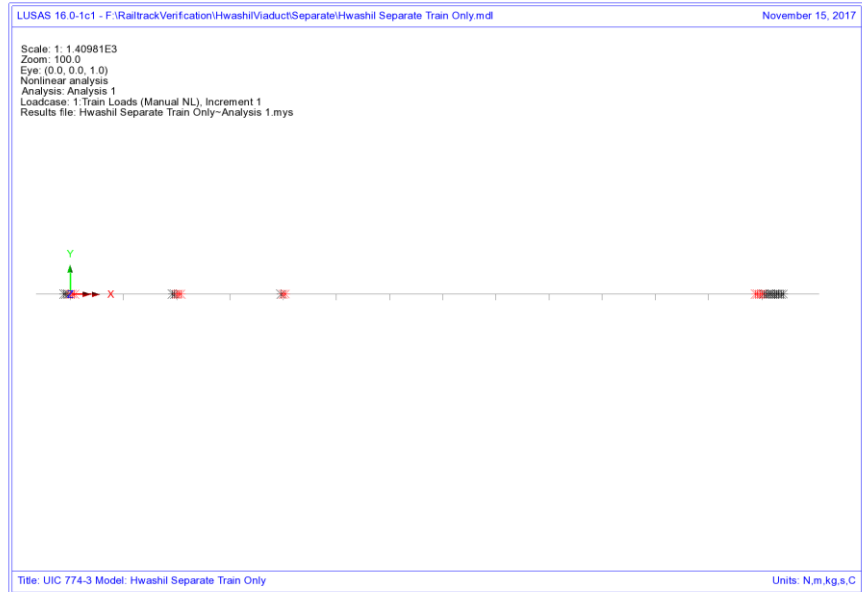
Looking now at the second track where the accelerating train is at the right-hand end of the structure, the interaction remains unloaded and so the rail axial stress observed is basically due to the bending of the bridge deck due to the action of the braking train load on the other track. Because there 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 78: Zoomed Axial Force In Rails Due To Accelerating Train Loads On Track 2**

Looking again at the yielding, Figure 79, 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 79: Yield In Track/Bridge Interaction Due To Train Acceleration Load On Track 2**

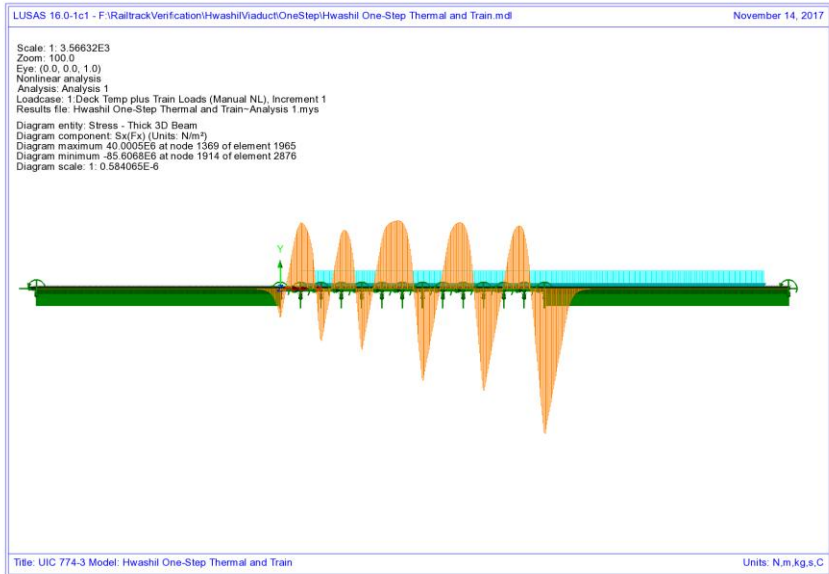
## Analysis of Combined Thermal and Rail Loading (One Step)

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.

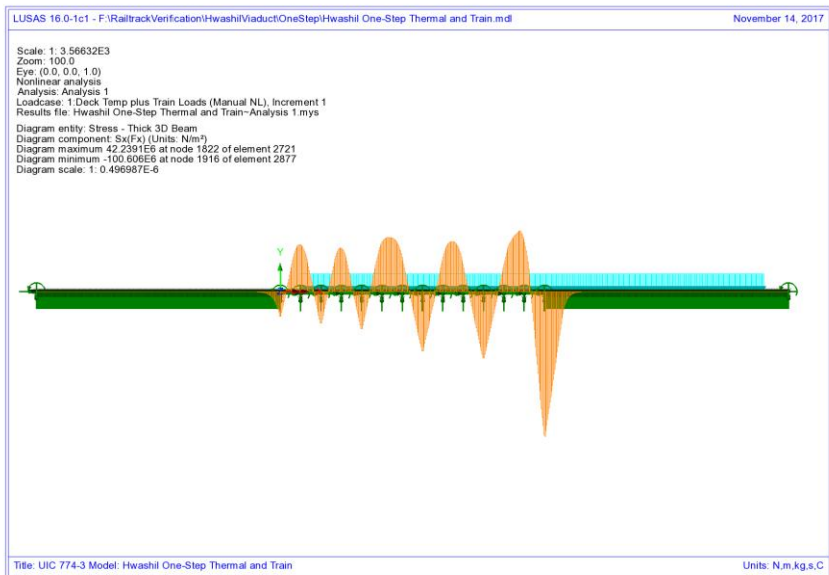
The results from the analysis are shown in the following figures and give the following results for the track peak compressive stresses:

<b>Track 1:</b>	<b>85.6 N/mm<sup>2</sup></b>
<b>Track 2:</b>	<b>100.6 N/mm<sup>2</sup></b>

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



**Figure 81: 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.

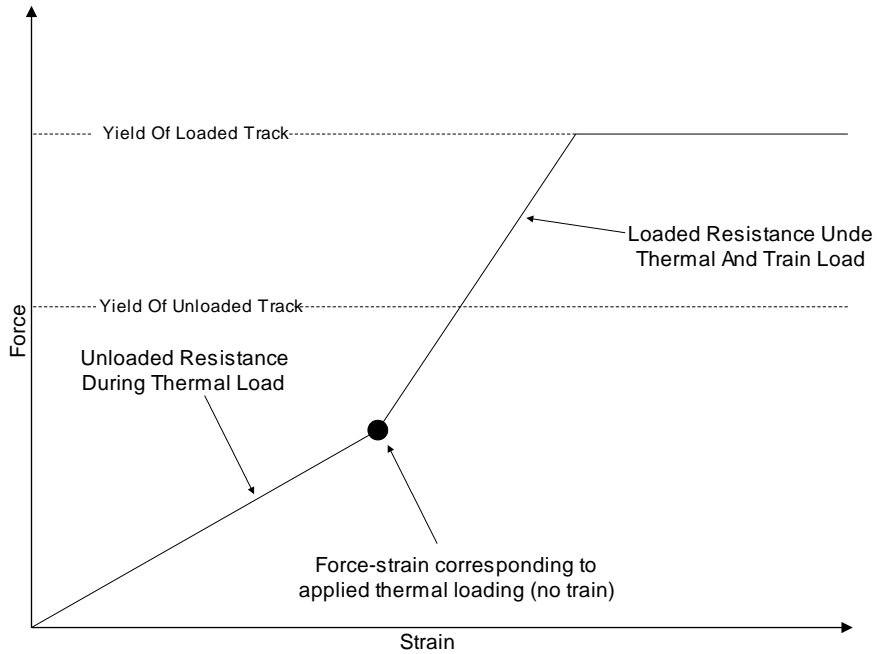
To illustrate the analysis, consider the following:

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 82: 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:

<b>Track 1 and 2 (Thermal Only):</b>	<b>46.06 N/mm<sup>2</sup></b>
<b>Track 1 (Thermal and Train):</b>	<b>79.06 N/mm<sup>2</sup></b>
<b>Track 2 (Thermal and Train):</b>	<b>92.60 N/mm<sup>2</sup></b>

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

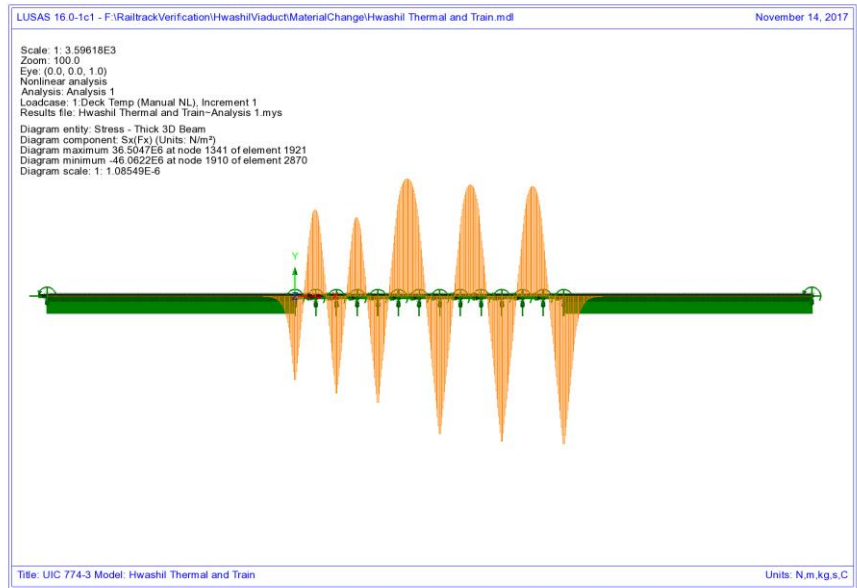


Figure 83: Axial Stress In Rails Due To Thermal Only

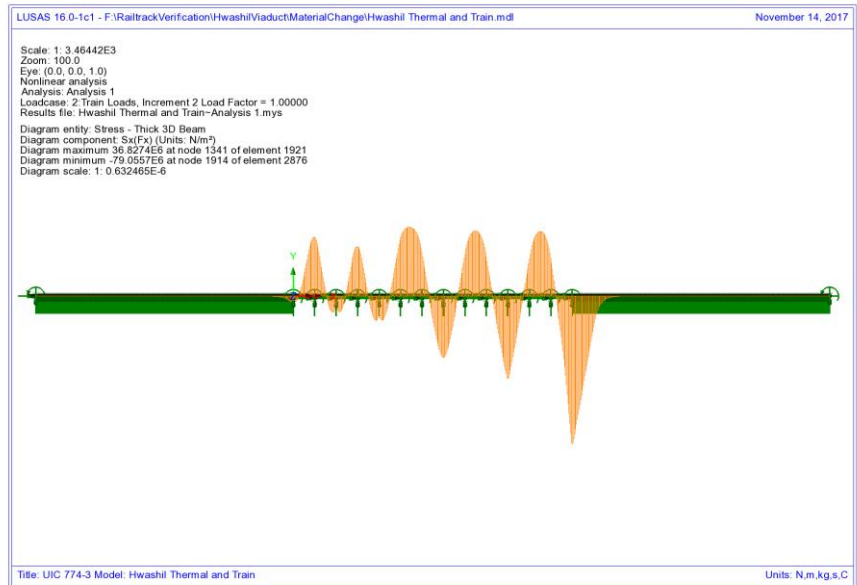
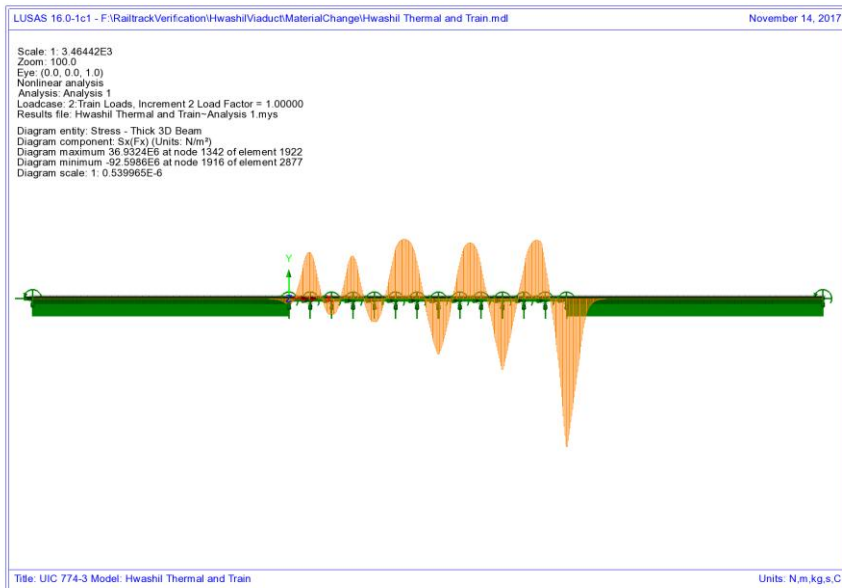


Figure 84: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track  
1



**Figure 85: 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 89) and the concurrent thermal/train loading analysis (Figure 88) 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

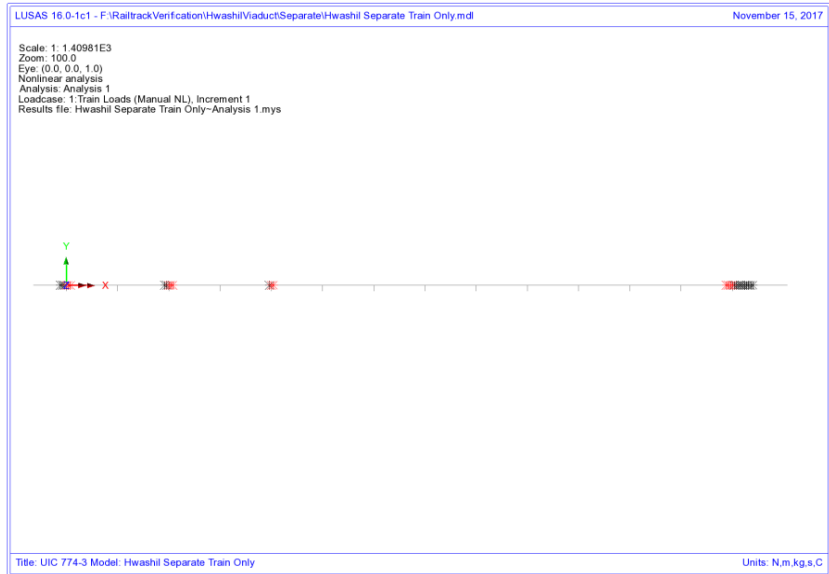
## Analysis of Combined Thermal and Rail Loading Taking Account of Effects of Material Change Under Rail Loading

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 86). In the separate train loading analysis very little yielding is indicated as being associated with the accelerating train loading analysis (Figure 87). 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 86: Track/Rail 2 Yield Due To Thermal Load On Track Alone**



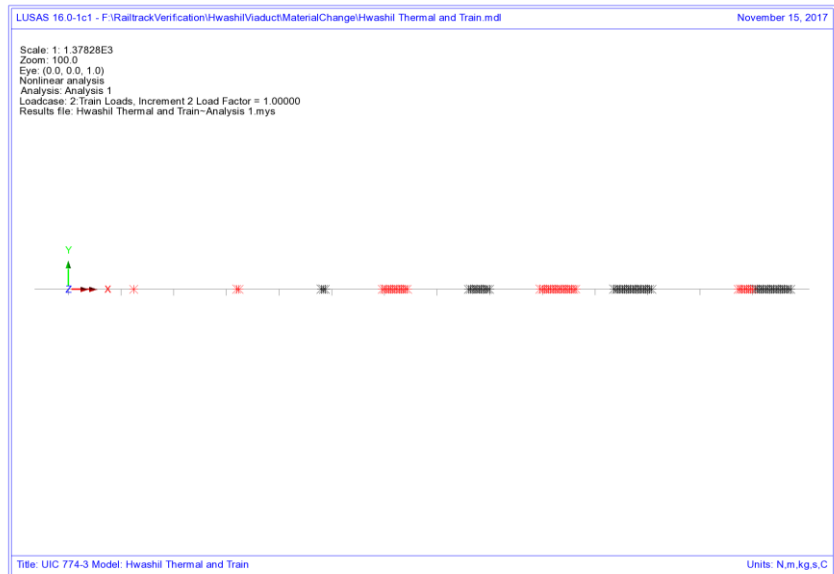
**Figure 87: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 – Separate Analysis**



**Figure 88: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 - Thermal And Rail Applied Concurrently**

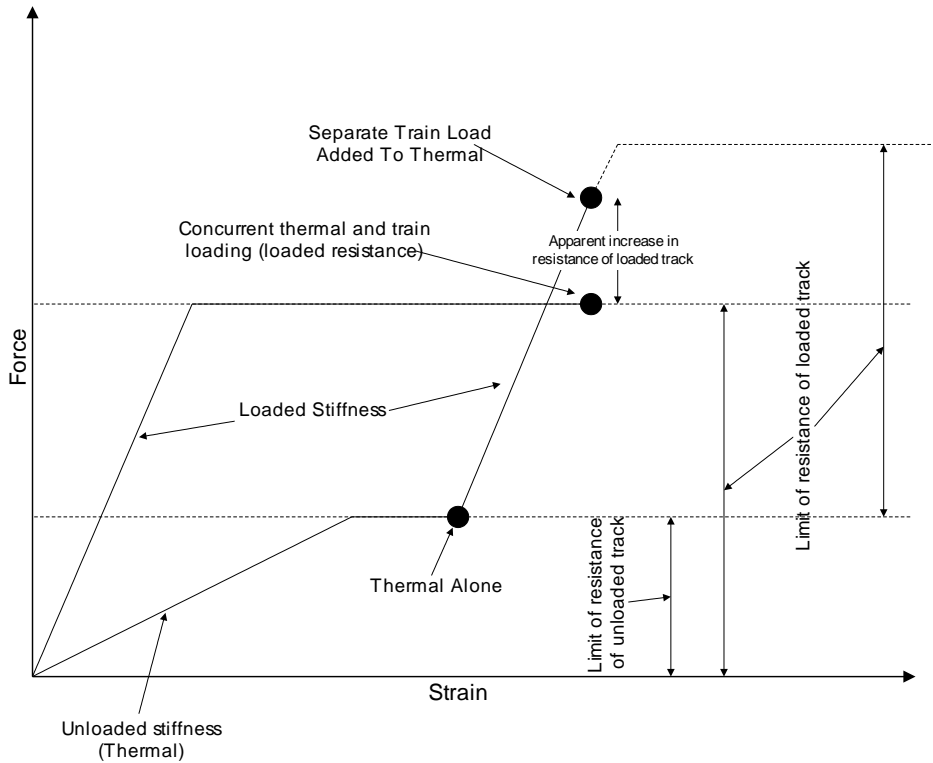


## Analysis of Combined Thermal and Rail Loading Taking Account of Effects of Material Change Under Rail Loading



**Figure 89: Track/Rail 2 Yield Due To Accelerating Train Load On Track 2 - LUSAS Combined Analysis**

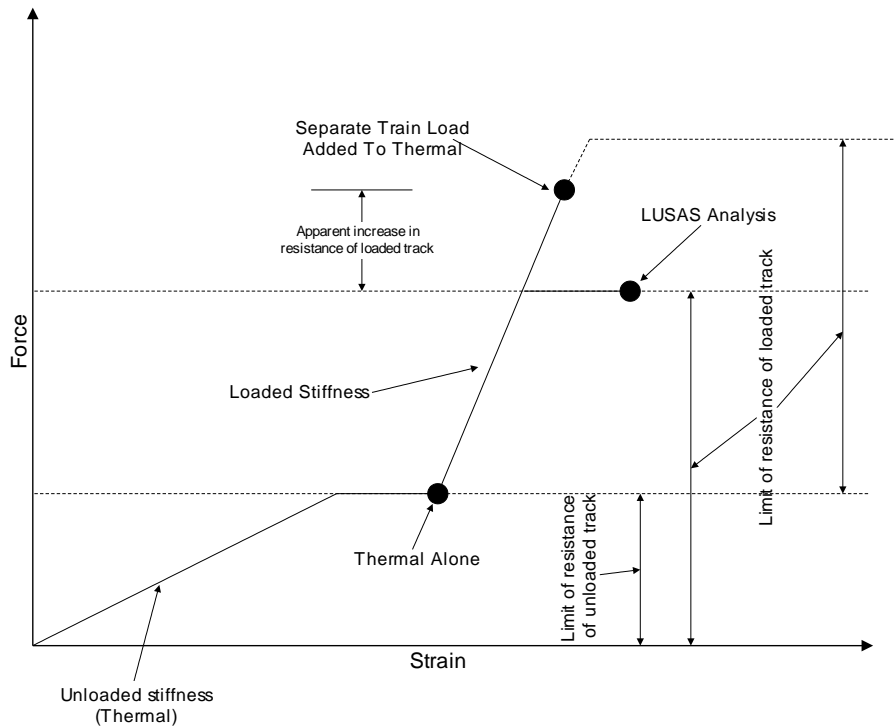
Looking at what is effectively happening in these analyses, Figure 90, the concurrent loading analysis uses the loaded resistance throughout the analysis and follows the loaded stiffness curve from the origin and potentially gives the location indicated on the plastic part of this curve as illustrated 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 90: 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 91. 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<sup>2</sup>.

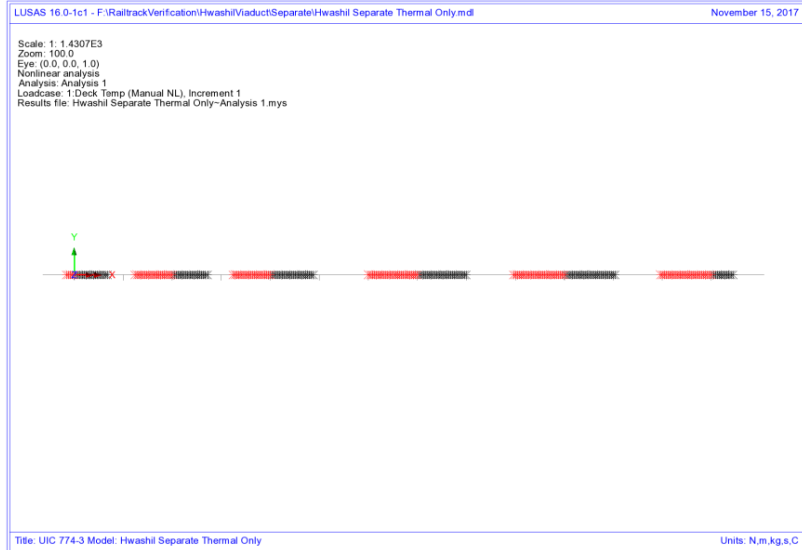


**Figure 91: Illustration Of Behaviour Of Separate Analysis Vs. LUSAS Analysis**

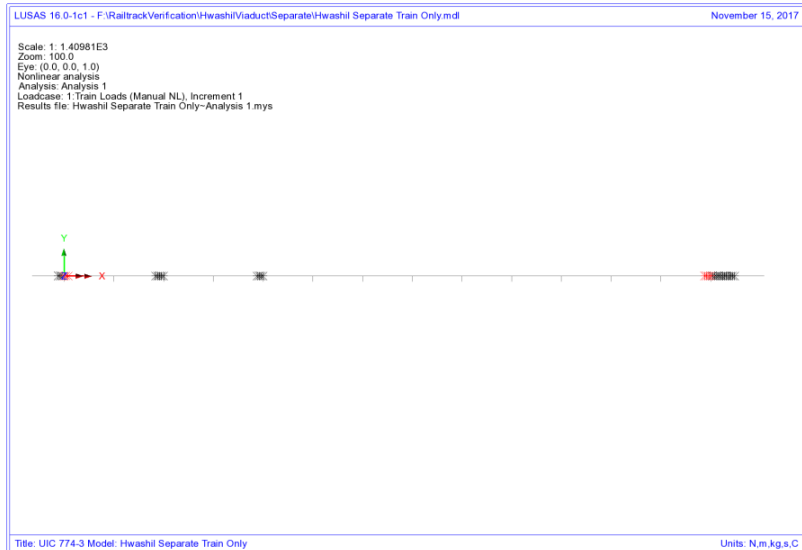
Looking now at the track/rail that has the braking train on it, the following figures show the same yield plots for this track/rail resistance. The immediate observation again is the different yield behaviour observed for the LUSAS analysis. Looking initially at the separate analysis and the concurrent thermal and rail loading analysis the yielding observed in the thermal alone for the separate analysis (Figure 92) shows close similarity to the yielding observed when the thermal and train loading are applied concurrently (Figure 94) – minimal yielding is observed under the action of the train load alone in the separate analysis (Figure 93).

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 93 and Figure 95 where the yielding

underneath the braking train is greater for the LUSAS analysis than in the separate rail load analysis.



**Figure 92: Track/Rail 1 Yield Due To Thermal Load On Track Alone**

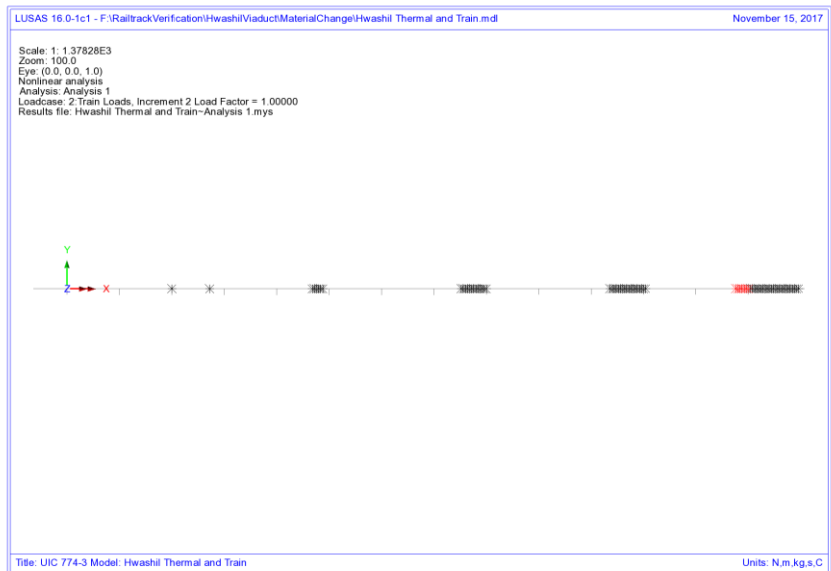


**Figure 93: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 – Separate Analysis**

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



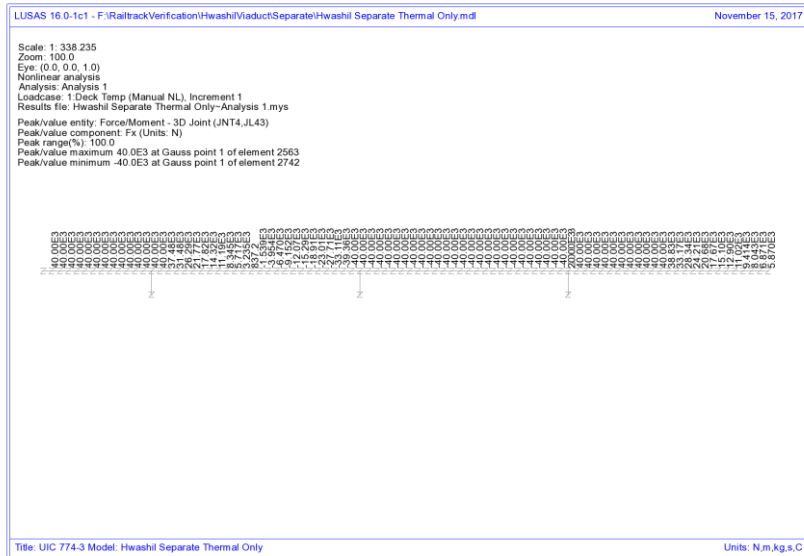
**Figure 94: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 - Thermal And Rail Applied Concurrently**



**Figure 95: Track/Rail 1 Yield Due To Braking Train Load On Track 1 - LUSAS Combined Analysis**

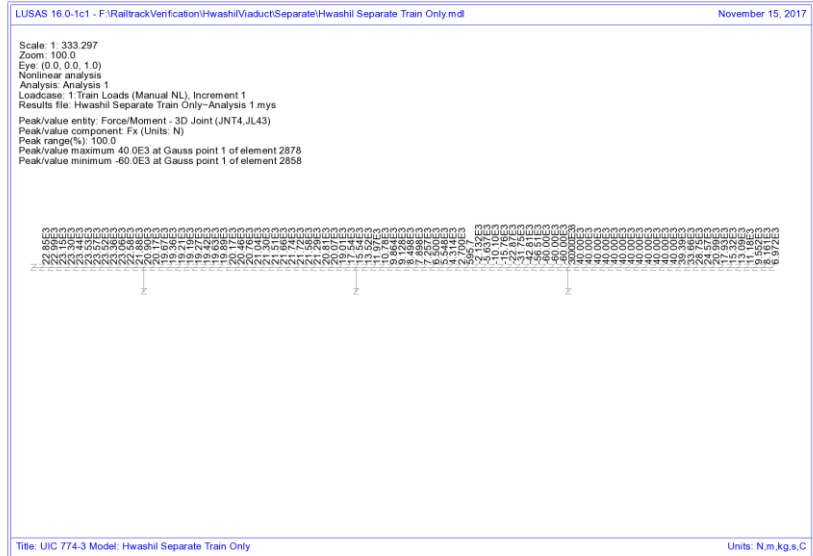
Looking at the behaviour of the track interaction for the separate analysis we can plot the values of the force per metre length for the track subjected to the braking train loads. Figure 96 and Figure 97 show the forces per metre length for the thermal loading and the train braking loading for the separate 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 98.

**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.

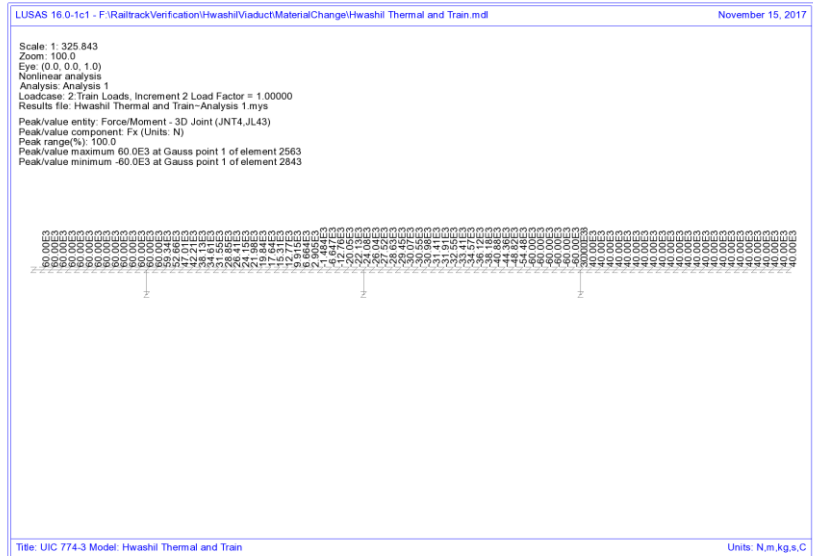


**Figure 96: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 – Separate Thermal Loading (N/m length)**

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



**Figure 97: 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 98: 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

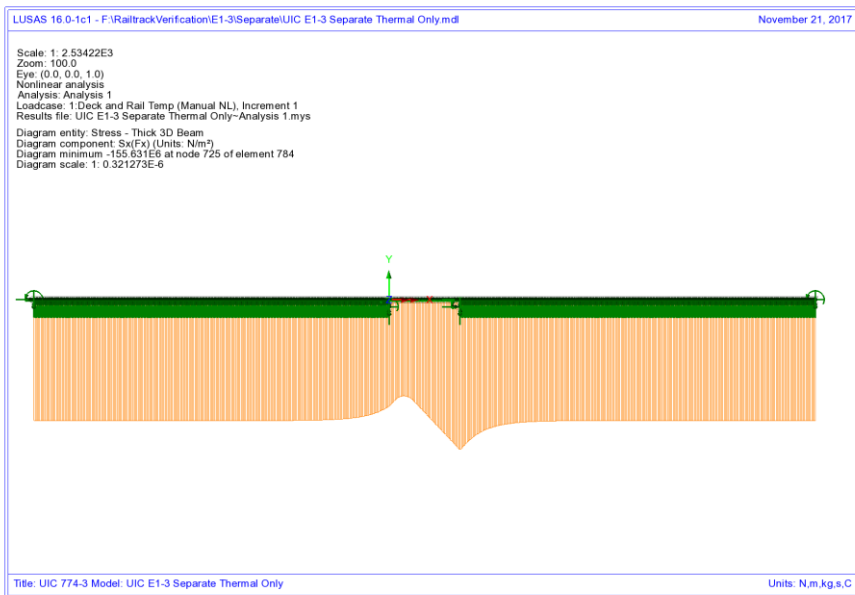
The standard UIC774-3 test E1-3 has been reanalysed using the following two approaches:

- ❑ 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

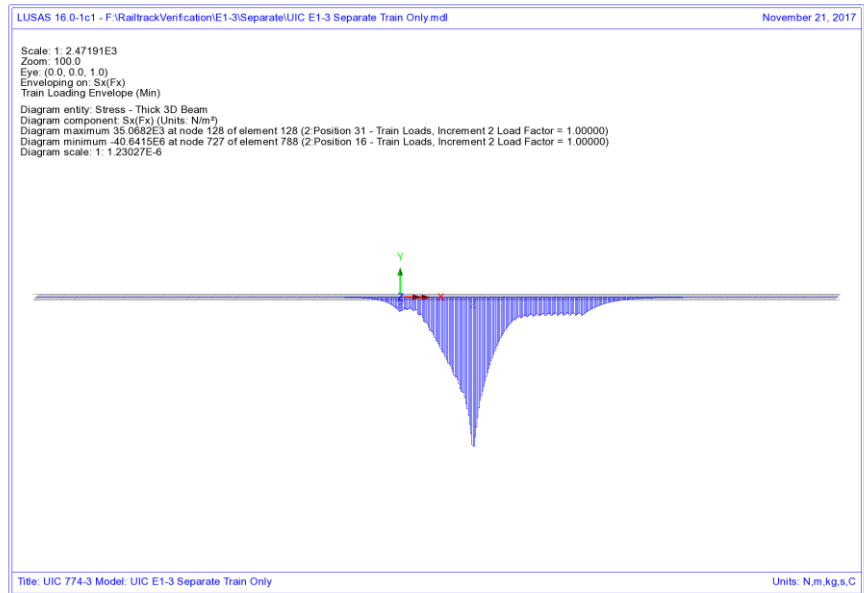
The analysis of the thermal effects due to the temperature in the bridge and rail are presented in the following figure. These two thermal effects give a peak compressive rail stress of  $155.63 \text{ N/mm}^2$  which compares well with the code of practice value of  $156.67 \text{ N/mm}^2$ .



**Figure 99: Axial Stress In Rails Due To Temperature In Bridge And Rail**

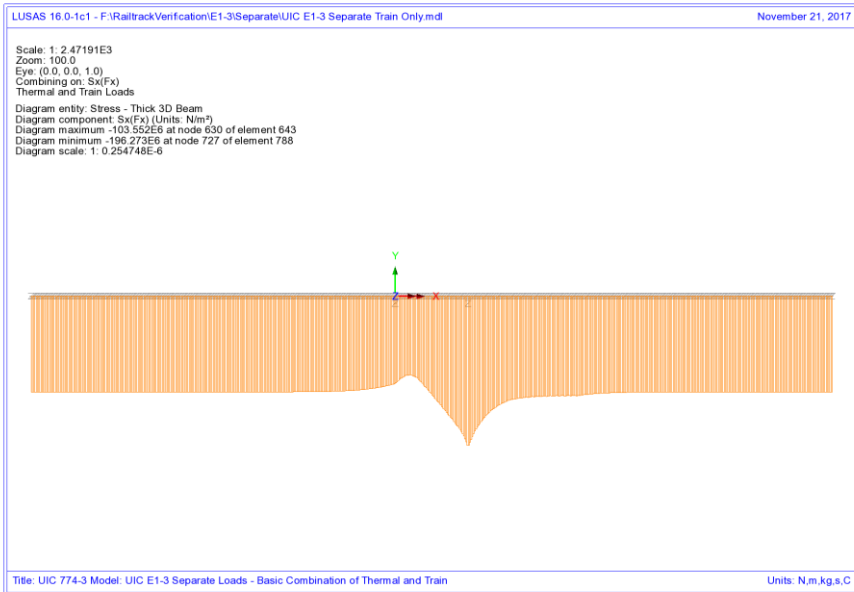
To determine the worst location of the train load for compressive rail stresses the bridge has been analysed with the rail loading at 31 separate locations (starting from the left abutment of the bridge and finishing 90m from the right abutment of the bridge – train moving from left to right) and these results enveloped. The results of this analysis are presented in the following figure which give a peak compressive rail stress of  $40.64 \text{ N/mm}^2$ .





**Figure 100: 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<sup>2</sup> (ignoring locations of the peaks) and combination of the results in LUSAS gives the same peak compressive rail stress of 196.27 N/mm<sup>2</sup> which occurs over the transition from the structure to the embankment at the right-hand abutment.



**Figure 101: 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<sup>2</sup> 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:

<b>Thermal:</b>	<b>155.63 N/mm<sup>2</sup></b>
<b>Thermal &amp; Rail:</b>	<b>193.06 N/mm<sup>2</sup></b>

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<sup>2</sup>.

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

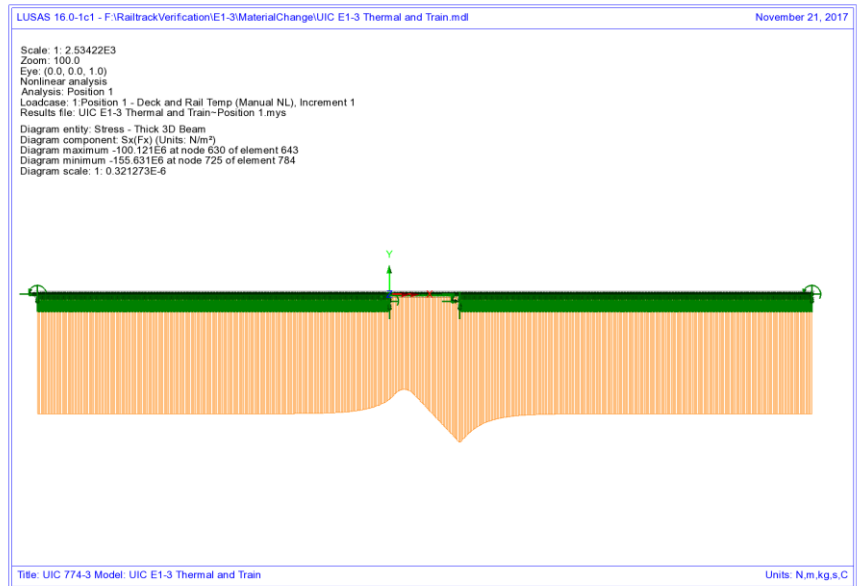


Figure 102: Axial Stress In Rails Due To Temperature In Bridge And Rail

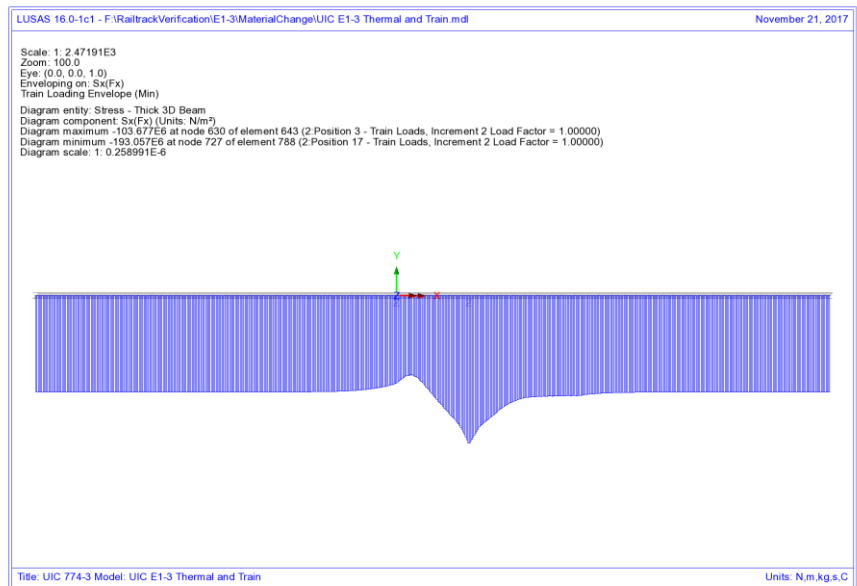
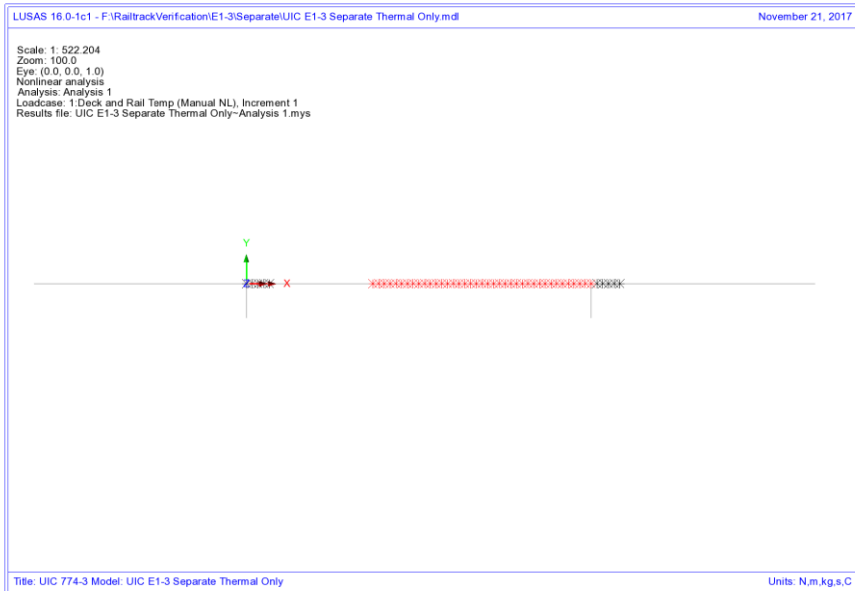


Figure 103: Axial Stress In Rails Due To Combined Temperature And Enveloped Rail Loading

## Discussion

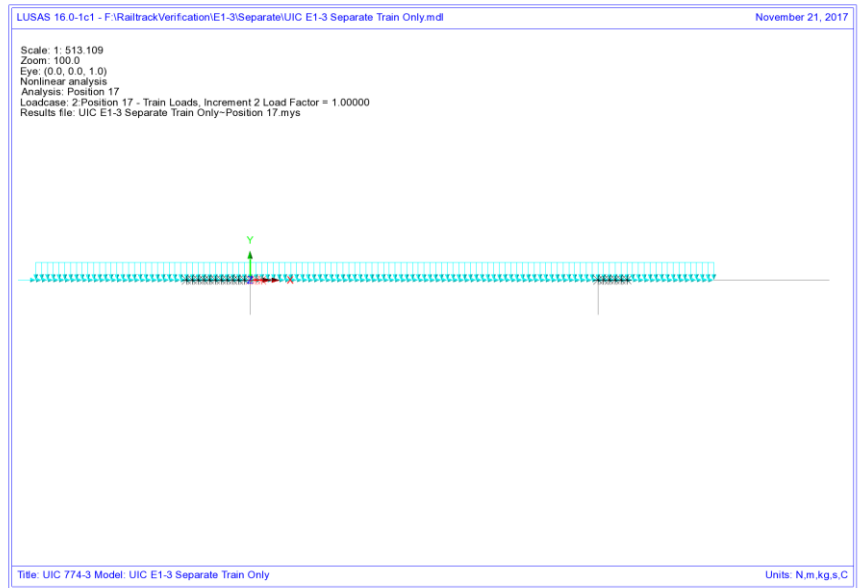
For this test case the difference in the results due to the track resistance modelling between the two methods is minimal. Combining the results of two nonlinear analysis, while invalid, gives almost identical results to the LUSAS analysis which correctly represents the transition from unloaded to loaded 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 104. 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 105 and Figure 106. 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.

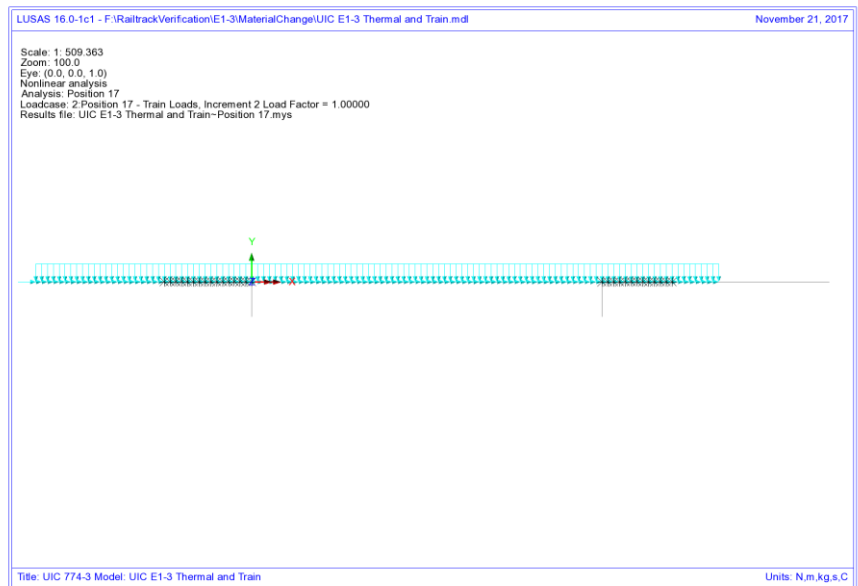


**Figure 104: Yield Layout For Thermal Loading Only**

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



**Figure 105: Yield Layout For Train Loading Only From Separate Analysis**

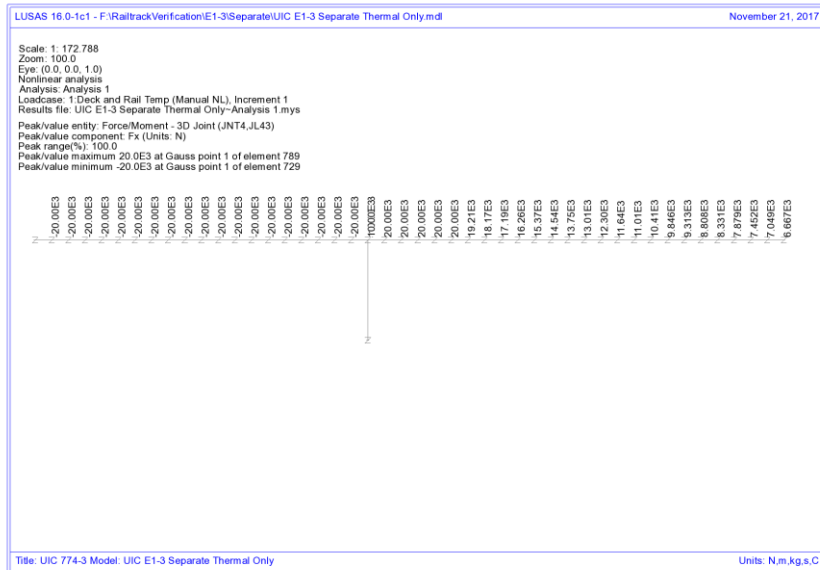


**Figure 106: Yield Layout For Combined Thermal And Train Loading From LUSAS Nonlinear Analysis**

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 109. 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 110.

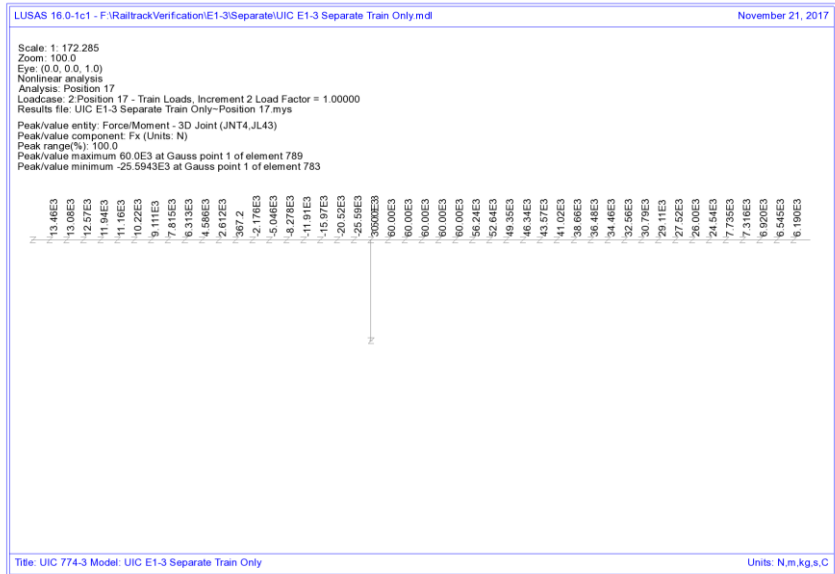
If, however, the train loading had induced interaction forces in the region of 40 kN/m (taking account of the track resistance already mobilised by the thermal loading) instead of the observed 25.6 kN/m then significant differences could be observed in the two analysis methods as the separate method 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.***

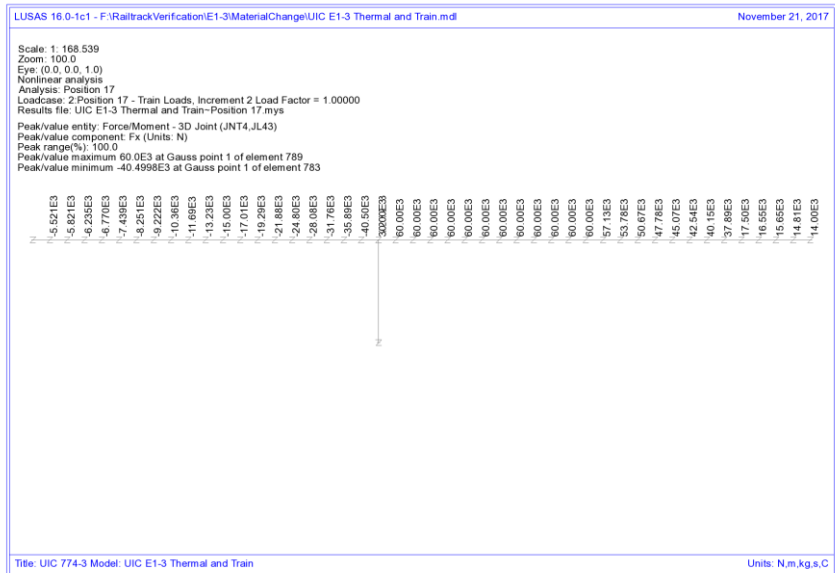


**Figure 107: Force Per Metre Length In Interaction From Thermal Loading - Separate Analysis**

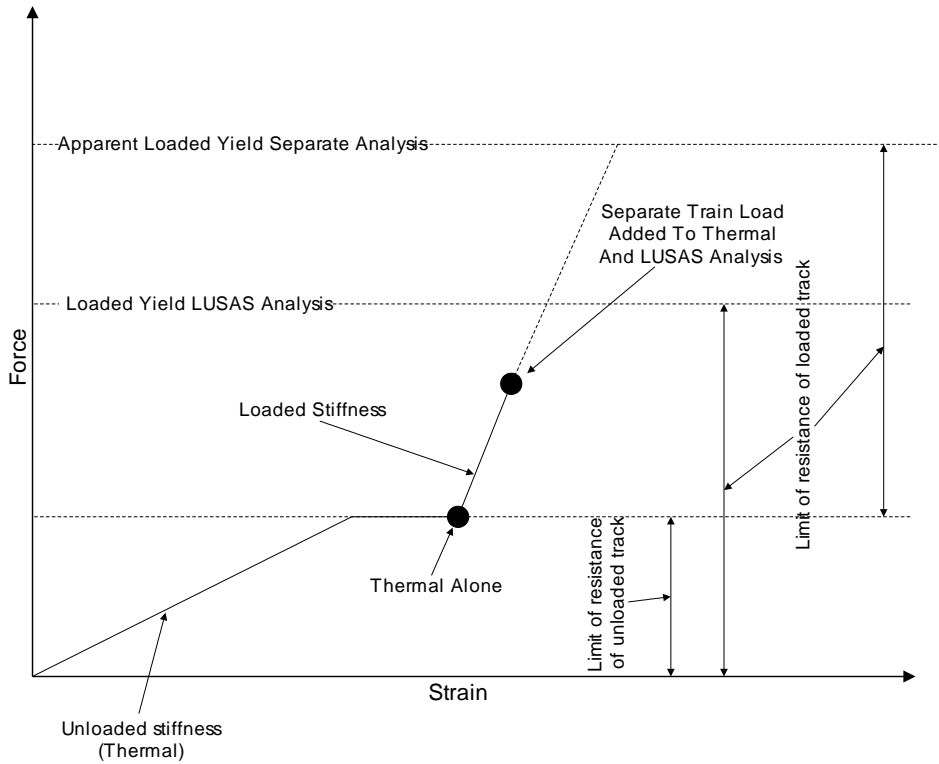
# Revisit of UIC774-3 Test E1-3 Using the Separate and LUSAS Methods of Analysis



**Figure 108: Force Per Metre Length In Interaction From Train Loading - Separate Analysis**



**Figure 109: Force Per Metre Length In Interaction From Combined Loading - LUSAS Analysis**



**Figure 110: 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  $167.77 \text{ N/mm}^2$  which compares very well with the code of practice value of  $169.14 \text{ N/mm}^2$ .

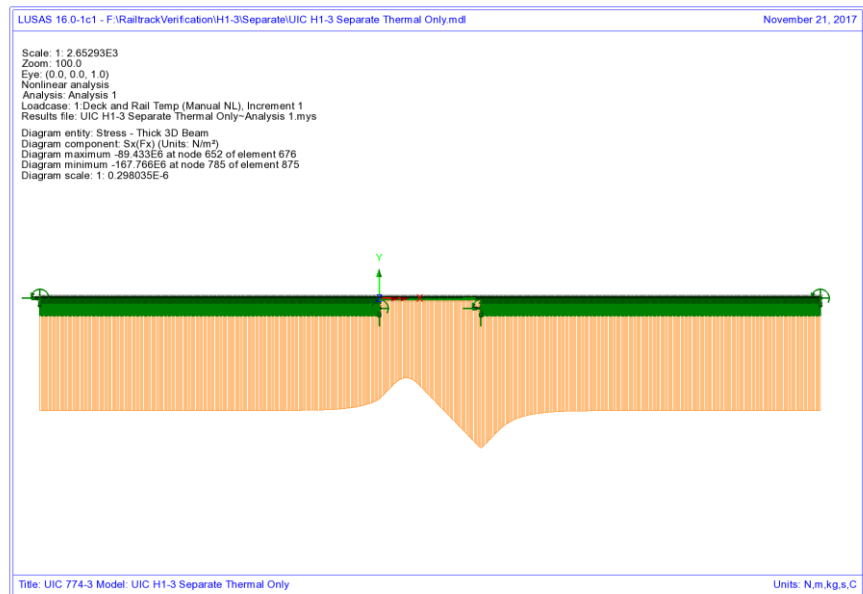
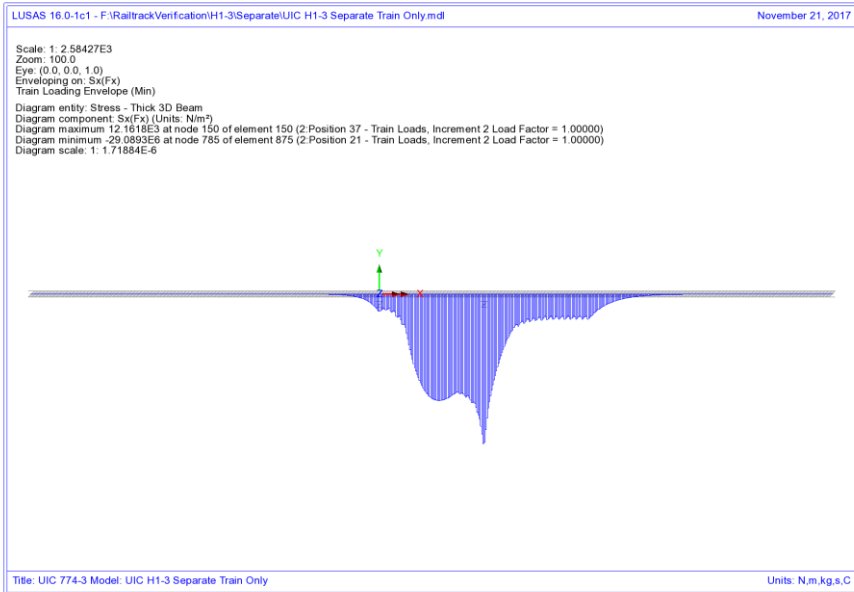


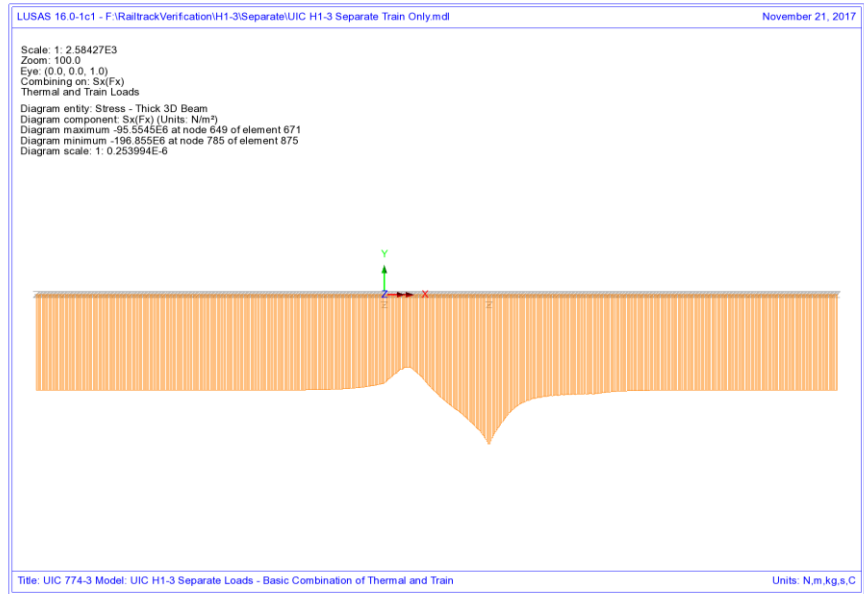
Figure 111: Axial Stress In Rails Due To Temperature In Bridge And Rail

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  $29.09 \text{ N/mm}^2$ .



**Figure 112: 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<sup>2</sup> (ignoring locations of the peaks) and combination of the results in LUSAS gives 196.86 N/mm<sup>2</sup> which occurs over the transition from the structure to the embankment at the right-hand abutment.



**Figure 113: Axial Stress In Rails Due To Combined Temperature And Rail Loading**

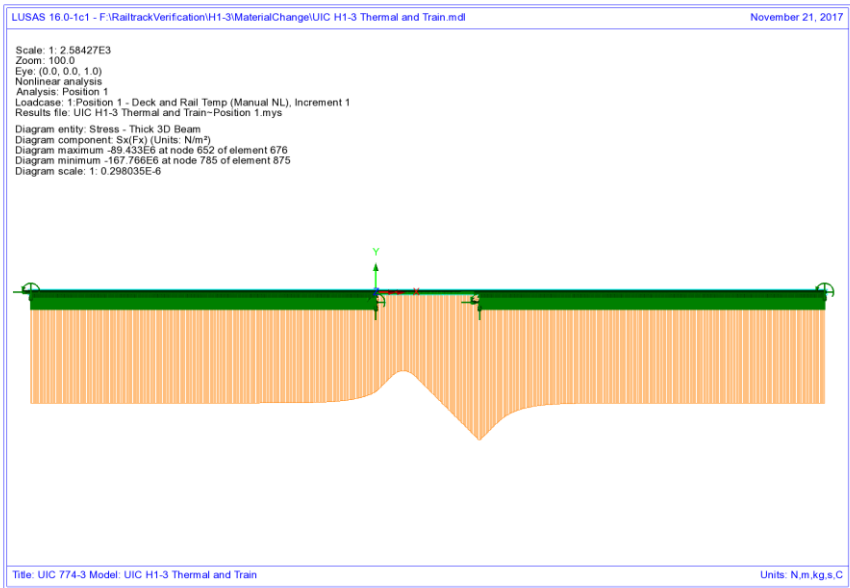
Comparison of these results with the UIC774-3 code of practice test results shows that the result compares well with the  $211.37 \text{ N/mm}^2$  compressive rail stress from the simplified and the  $188.23 \text{ N/mm}^2$  compressive rail stress from the rigorous analysis in the test case.

### **LUSAS Nonlinear Analysis**

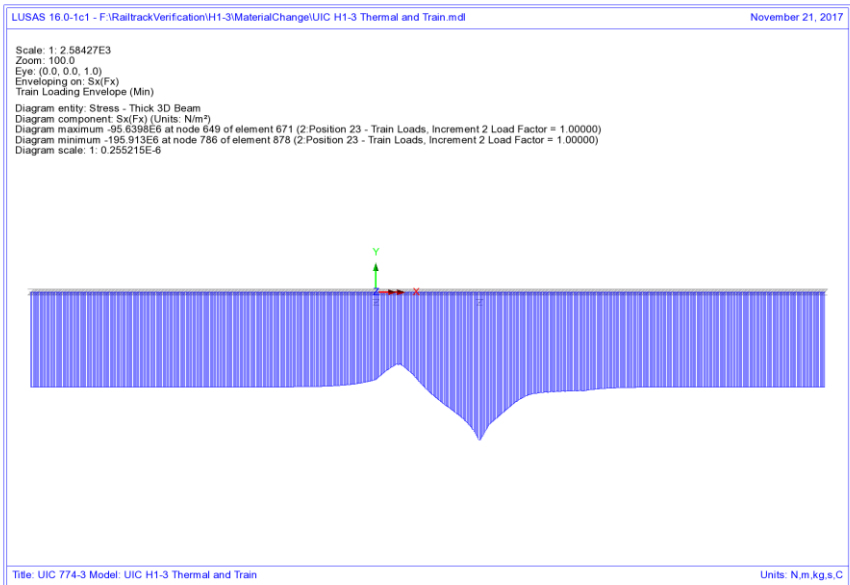
The UIC774-3 H1-3 test case has been reanalysed using the LUSAS rail option and gives the following peak compressive rail stress for the thermal loading alone and the combined thermal and rail loading:

<b>Thermal:</b>	<b><math>167.77 \text{ N/mm}^2</math></b>
<b>Thermal &amp; Rail:</b>	<b><math>195.91 \text{ N/mm}^2</math></b>

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  $188.23 \text{ N/mm}^2$ .



**Figure 114: Axial Stress In Rails Due To Temperature In Bridge And Rail**



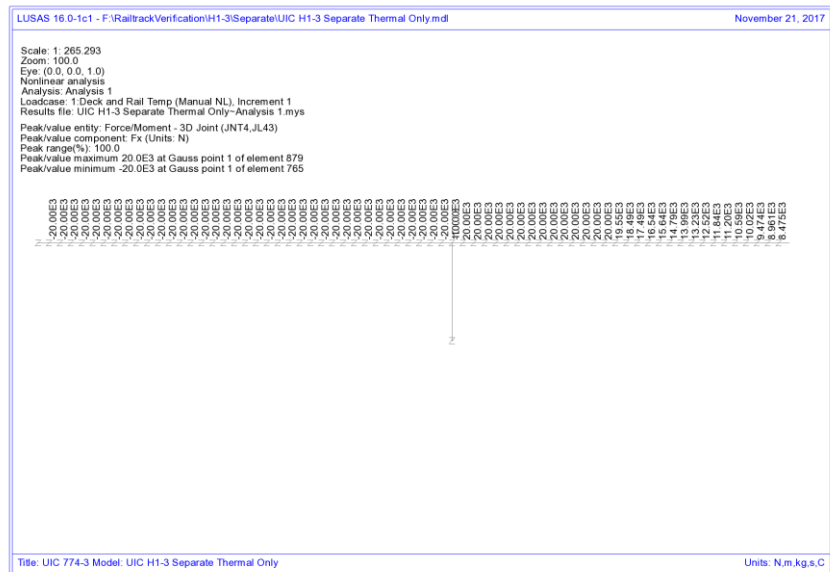
**Figure 115: Axial Stress In Rails Due To Combined Temperature And Enveloped Rail Loading**

## Discussion

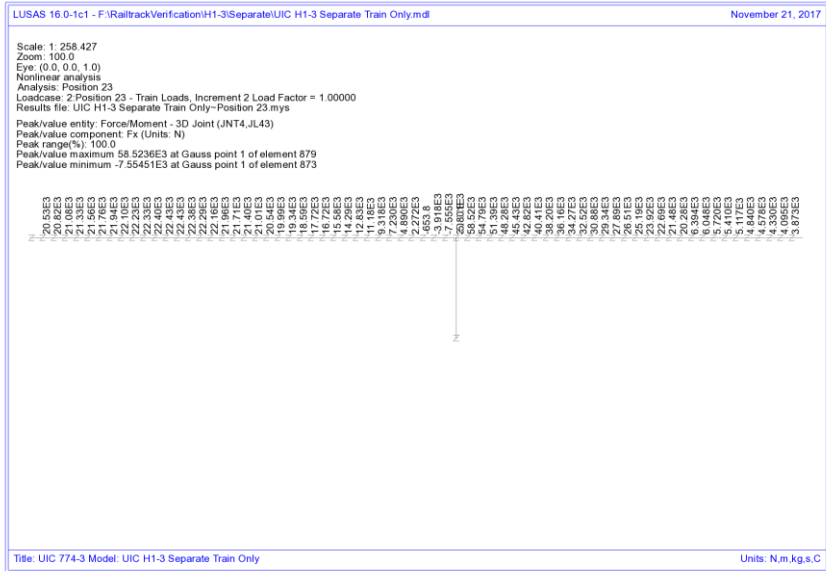
As with the previous E1-3 test case, the difference in the results due to the track resistance modelling between the two methods is minimal. Combining the results of two nonlinear analysis, while invalid, gives almost identical results to the LUSAS analysis which correctly represents the transition from 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.

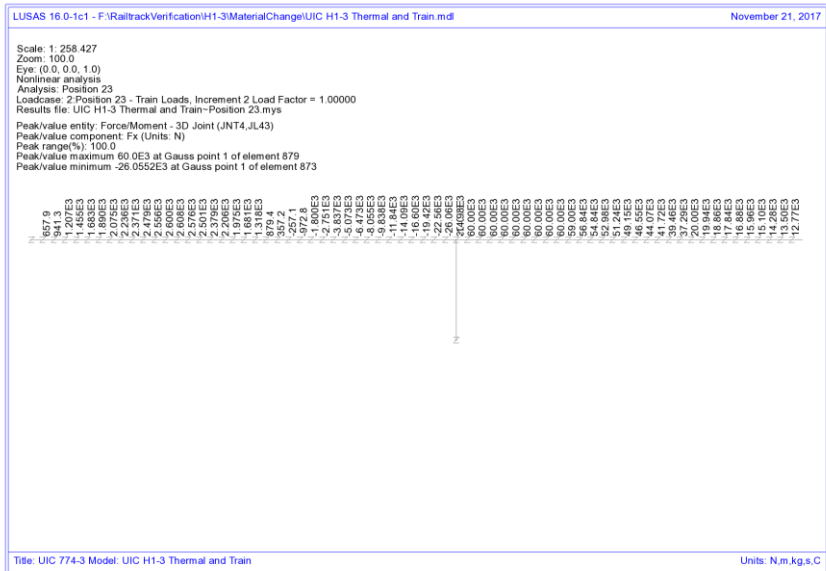
<b>Separate:</b>	<b>27.6 kN/m</b>
<b>LUSAS:</b>	<b>26.1 kN/m</b>



**Figure 116: Force Per Metre Length In Interaction From Thermal Loading - Separate Analysis**



**Figure 117: Force Per Metre Length In Interaction From Train Loading - Separate Analysis**



**Figure 118: 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 90 and Figure 91, 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	85.6	79.06
Track 2 (Accelerating)	103.66	100.6	92.60

**Table 2: Comparison Of Peak Compressive Rail Stresses (in N/mm<sup>2</sup>) 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







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