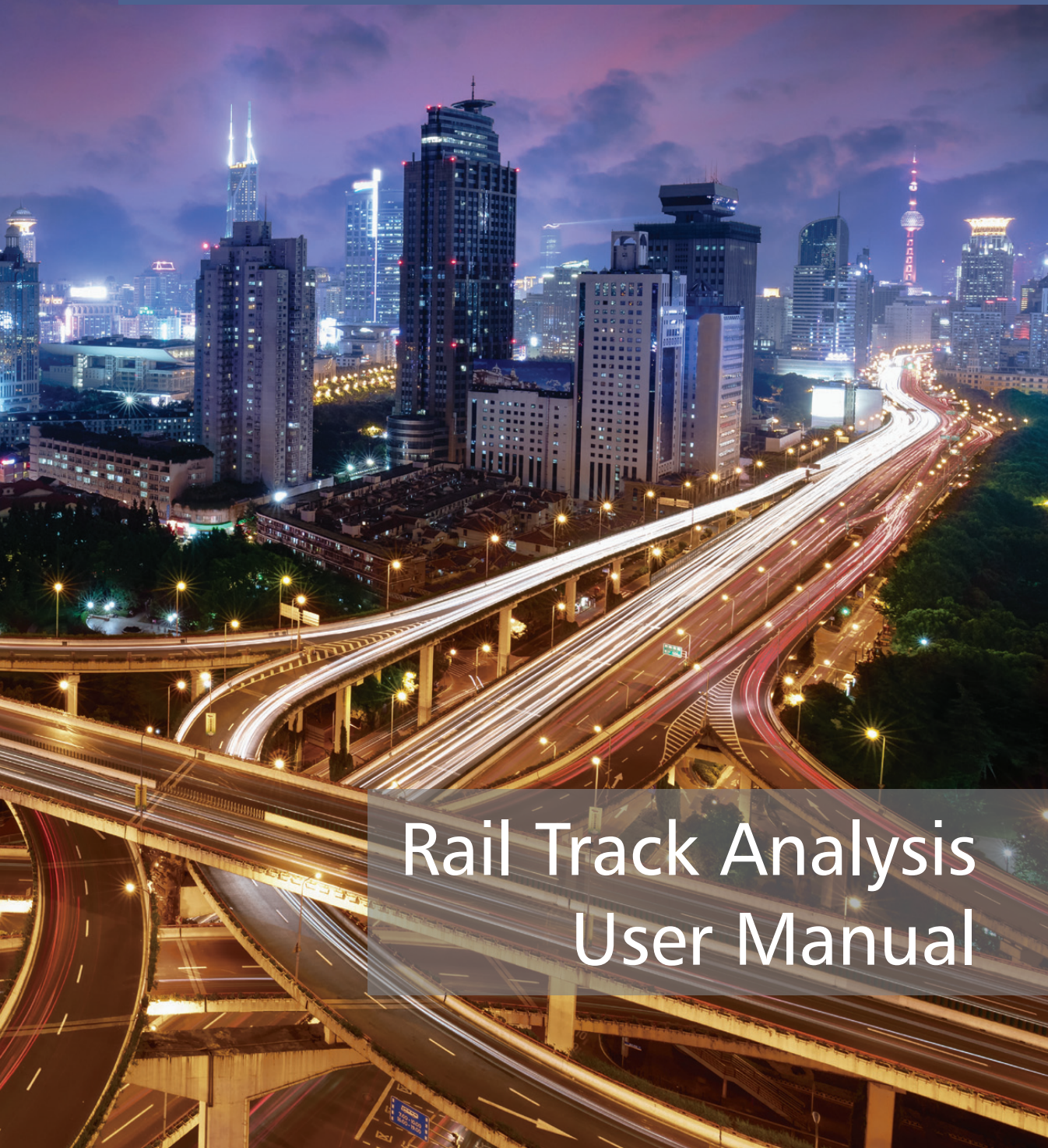
LUSAS



Rail Track Analysis User Manual

Rail Track Analysis User Manual

LUSAS Version 19.0 : Issue 1

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Table of Contents

Rail Track Analysis 1
Introduction 1
UIC774-3 Code of Practice 1
LUSAS Rail Track Analysis 4
Worked Example 4
The Rail Track Analysis Spreadsheet 4
Worksheet 1: Decks, Tracks and Embankment Lengths 5
Worksheet 2: Structure Definition 6
Worksheet 3: Geometric Properties 12
Worksheet 4: Material Properties 23
Worksheet 5: Interaction and Expansion Joint Properties 24
Worksheet 6: Thermal and Train Loading 28
Rail Track Analysis Menu Options 34
Build Model Dialog 34
Apply Rail Loads Dialog 37
Extract Results To Microsoft Excel Dialog 39
Rail Track Analysis Results Spreadsheet 40
Results worksheets created 40
Post-processing of automatically defined groups 40
Additional Results from Enveloping in Microsoft Excel 48
Post-processing of selected track / rail nodes 64
Post-processing of selected lines if groups are missing 64
Limitations of Use 67
Appendix A: Verification Testing 69
Introduction 69
Description 69
Combination of Separate Thermal and Rail Loading 70
Analysis of Combined Thermal and Rail Loading (One Step) 78
Analysis of Combined Thermal and Rail Loading Taking Account of Effects of Material Change Under Rail Loading 80
Discussion 83
Revisit of UIC774-3 Test E1-3 Using the Separate and LUSAS Methods of Analysis 93
Separate Analyses 93
LUSAS Nonlinear Analysis 95
Discussion 97
Revisit of UIC774-3 Test H1-3 Using the Separate and LUSAS Methods of Analysis 102
Separate Analyses 102
LUSAS Nonlinear Analysis 104
Discussion 106
Conclusions 108
Separate Thermal and Rail Loading Analysis 108
Concurrent Thermal and Rail Loading Analysis 108
LUSAS Nonlinear Thermal and Rail Analysis with Material Change 108
References 109
Appendix B: Definition of Complex Trainset Configurations 111
Introduction 111
Definition of Trainset Configurations With UDLs Alone 111
EuroCode Load Model SW/0 Loading Configuration 112
Definition of Trainset Configurations With Concentrated Loads 114
EuroCode Load Model 71 Loading Configuration 114
EuroCode Load Model HSLM-A Loading Configuration 117
References 131

Rail Track Analysis

Introduction

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

UIC774-3 Code of Practice

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

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

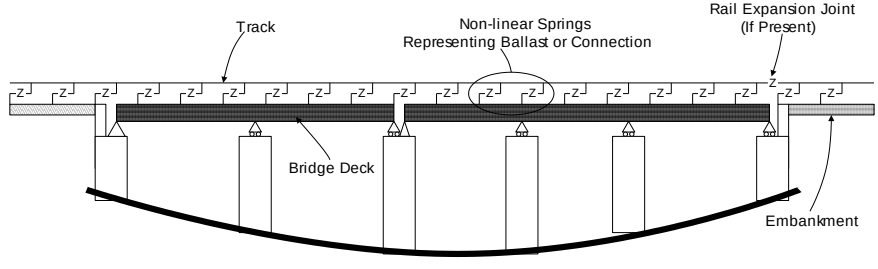


Figure 1: Representation of Structural System for Evaluation of Interaction Effects

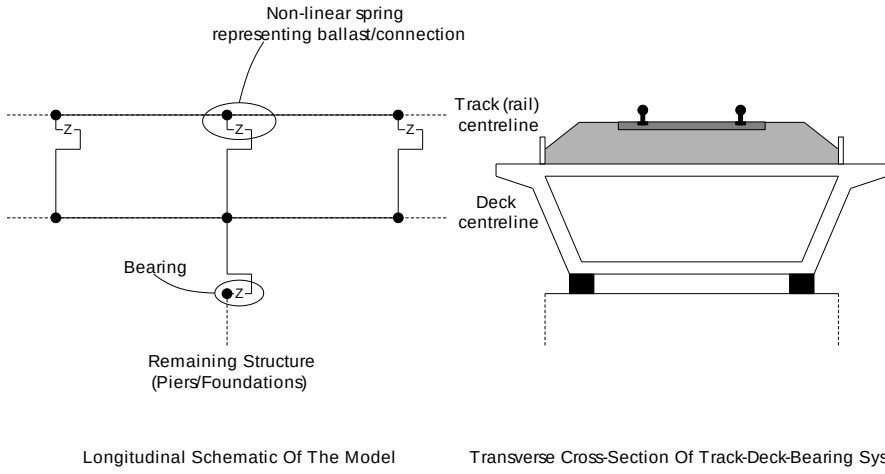


Figure 2: Typical Model of Track-Deck-Bearing System

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

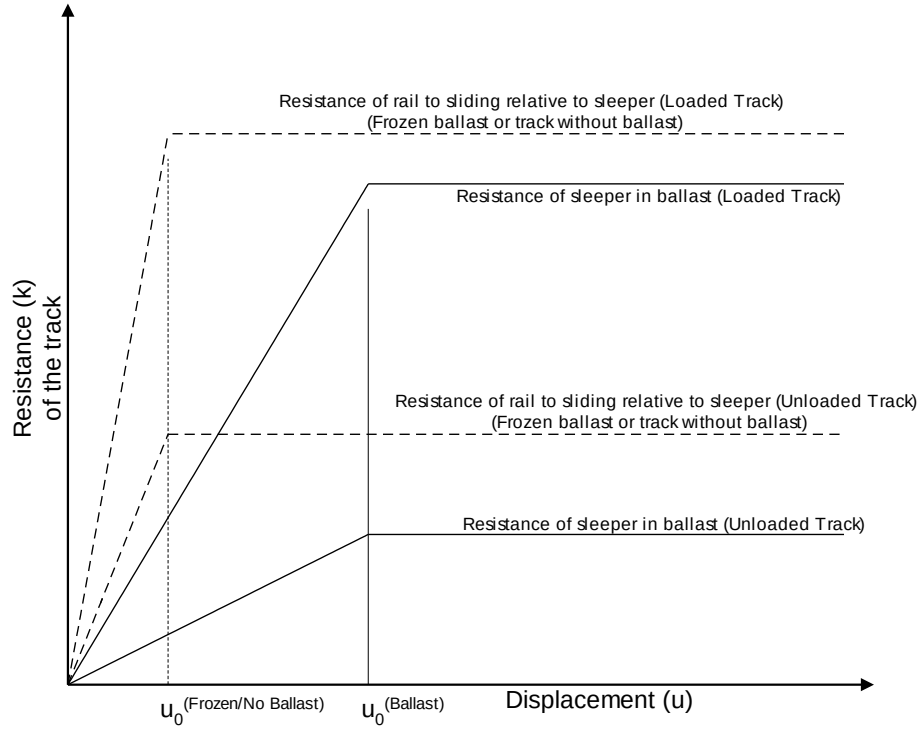


Figure 3: Resistance (k) of the Track per Unit Length versus Longitudinal Relative Displacement of Rails

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

Displacement between the elastic and plastic zones, u_o:

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

Resistance of sleeper in the ballast = 2.0 mm

Resistance in the plastic zone, k:

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

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

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

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

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

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

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

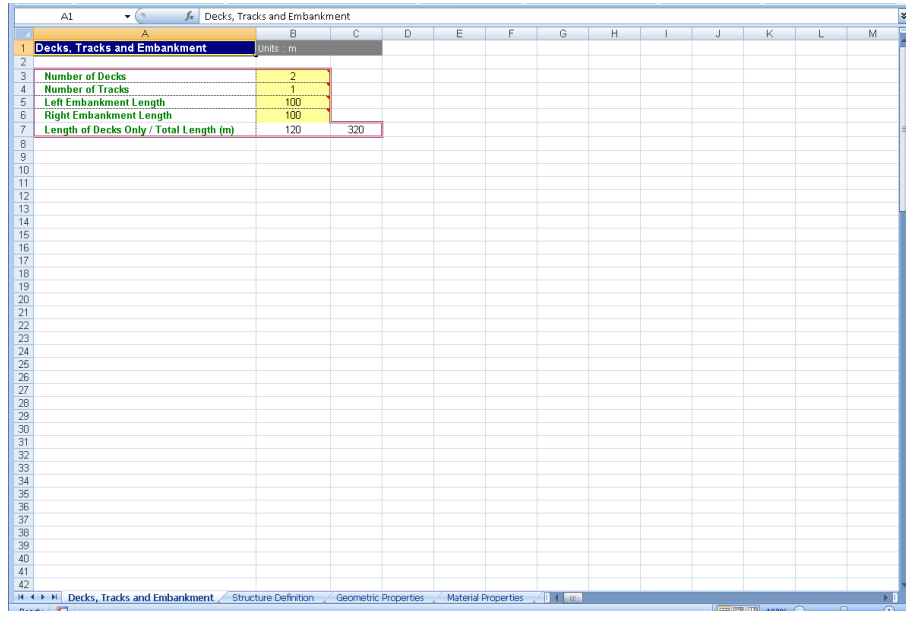


Figure 4: Definition of Number of Decks, Tracks and Embankment Lengths

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).

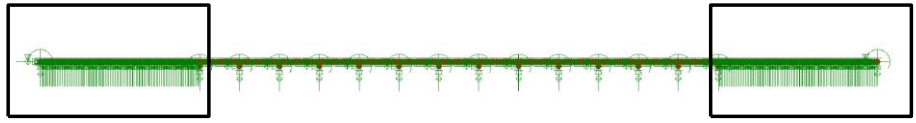
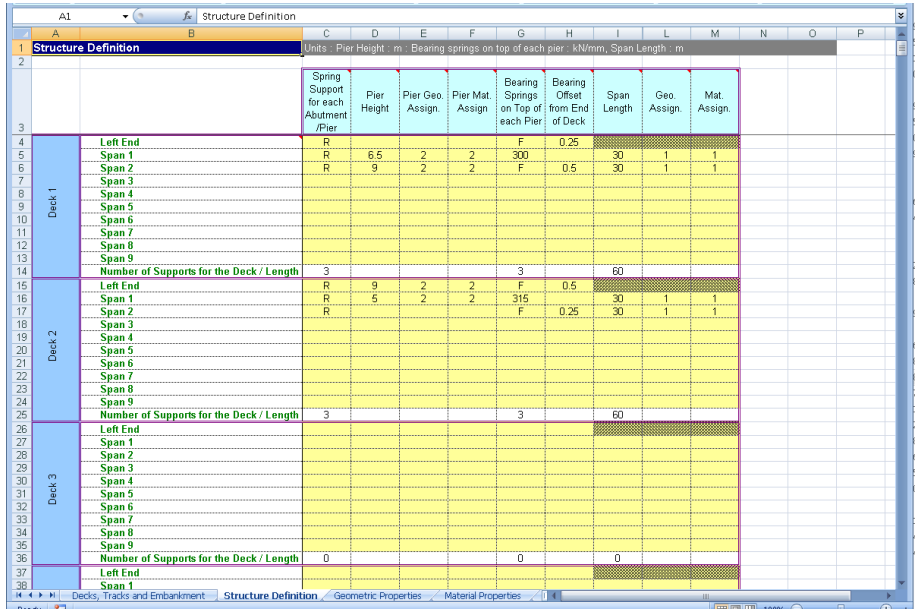


Figure 5: Left and Right Embankments in Model

Worksheet 2: Structure Definition



		Structure Definition	Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m								
			Spring Support for each Abutment /Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign	Bearing Springs on Top of each Pier	Bearing Offset from End of Deck	Span Length	Geo. Assign.	Mat. Assign.
Deck 1	Left End		R				F	0.25			
	Span 1		R	6.5	2	2	300		30	1	1
	Span 2		R	9	2	2	F	0.5	30	1	1
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length		3				3		60		
Deck 2	Left End		R	9	2	2	F	0.5			
	Span 1		R	5	2	2	315		30	1	1
	Span 2		R				F	0.25	30	1	1
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length		3				3		60		
Deck 3	Left End										
	Span 1										
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
	Number of Supports for the Deck / Length		0				0		0		
	Left End										
	Span 1										

Figure 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:

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

where

δ_p = displacement at top of support due to elastic deformation

δ_φ = displacement at top of support due to rotation of the foundation

δ_h = displacement at top of support due to horizontal movement of the foundation

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

and the total spring stiffness is calculated from:

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

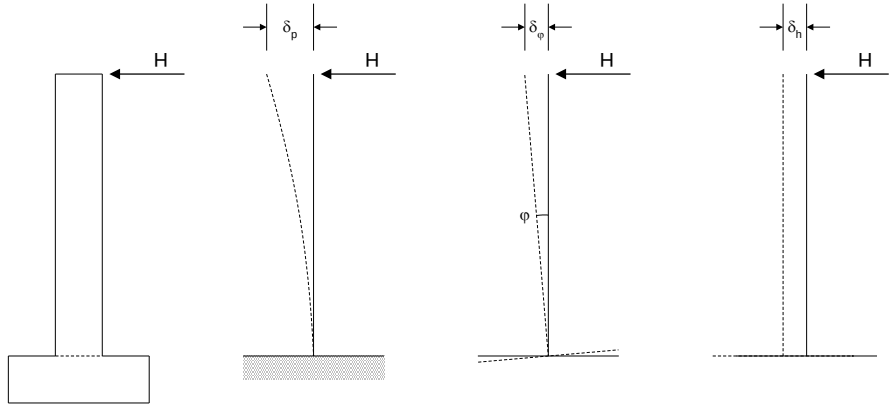


Figure 7: Component Behaviour for Calculating Support Stiffness

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.

Bearing offset from end of deck

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

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

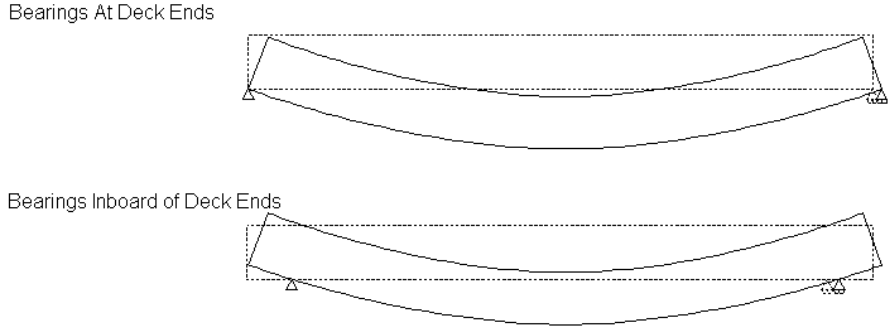


Figure 8: Effect of Bearings Inboards of the Deck Ends

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

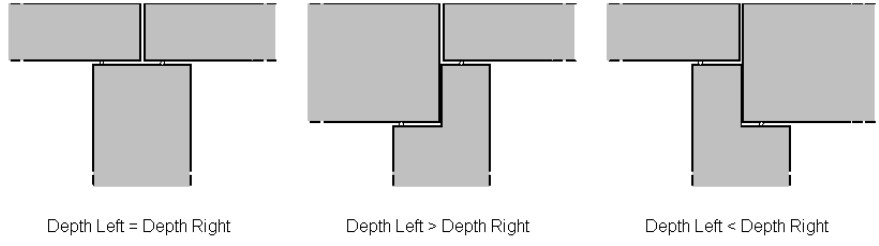


Figure 9: Pier Geometry Configurations for Bearing Elevations

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

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

Span Length

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.

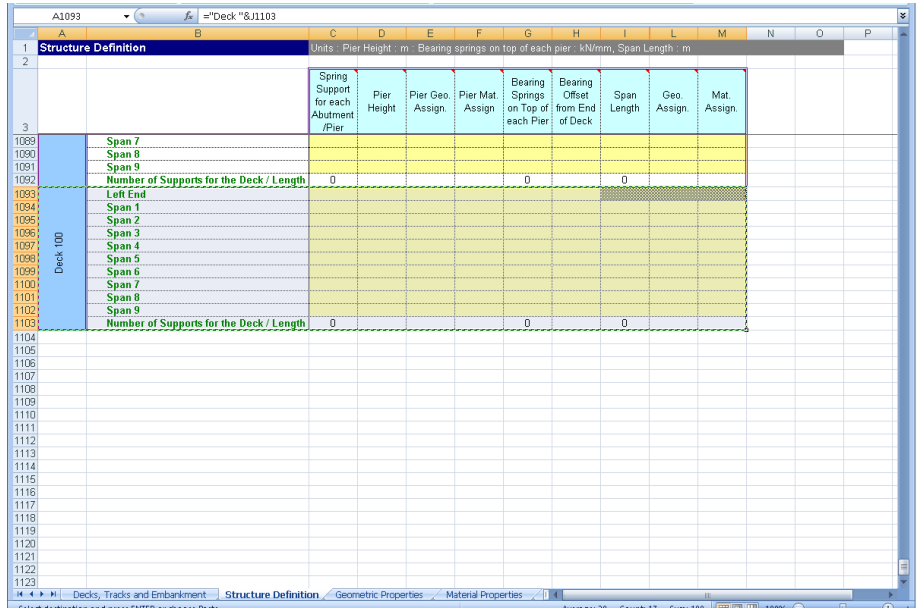


Figure 10: Selection and Copying of Structure Definition Worksheet to Increase Number of Decks

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.

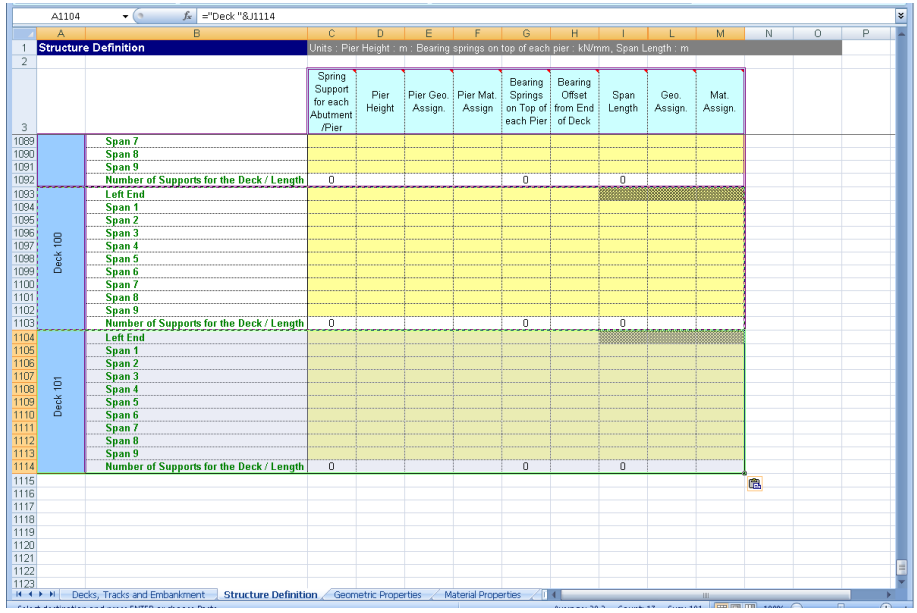


Figure 11: Pasting of Additional Decks to Ensure Formatting Maintained

Worksheet 3: Geometric Properties

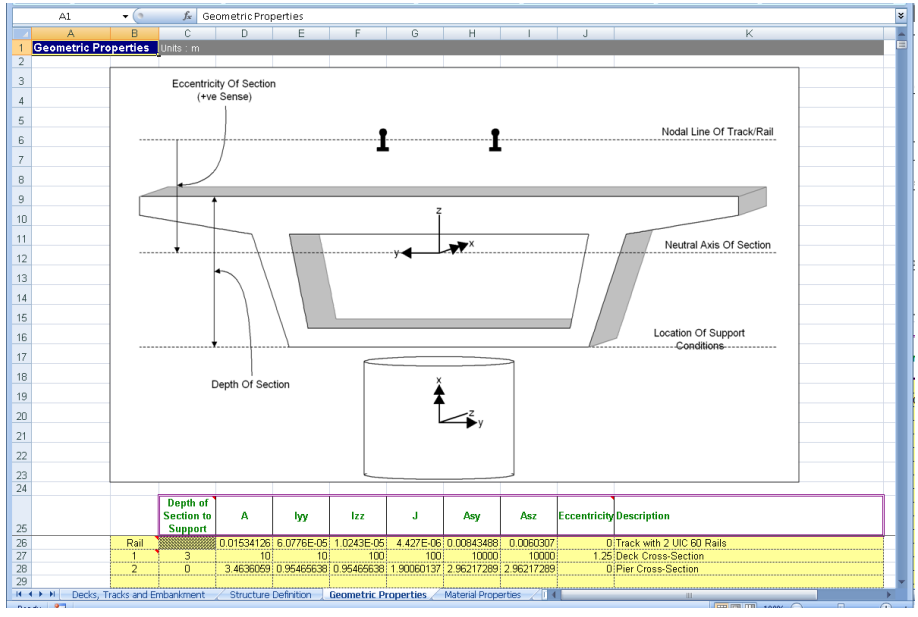


Figure 12: Geometric Properties Table for Structure

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

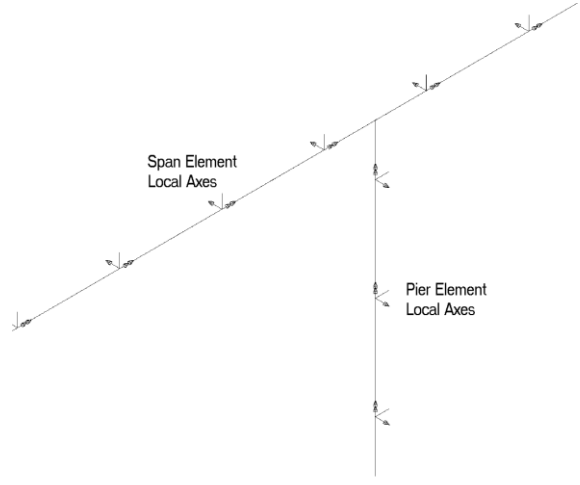


Figure 13: Beam Element Local Axes for Deck and Pier Modelling

For defining the geometric properties of the decks and rails the section axes are illustrated in Figure 14.

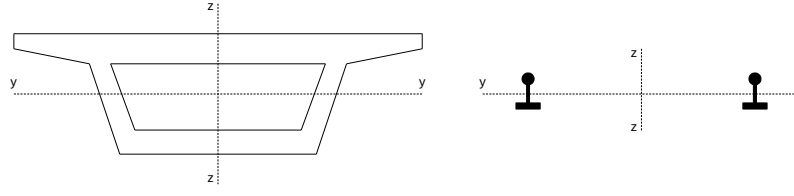


Figure 14: Section Axes for Deck and Rail Definitions

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.

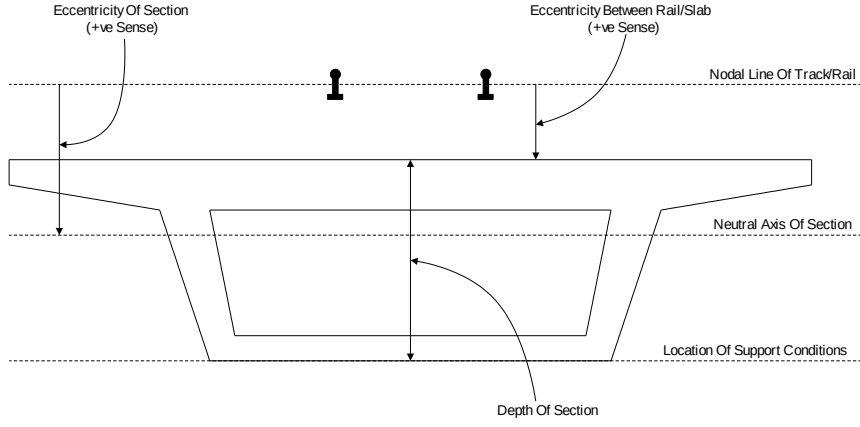


Figure 15: Eccentricity Definition for Geometric Properties and Depth of Section

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.

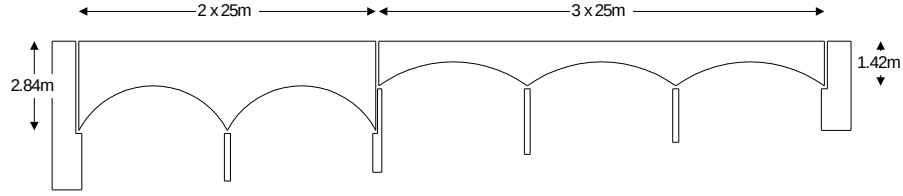
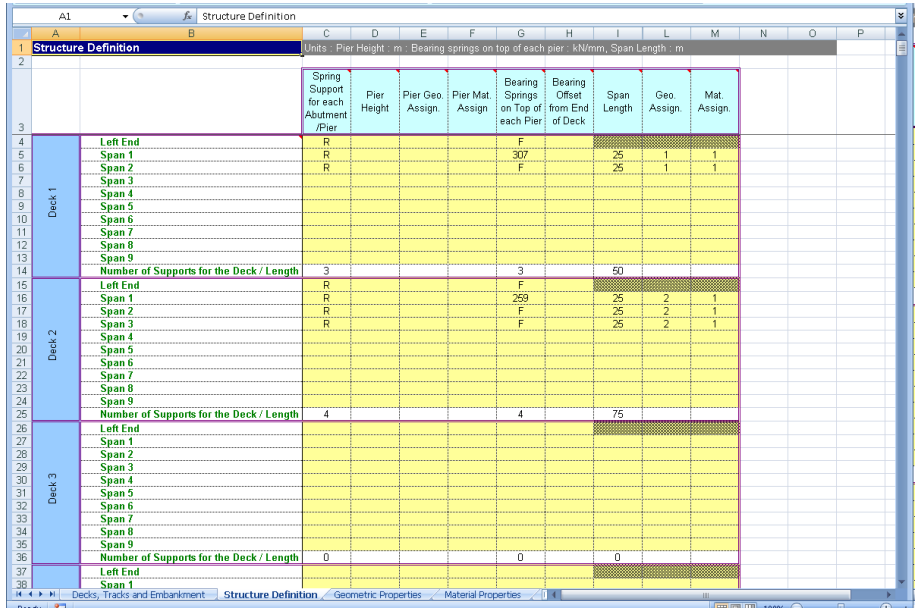


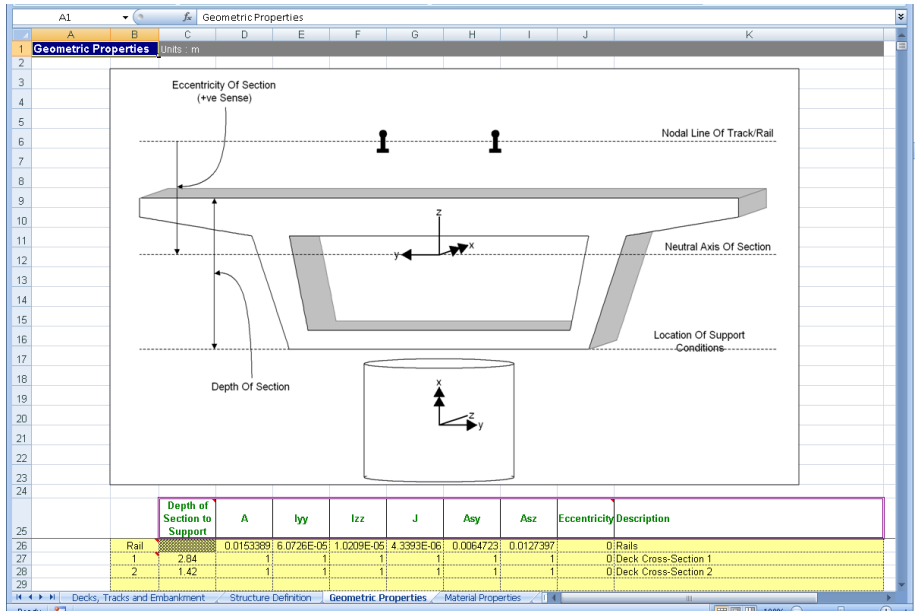
Figure 16: Example Varying Section Structure

If the structure in Figure 16 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 17 and Figure 18. This would define the base model indicated in Figure 19.



		Spring Support for each Abutment /Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign	Bearing Springs on Top of each Pier	Bearing Offset from End of Deck	Span Length	Geo. Assign.	Mat. Assign.
Structure Definition	Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m									
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									
	Span 6									
	Span 7									
	Span 8									
	Span 9									
	Number of Supports for the Deck / Length	0				0		0		
	Left End									
	Span 1									

Figure 17: Structure Definition for Sample Varying Section Structure



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

Figure 18: Geometric Properties for Sample Varying Section Structure

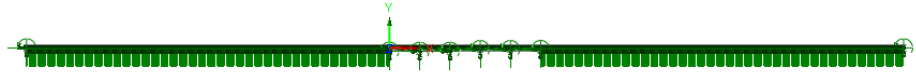


Figure 19: Base Model for Sample Varying Section Structure

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).

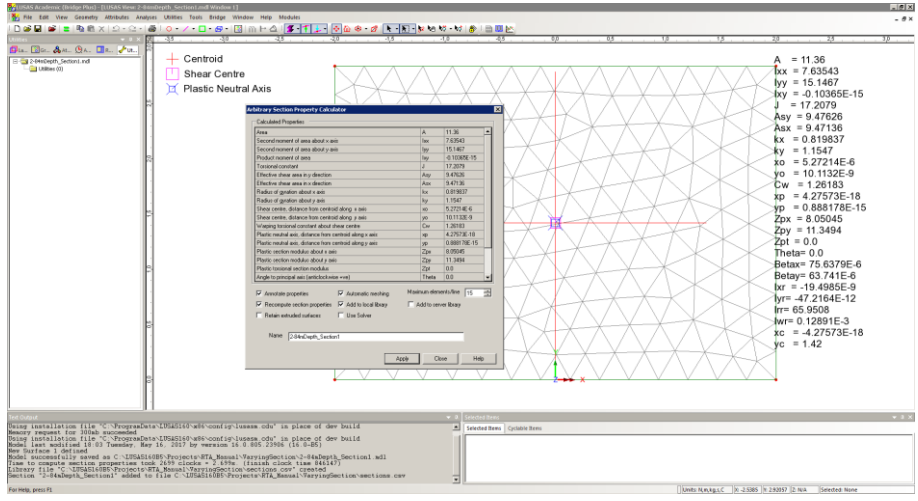


Figure 20: Arbitrary Section Property Calculation for 2.84m Depth of Section Span

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 21 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 22 where each reference path has been offset in the Y direction for visualisation purposes.

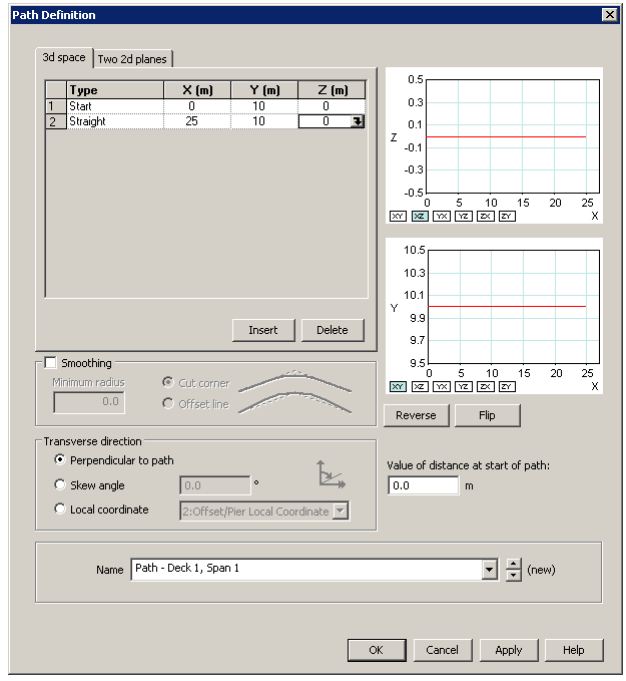


Figure 21: Definition of Reference Path for Deck 1, Span 1

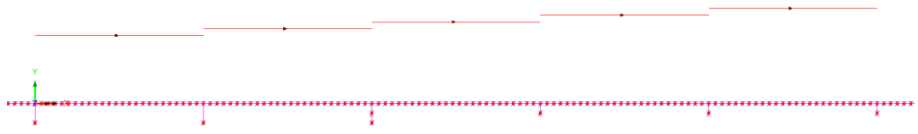


Figure 22: Reference Path for all Decks and Spans (Offset for Visualisation Purposes)

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 21). 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 23.

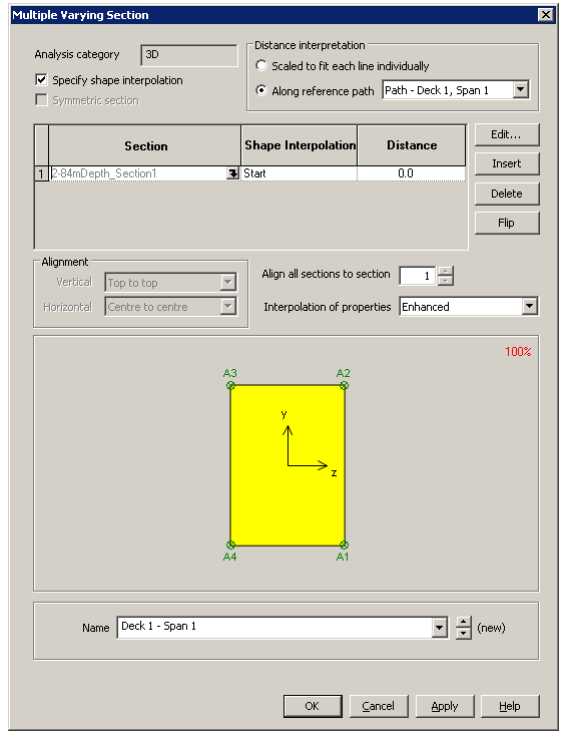


Figure 23: Definition of Multiple Varying Section for Deck 1, Span 1 (1 of 2)

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

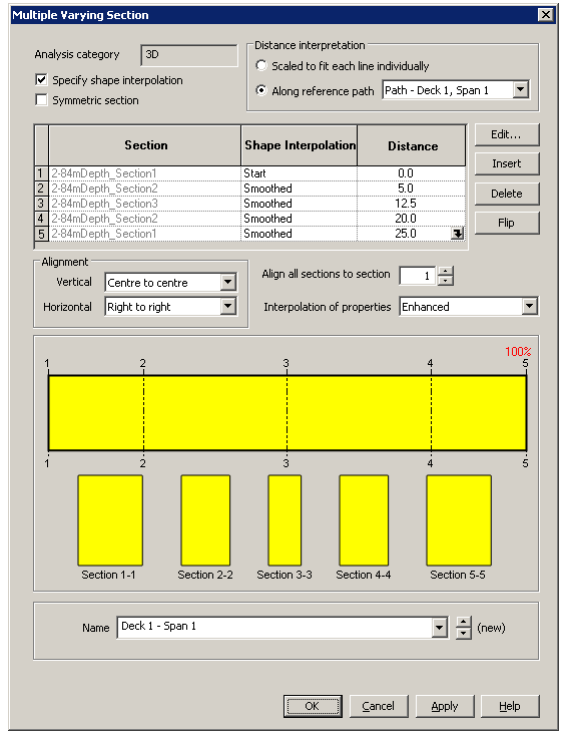


Figure 24: Definition of Multiple Varying Section for Deck 1, Span 1 (2 of 2)

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 25.

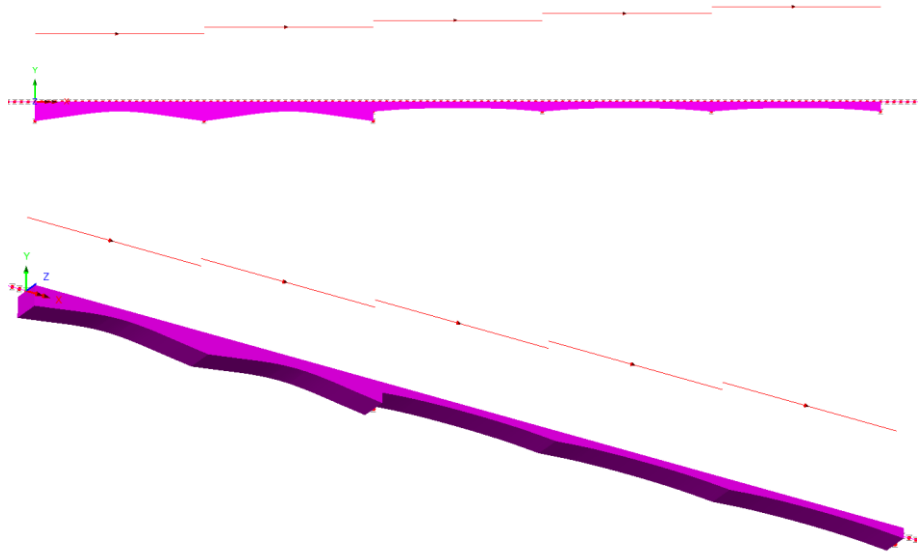


Figure 25: Model after Assignment of Multiple Varying Sections

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 26. When modelling structures where the sections do not vary smoothly, for example over a pier as indicated in Figure 16, 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 27 and Figure 28 which examine the behaviour at an intermediate pier of a deck when a single path is used for each deck. In Figure 28 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.

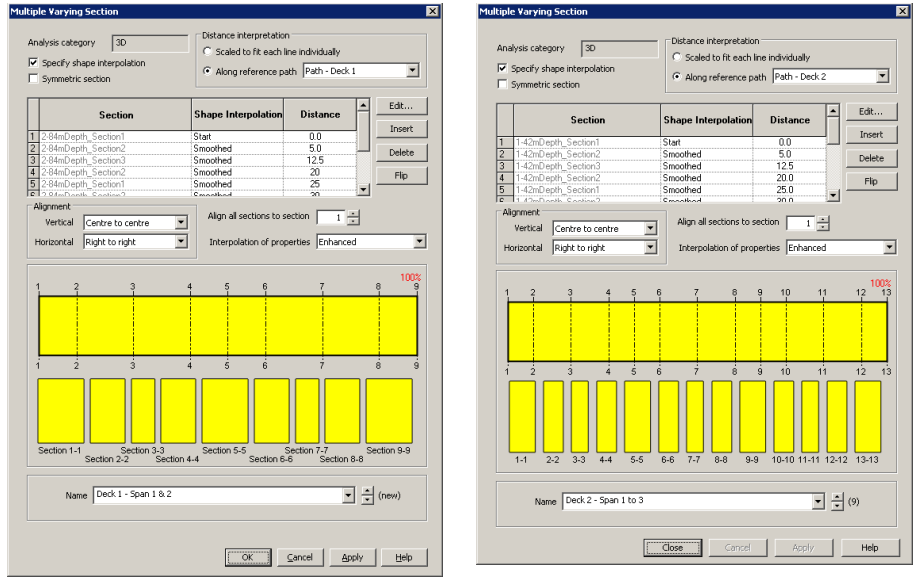


Figure 26: Definition of Multiple Varying Section for Deck 1 and Deck 2 for Two Reference Paths

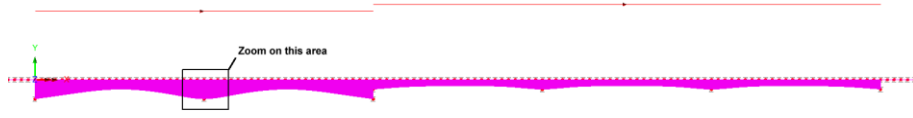
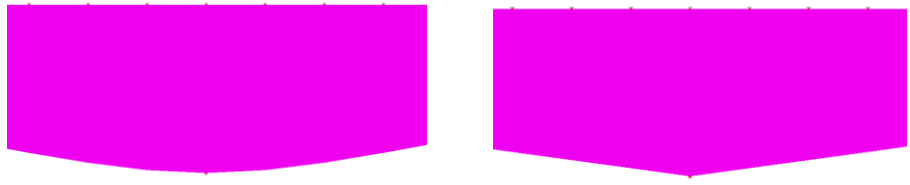


Figure 27: Model after Assignment of Multiple Varying Sections with Two Reference Paths



(a) **(b)**

Figure 28: Zoomed Plot of Pier Location between Spans of Deck 1 Showing (a) Smoothed Section for a Multiple Varying Sections with One Reference Path per Deck and (b) Correct Unsmoothed Section for a Multiple Varying Sections with One Reference Path per Span

Worksheet 4: Material Properties

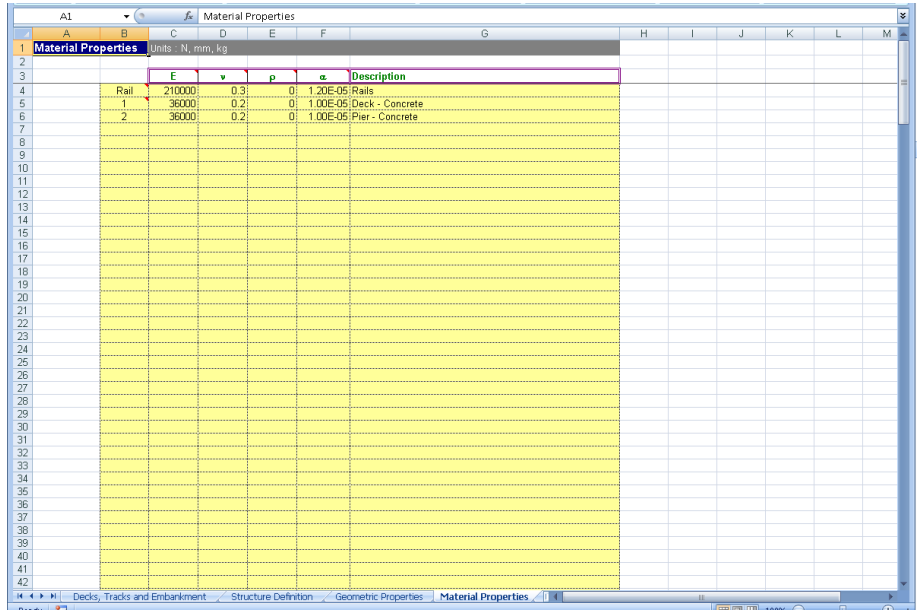


Figure 29: Material Properties Table for Structure

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

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

Worksheet 5: Interaction and Expansion Joint Properties

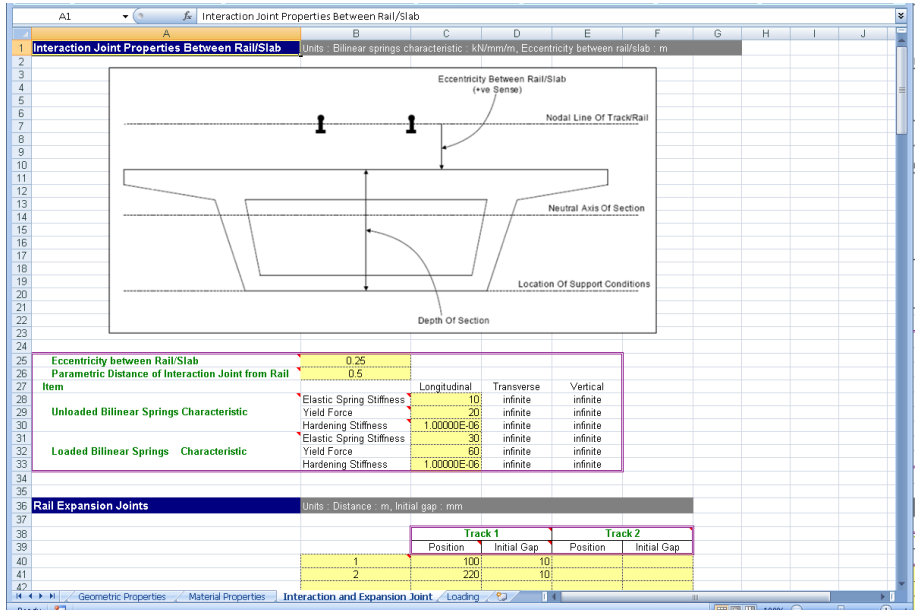


Figure 30: Interaction Properties Between the Track/Bridge and Expansion Joint Definition

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.

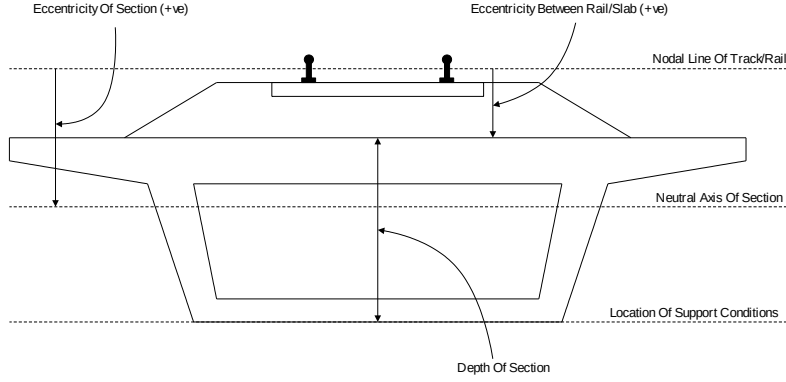
Eccentricity Between Rail/Slab

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.

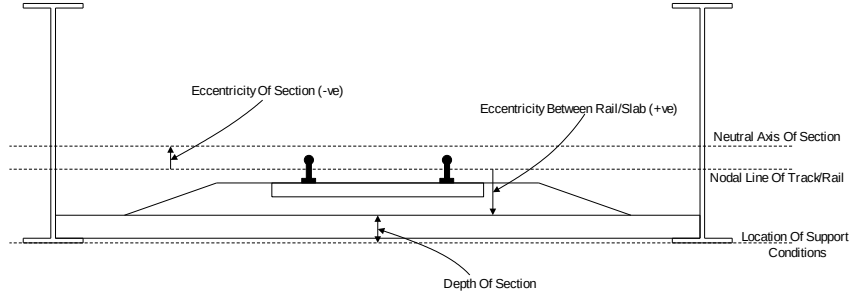
Parametric Distance of Interaction Joint from Rail

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.



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



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

Figure 31: 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 elastic spring stiffness is defined in kN/mm per metre length of track, the yield force (onset of plastic yield) is defined in kN per metre length and the hardening stiffness defined as a small value so there is no stiffness once plastic yielding has started. The values in Figure 30 are for unballasted track where the displacement

between the elastic and plastic zones and the associated resistance in the plastic zone are (see the earlier discussion on the bilinear relationship):

$u_0 = 0.5\text{mm}$

$k = 40\text{kN / m (Unloaded)}$

$k = 60\text{kN / m (Loaded)}$

The elastic spring stiffness is calculated directly from:

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

giving 80 kN/mm/m for the unloaded and 120 kN/mm/m for the loaded interaction elastic spring 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 yield force (1.0E12 kN/mm per metre length for example) and ensuring that the hardening stiffness is set to the same stiffness value as the elastic spring stiffness.

Note. If a zero or small yield force is used in the interaction characteristics the default settings for the nonlinear convergence scheme used in the solution may not result in a converged solution. These convergence parameters my 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.

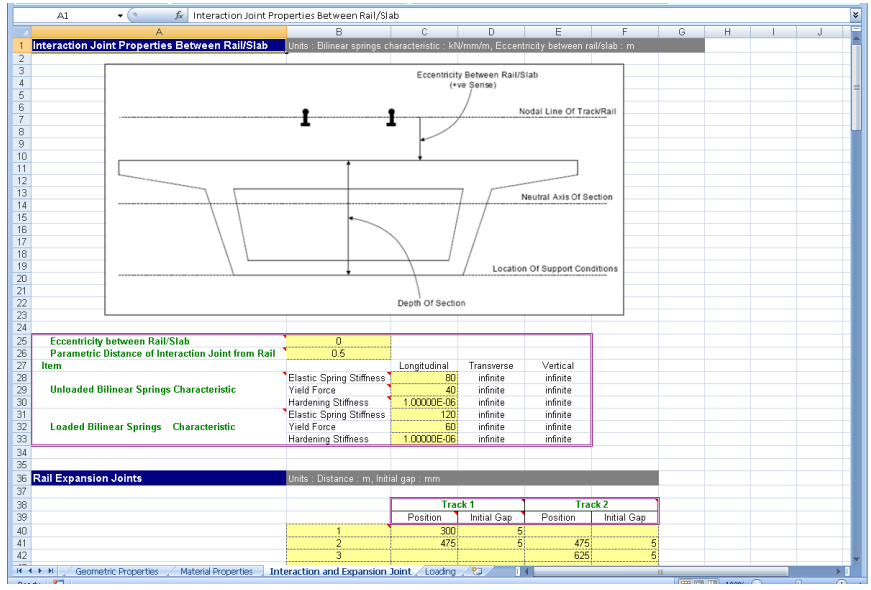
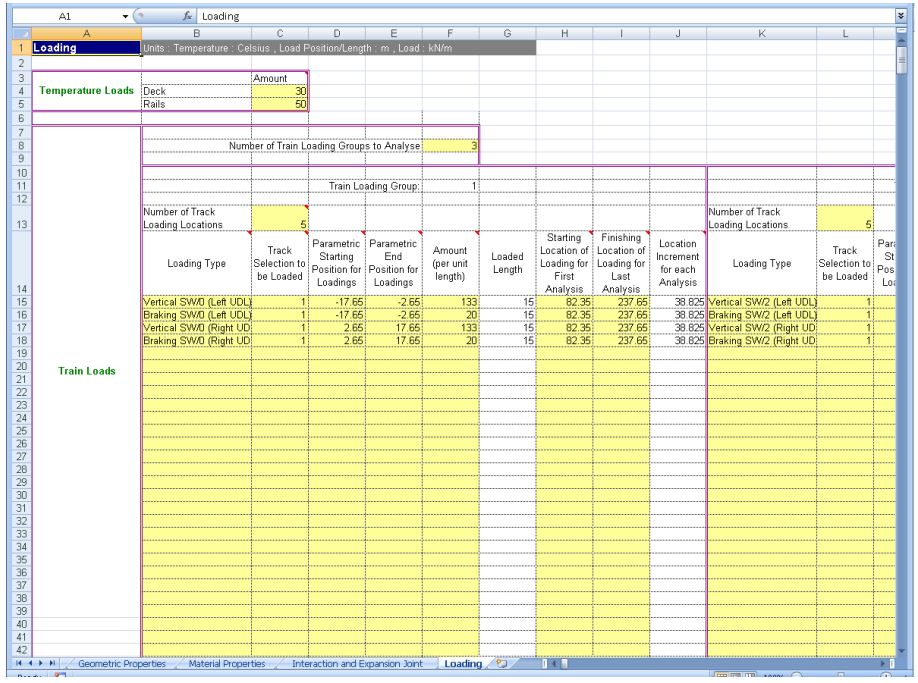


Figure 32: Sample Expansion Joint Definitions

Worksheet 6: Thermal and Train Loading



Loading

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

Temperature Loads		Amount
	Deck	30
	Rails	50

Number of Train Loading Groups to Analyse: 3

Train Loading Group: 1

Number of Track Loading Locations: 5

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

Train Loads

Number of Track Loading Locations: 5

Loading Type	Track Selection to be Loaded
Vertical SW/2 (Left UDL)	1
Braking SW/2 (Left UDL)	1
Vertical SW/2 (Right UD	1
Braking SW/2 (Right UD	1

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

Figure 33: Definition of Thermal and Train Loading for Structure

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

Temperature Loading

The temperature effects in the rails for a continuously welded rail (CWR) track do not cause a displacement of the track and do not need to be considered (UIC774-3 Clause 1.4.2). 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 Rail Track Analysis tool allows the analysis of the positioning / movement of multiple trainset configurations within the same overall Rail Track Analysis. This is done through the Train Loading Groups and parametric positioning of the trainsets within each of these. This can be used for either the global passage of multiple different trainset configurations across the whole structure (such as an analysis containing SW/0, SW/2 and HSLM-A trainset configurations / loadings to assess the overall behaviour to each of these) or the targeted and / or more detailed placement of a single (or more) trainset configurations at critical positions indicated by a prior global analysis or by engineering judgement.

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

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

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

As many rail/train loads that are required can be defined in the spreadsheet with data input terminating when blank data is detected in the loading type column. This allows more complex loading patterns to be defined such as those illustrated in Figure 34 and "Appendix B: Definition of Complex Trainset Configurations". To extend the bottom of the table extra rows can be inserted (making sure to copy the formulae in columns G and J for Train Loading Group 1 and similarly for others) or the last rows copied and pasted as many times as required.

Similarly, should the number of Train Loading Groups need to be increased from the 10 provided in the template this can be done by selecting the whole of the region defining the tenth Train Loading Group (as indicated in Figure 35) and pasting it as many times to the right of the existing Train Loading Groups (as indicated in Figure 36).

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.

The inputs to the worksheet are:

Number of train loading groups to analyse

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

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

Number of track loading locations

Defines the number of parametric locations for the placement of the trainset loading carried out in the analysis of this Train Loading Group. If only a single position of the trainset loading is to be considered then this should be set to 1. To analyse more than 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, **T**raction and **V**ertical. A more descriptive definition of the loading type may be entered if required as illustrated in "Appendix B: Definition of Complex Trainset Configurations" so long as the first character is set to either A, B, T or V.

Track selection to be loaded

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

Parametric end position for loadings

Defines the ending parametric position of the loading of the trainset for the current Train Loading Group. For the trainset the ending position is the right-most position of the load when considering the trainset alone (i.e. independent of the structure). These

are relative to the reference position as described for the parametric starting position above.

Amount (per unit length)

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

Loaded length

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

Figure 34 illustrates some trainset loading configurations and their input into the worksheet. Examples (d) and (e) in this figure are equivalent and both definition methods are equally valid in the worksheet. Further examples are illustrated in "Appendix B: Definition of Complex Trainset Configurations".

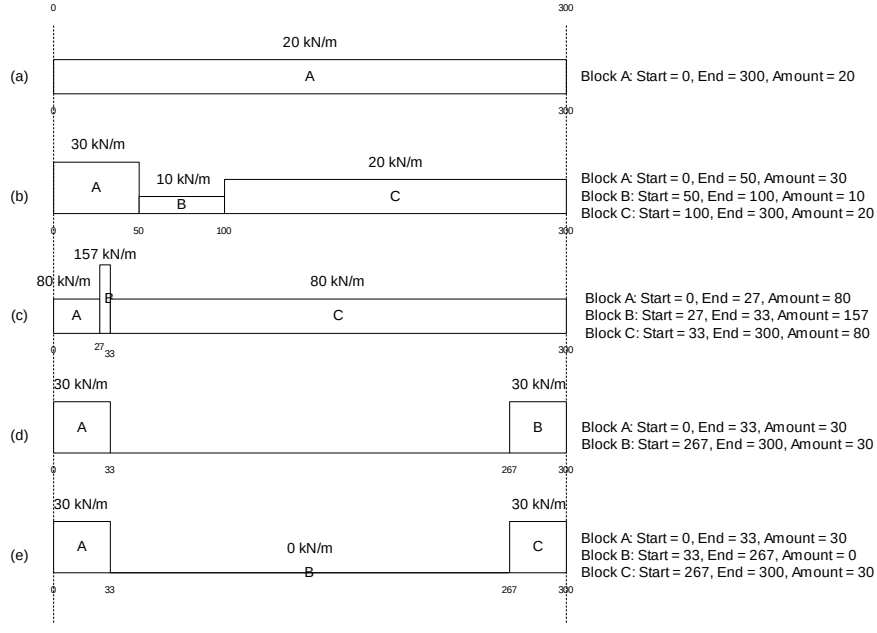


Figure 34: Sample Trainset Loading Position Definitions

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

Starting location of loading for first analysis

Defines the starting location of the reference position of the parametric trainset loading on the track for the first analysis for the current Train Loading Group. The location should be defined from the left-most end of the left-hand embankment which is at a location of 0.0m. The starting position 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 (TotalLengthTrack - 150)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 for the current Train Loading Group. The location should be defined from the left-most end of the left-hand embankment which is at a location of 0.0m. The finishing position 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.

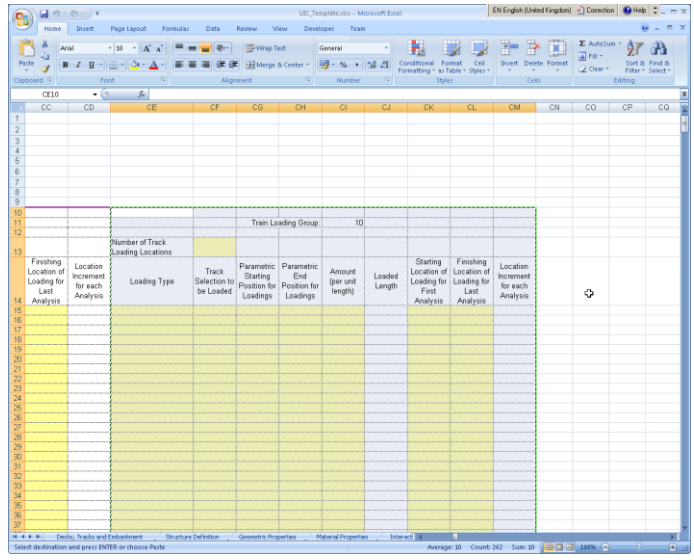


Figure 35: Adding Extra Train Loading Groups (Copy)

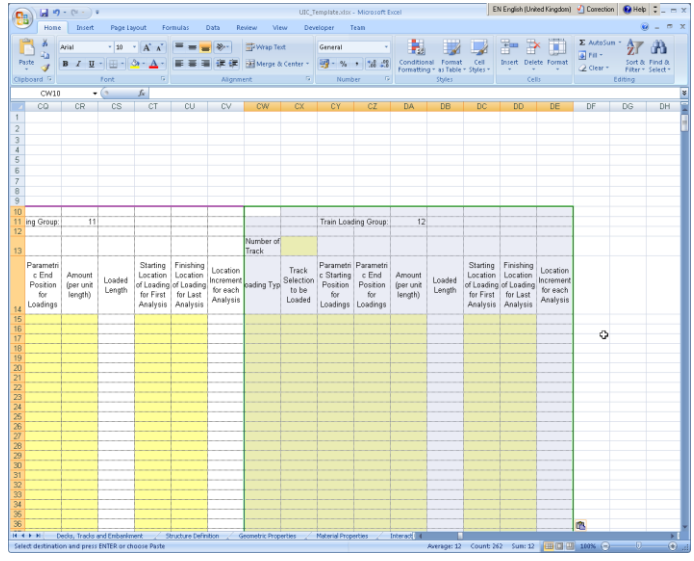


Figure 36: Adding Extra Train Loading Groups (Paste)

Rail Track Analysis Menu Options

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

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

Build Model Dialog

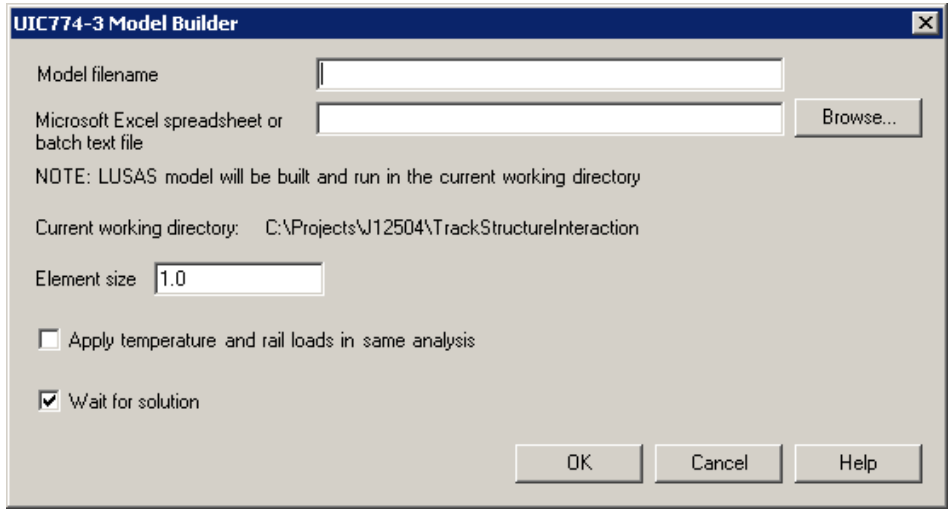


Figure 37: UIC774-3 Model Builder Dialog

- **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 38: Example Batch Text File With Three Bridges To Build

- **Element Size** The element size to use in the Finite Element mesh should be specified in this box. According to the UIC774-3 Code of Practice, the maximum element size that is permitted in an analysis is 2.0m (Clause 1.7.3). The dialog therefore generally allows element sizes of $0 <$ Element Size ≤ 2.0m 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

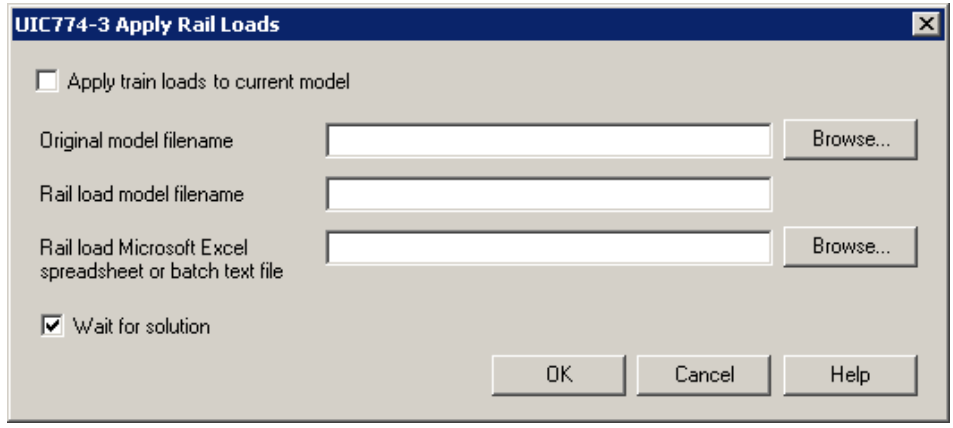


Figure 39: UIC774-3 Apply Rail Loads Dialog

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 40: 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

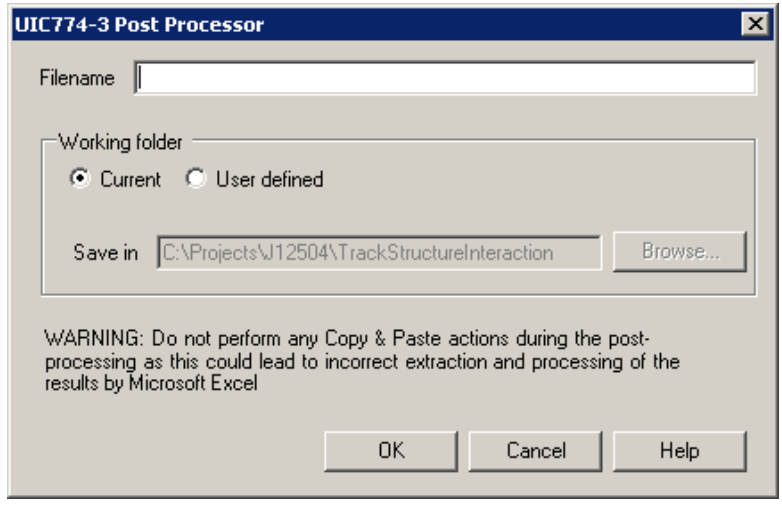


Figure 41: UIC774-3 Post Processor Dialog

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**

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

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

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.

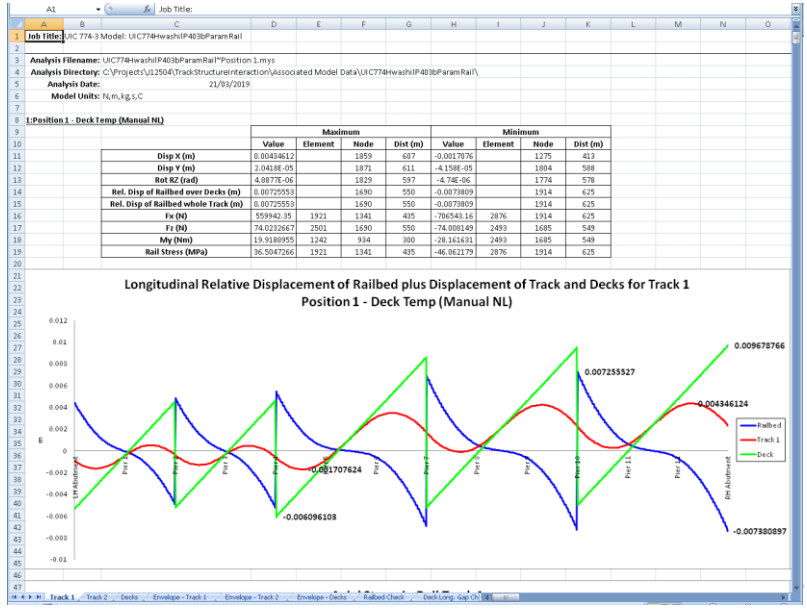
Note. Basic combinations that contain only pure loadcases can be post-processed but basic combinations that contain envelopes or smart combinations cannot be post-processed. Envelopes cannot be post-processed if they contain smart combinations. It should, however, be noted that combinations of nonlinear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

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 42 to Figure 44. 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 45 to Figure 47.

Figure 48 shows a zoomed out version of the worksheet showing the output for multiple results files. In this figure the temperature only and combined results for two results files are illustrated with the analyses incrementing from left to right and for each, the first column of results and graphs are for the temperature only case and the second column are for the combined case for each analysis.

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



Job Title:

Job Title:	UIC 774-3 Model: UIC774HwashIP403bParamRail

Analysis Filename: UIC774HwashIP403bParamRail~Position 1.mys
Analysis Directory: C:\Projects\U12504\TrackStructureInteraction\Associated Model Data\UIC774HwashIP403bParamRail\
Analysis Date: 21/03/2019
Model Units: N,m,kg,s,C

1:Position 1 - Deck Temp (Manual NL)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00434612		1859	687	-0.0017076		1275	413
Disp Y (m)	2.0418E-05		1871	611	-4.158E-05		1804	588
Rot RZ (rad)	4.8877E-06		1829	597	-4.74E-06		1774	578
Rel. Disp of Railbed over Decks (m)	0.00725553		1690	550	-0.0073809		1914	625
Rel. Disp of Railbed whole Track (m)	0.00725553		1690	550	-0.0073809		1914	625
Fx (N)	559942.35	1921	1341	435	-706543.16	2876	1914	625
Fz (N)	74.0232667	2501	1690	550	-74.008149	2493	1685	549
My (Nm)	19.9188955	1242	934	300	-28.161631	2493	1685	549
Rail Stress (MPa)	36.5047266	1921	1341	435	-46.062179	2876	1914	625

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

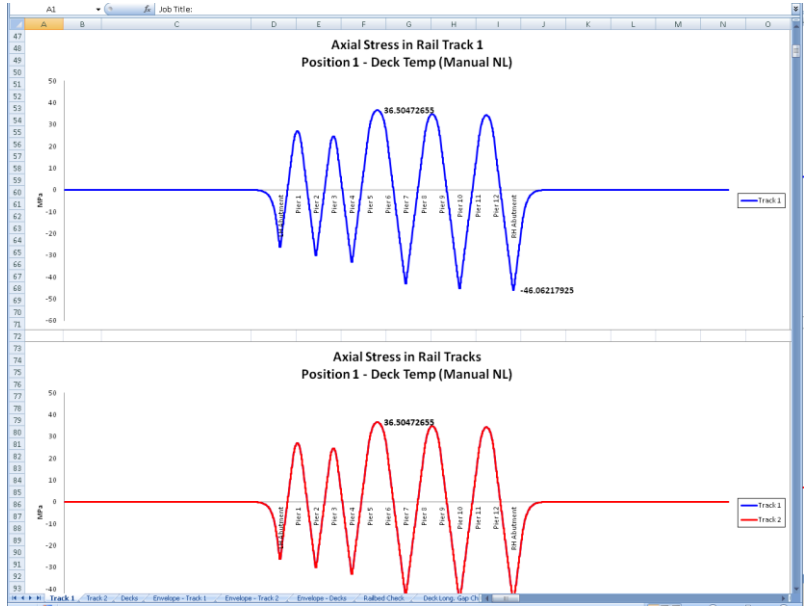
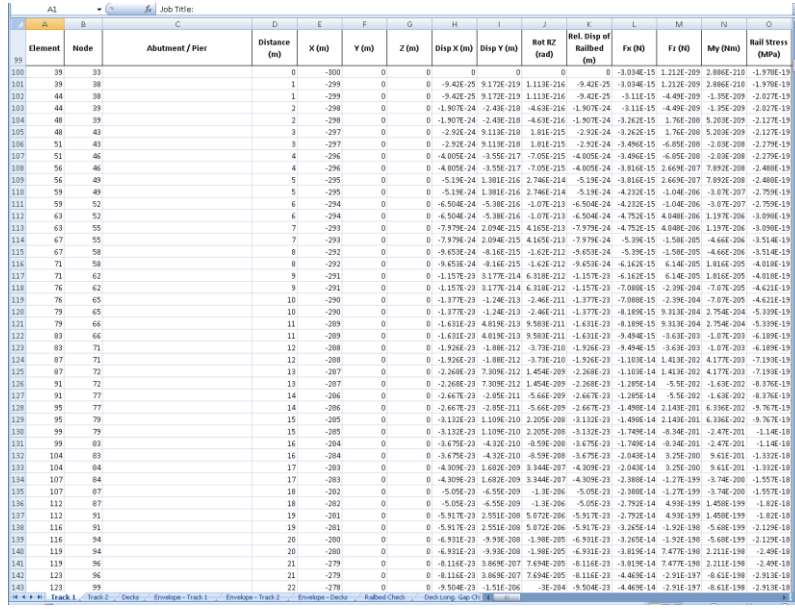
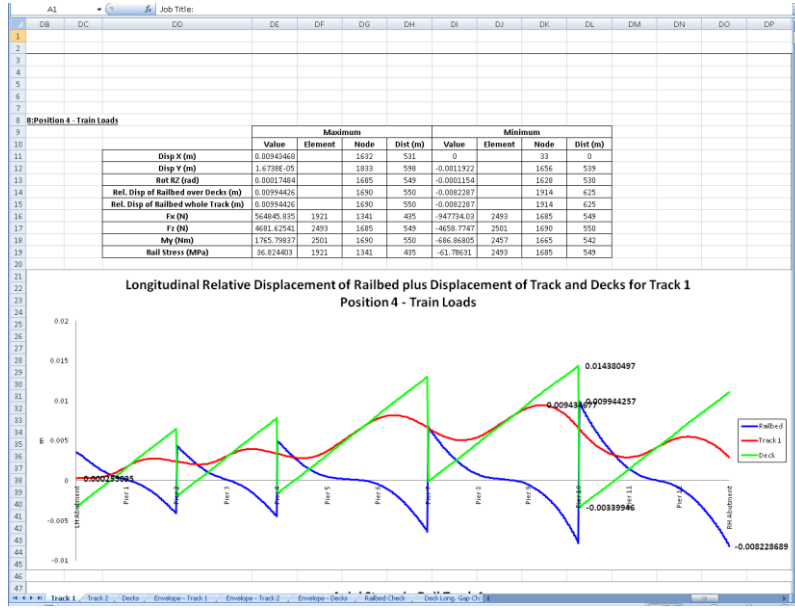


Figure 43: Track Worksheet Rail Stress Graphs for Temperature Only Results of Analysis, Increment 1 (2 of 3)



Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Rel. Disp of Railbed (m)	Fx (N)	Fz (N)	My (Nm)	Rail Stress (MPa)
39	33		0	-300	0	0	0	0	0	0	-3.034E-15	1.212E-209	2.886E-210	-1.978E-19
39	38		1	-299	0	0	-9.42E-25	9.172E-219	1.113E-216	-9.42E-25	-3.034E-15	1.212E-209	2.886E-210	-1.978E-19
44	38		1	-299	0	0	-9.42E-25	9.172E-219	1.113E-216	-9.42E-25	-3.11E-15	-4.49E-209	-1.35E-209	-2.027E-19
44	39		2	-298	0	0	-1.907E-24	-2.43E-218	-4.63E-216	-1.907E-24	-3.11E-15	-4.49E-209	-1.35E-209	-2.027E-19
48	39		2	-298	0	0	-1.907E-24	-2.43E-218	-4.63E-216	-1.907E-24	-3.262E-15	1.76E-208	5.203E-209	-2.127E-19
48	43		3	-297	0	0	-2.92E-24	9.113E-218	1.81E-215	-2.92E-24	-3.262E-15	1.76E-208	5.203E-209	-2.127E-19
51	43		3	-297	0	0	-2.92E-24	9.113E-218	1.81E-215	-2.92E-24	-3.496E-15	-6.85E-208	-2.03E-208	-2.279E-19
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
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
56	49		5	-295	0	0	-5.19E-24	1.381E-216	2.746E-214	-5.19E-24	-3.816E-15	2.669E-207	7.892E-208	-2.480E-19
59	49		5	-295	0	0	-5.19E-24	1.381E-216	2.746E-214	-5.19E-24	-4.232E-15	-1.04E-206	-3.07E-207	-2.759E-19
59	52		6	-294	0	0	-6.504E-24	-5.38E-216	-1.07E-213	-6.504E-24	-4.232E-15	-1.04E-206	-3.07E-207	-2.759E-19
63	52		6	-294	0	0	-6.504E-24	-5.38E-216	-1.07E-213	-6.504E-24	-4.752E-15	4.048E-206	1.197E-206	-3.098E-19
63	55		7	-293	0	0	-7.979E-24	2.094E-215	4.165E-213	-7.979E-24	-4.752E-15	4.048E-206	1.197E-206	-3.098E-19
67	55		7	-293	0	0	-7.979E-24	2.094E-215	4.165E-213	-7.979E-24	-5.39E-15	-1.58E-205	-4.66E-206	-3.514E-19
67	58		8	-292	0	0	-9.653E-24	-8.16E-215	-1.62E-212	-9.653E-24	-5.39E-15	-1.58E-205	-4.66E-206	-3.514E-19
71	58		8	-292	0	0	-9.653E-24	-8.16E-215	-1.62E-212	-9.653E-24	-6.162E-15	6.14E-205	1.816E-205	-4.010E-19
71	62		9	-291	0	0	-1.157E-23	3.177E-214	6.318E-212	-1.157E-23	-6.162E-15	6.14E-205	1.816E-205	-4.010E-19
76	62		9	-291	0	0	-1.157E-23	3.177E-214	6.318E-212	-1.157E-23	-7.088E-15	-2.39E-204	-7.07E-205	-4.621E-19
76	65		10	-290	0	0	-1.377E-23	-1.24E-213	-2.46E-211	-1.377E-23	-7.088E-15	-2.39E-204	-7.07E-205	-4.621E-19
79	65		10	-290	0	0	-1.377E-23	-1.24E-213	-2.46E-211	-1.377E-23	-8.189E-15	9.313E-204	2.754E-204	-5.339E-19
79	66		11	-289	0	0	-1.631E-23	4.819E-213	9.583E-211	-1.631E-23	-8.189E-15	9.313E-204	2.754E-204	-5.339E-19
83	66		11	-289	0	0	-1.631E-23	4.819E-213	9.583E-211	-1.631E-23	-9.494E-15	-3.63E-203	-1.07E-203	-6.189E-19
83	71		12	-288	0	0	-1.926E-23	-1.88E-212	-3.73E-210	-1.926E-23	-9.494E-15	-3.63E-203	-1.07E-203	-6.189E-19
87	71		12	-288	0	0	-1.926E-23	-1.88E-212	-3.73E-210	-1.926E-23	-1.103E-14	1.413E-202	4.177E-203	-7.193E-19
87	72		13	-287	0	0	-2.268E-23	7.309E-212	1.454E-209	-2.268E-23	-1.103E-14	1.413E-202	4.177E-203	-7.193E-19
91	72		13	-287	0	0	-2.268E-23	7.309E-212	1.454E-209	-2.268E-23	-1.285E-14	-5.5E-202	-1.63E-202	-8.376E-19
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
95	77		14	-286	0	0	-2.667E-23	-2.85E-211	-5.66E-209	-2.667E-23	-1.498E-14	2.143E-201	6.336E-202	-9.767E-19
95	79		15	-285	0	0	-3.132E-23	1.109E-210	2.205E-208	-3.132E-23	-1.498E-14	2.143E-201	6.336E-202	-9.767E-19
99	79		15	-285	0	0	-3.132E-23	1.109E-210	2.205E-208	-3.132E-23	-1.749E-14	-8.34E-201	-2.47E-201	-1.14E-18
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
104	83		16	-284	0	0	-3.675E-23	-4.32E-210	-8.59E-208	-3.675E-23	-2.043E-14	3.25E-200	9.61E-201	-1.332E-18
104	84		17	-283	0	0	-4.309E-23	1.682E-209	3.344E-207	-4.309E-23	-2.043E-14	3.25E-200	9.61E-201	-1.332E-18
107	84		17	-283	0	0	-4.309E-23	1.682E-209	3.344E-207	-4.309E-23	-2.388E-14	-1.27E-199	-3.74E-200	-1.557E-18
107	87		18	-282	0	0	-5.05E-23	-6.55E-209	-1.3E-206	-5.05E-23	-2.388E-14	-1.27E-199	-3.74E-200	-1.557E-18
112	87		18	-282	0	0	-5.05E-23	-6.55E-209	-1.3E-206	-5.05E-23	-2.792E-14	4.93E-199	1.458E-199	-1.82E-18
112	91		19	-281	0	0	-5.917E-23	2.551E-208	5.072E-206	-5.917E-23	-2.792E-14	4.93E-199	1.458E-199	-1.82E-18
116	91		19	-281	0	0	-5.917E-23	2.551E-208	5.072E-206	-5.917E-23	-3.265E-14	-1.92E-198	-5.68E-199	-2.129E-18
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
119	94		20	-280	0	0	-6.931E-23	-9.93E-208	-1.98E-205	-6.931E-23	-3.819E-14	7.477E-198	2.211E-198	-2.49E-18
119	96		21	-279	0	0	-8.116E-23	3.869E-207	7.694E-205	-8.116E-23	-3.819E-14	7.477E-198	2.211E-198	-2.49E-18
123	96		21	-279	0	0	-8.116E-23	3.869E-207	7.694E-205	-8.116E-23	-4.469E-14	-2.91E-197	-8.61E-198	-2.913E-18
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 44: Track Worksheet Tabulated Output for Temperature Only Results of Analysis, Increment 1 (3 of 3)



8:Position 4 - Train Loads

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00943469		1632	531	0		33	0
Disp Y (m)	1.6738E-05		1833	598	-0.0011922		1656	539
Rot RZ (rad)	0.00017484		1685	549	-0.0001154		1628	530
Rel. Disp of Railbed over Decks (m)	0.00994426		1690	550	-0.0082287		1914	625
Rel. Disp of Railbed whole Track (m)	0.00994426		1690	550	-0.0082287		1914	625
Fx (N)	564845.835	1921	1341	435	-947734.03	2493	1685	549
Fz (N)	4681.62541	2493	1685	549	-4658.7747	2501	1690	550
My (Nm)	1765.79837	2501	1690	550	-686.86805	2457	1665	542
Rail Stress (MPa)	36.824403	1921	1341	435	-61.78631	2493	1685	549

Figure 45: Track Worksheet Summary and Railbed Graph for Temperature and Trainset Results of Analysis, Increment 2 (1 of 3)

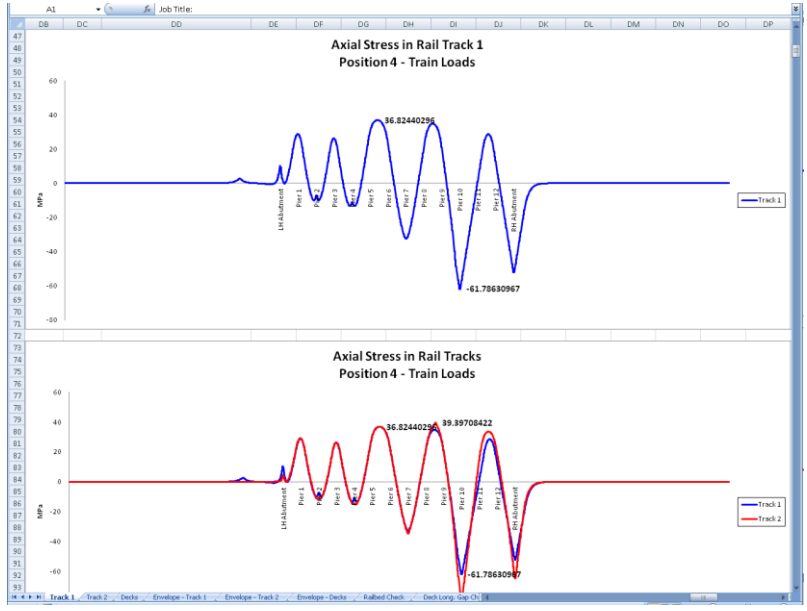
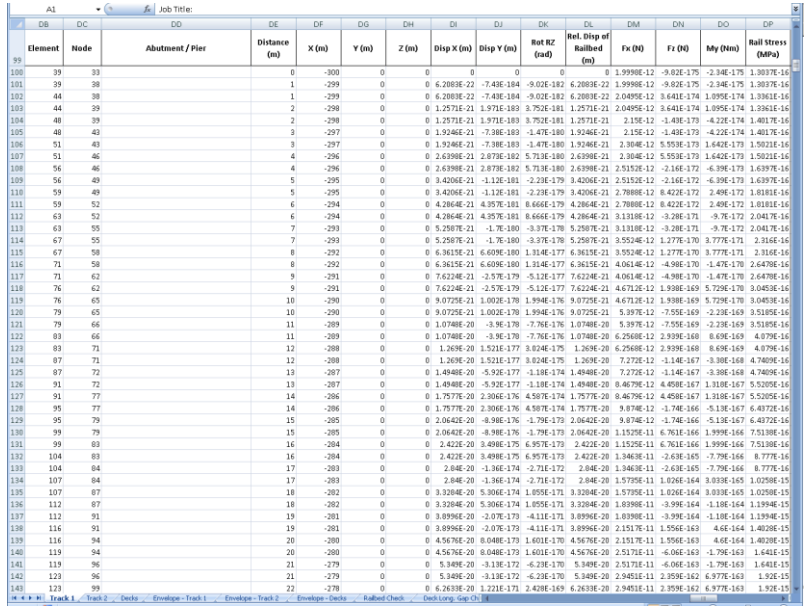


Figure 46: Track Worksheet Rail Stress Graphs for Temperature and Trainset Results of Analysis, Increment 2 (2 of 3)



Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Rel. Disp of Railbed (m)	Fx (N)	Fz (N)	My (Nm)	Rail Stress (MPa)
39	33		0	-300	0	0	0	0	0	8	1.9990E-12	-9.02E-175	-2.34E-175	1.3037E-16
39	38		1	-299	0	0	6.2083E-22	-7.43E-184	-9.02E-182	6.2083E-22	1.9990E-12	-9.02E-175	-2.34E-175	1.3037E-16
44	38		1	-299	0	0	6.2083E-22	-7.43E-184	-9.02E-182	6.2083E-22	2.0495E-12	3.641E-174	1.095E-174	1.3361E-16
44	39		2	-298	0	0	1.2571E-21	1.971E-183	3.752E-181	1.2571E-21	2.0495E-12	3.641E-174	1.095E-174	1.3361E-16
48	39		2	-298	0	0	1.2571E-21	1.971E-183	3.752E-181	1.2571E-21	2.15E-12	-1.43E-173	-4.22E-174	1.4017E-16
48	43		3	-297	0	0	1.9246E-21	-7.38E-183	-1.47E-180	1.9246E-21	2.15E-12	-1.43E-173	-4.22E-174	1.4017E-16
51	43		3	-297	0	0	1.9246E-21	-7.38E-183	-1.47E-180	1.9246E-21	2.304E-12	5.553E-173	1.642E-173	1.5021E-16
51	46		4	-296	0	0	2.6398E-21	2.073E-182	5.713E-180	2.6398E-21	2.304E-12	5.553E-173	1.642E-173	1.5021E-16
56	46		4	-296	0	0	2.6398E-21	2.073E-182	5.713E-180	2.6398E-21	2.5152E-12	-2.16E-172	-6.39E-173	1.6397E-16
56	49		5	-295	0	0	3.4206E-21	-1.12E-181	-2.23E-179	3.4206E-21	2.5152E-12	-2.16E-172	-6.39E-173	1.6397E-16
59	49		5	-295	0	0	3.4206E-21	-1.12E-181	-2.23E-179	3.4206E-21	2.7888E-12	8.422E-172	2.49E-172	1.8181E-16
59	52		6	-294	0	0	4.2864E-21	4.357E-181	8.666E-179	4.2864E-21	2.7888E-12	8.422E-172	2.49E-172	1.8181E-16
63	52		6	-294	0	0	4.2864E-21	4.357E-181	8.666E-179	4.2864E-21	3.1318E-12	-3.28E-171	-9.7E-172	2.0417E-16
63	55		7	-293	0	0	5.2587E-21	-1.7E-180	-3.37E-178	5.2587E-21	3.1318E-12	-3.28E-171	-9.7E-172	2.0417E-16
67	55		7	-293	0	0	5.2587E-21	-1.7E-180	-3.37E-178	5.2587E-21	3.5524E-12	1.277E-170	3.777E-171	2.316E-16
67	58		8	-292	0	0	6.3615E-21	6.609E-180	1.314E-177	6.3615E-21	3.5524E-12	1.277E-170	3.777E-171	2.316E-16
71	58		8	-292	0	0	6.3615E-21	6.609E-180	1.314E-177	6.3615E-21	4.0614E-12	-4.98E-170	-1.47E-170	2.6478E-16
71	62		9	-291	0	0	7.6224E-21	-2.57E-179	-5.12E-177	7.6224E-21	4.0614E-12	-4.98E-170	-1.47E-170	2.6478E-16
76	62		9	-291	0	0	7.6224E-21	-2.57E-179	-5.12E-177	7.6224E-21	4.6712E-12	1.938E-169	5.729E-170	3.0453E-16
76	65		10	-290	0	0	9.0725E-21	1.002E-178	1.994E-176	9.0725E-21	4.6712E-12	1.938E-169	5.729E-170	3.0453E-16
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
79	66		11	-289	0	0	1.0748E-20	-3.9E-178	-7.76E-176	1.0748E-20	5.397E-12	-7.55E-169	-2.23E-169	3.5185E-16
83	66		11	-289	0	0	1.0748E-20	-3.9E-178	-7.76E-176	1.0748E-20	6.2568E-12	2.939E-168	8.69E-169	4.079E-16
83	71		12	-288	0	0	1.269E-20	1.521E-177	3.024E-175	1.269E-20	6.2568E-12	2.939E-168	8.69E-169	4.079E-16
87	71		12	-288	0	0	1.269E-20	1.521E-177	3.024E-175	1.269E-20	7.272E-12	-1.14E-167	-3.38E-168	4.7409E-16
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
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
91	77		14	-286	0	0	1.7577E-20	2.306E-176	4.587E-174	1.7577E-20	8.4679E-12	4.458E-167	1.318E-167	5.5205E-16
95	77		14	-286	0	0	1.7577E-20	2.306E-176	4.587E-174	1.7577E-20	9.874E-12	-1.74E-166	-5.13E-167	6.4372E-16
95	79		15	-285	0	0	2.0642E-20	-8.98E-176	-1.79E-173	2.0642E-20	9.874E-12	-1.74E-166	-5.13E-167	6.4372E-16
99	79		15	-285	0	0	2.0642E-20	-8.98E-176	-1.79E-173	2.0642E-20	1.1525E-11	6.761E-166	1.999E-166	7.5138E-16
99	83		16	-284	0	0	2.422E-20	3.498E-175	6.957E-173	2.422E-20	1.1525E-11	6.761E-166	1.999E-166	7.5138E-16
104	83		16	-284	0	0	2.422E-20	3.498E-175	6.957E-173	2.422E-20	1.3463E-11	-2.63E-165	-7.79E-166	8.777E-16
104	84		17	-283	0	0	2.84E-20	-1.36E-174	-2.71E-172	2.84E-20	1.3463E-11	-2.63E-165	-7.79E-166	8.777E-16
107	84		17	-283	0	0	2.84E-20	-1.36E-174	-2.71E-172	2.84E-20	1.5735E-11	1.026E-164	3.033E-165	1.0258E-15
107	87		18	-282	0	0	3.3284E-20	5.306E-174	1.055E-171	3.3284E-20	1.5735E-11	1.026E-164	3.033E-165	1.0258E-15
112	87		18	-282	0	0	3.3284E-20	5.306E-174	1.055E-171	3.3284E-20	1.8398E-11	-3.99E-164	-1.18E-164	1.1994E-15
112	91		19	-281	0	0	3.8996E-20	-2.07E-173	-4.11E-171	3.8996E-20	1.8398E-11	-3.99E-164	-1.18E-164	1.1994E-15
116	91		19	-281	0	0	3.8996E-20	-2.07E-173	-4.11E-171	3.8996E-20	2.1517E-11	1.556E-163	4.6E-164	1.4028E-15
116	94		20	-280	0	0	4.5676E-20	8.048E-173	1.601E-170	4.5676E-20	2.1517E-11	1.556E-163	4.6E-164	1.4028E-15
119	94		20	-280	0	0	4.5676E-20	8.048E-173	1.601E-170	4.5676E-20	2.5171E-11	-6.06E-163	-1.79E-163	1.641E-15
119	96		21	-279	0	0	5.349E-20	-3.13E-172	-6.23E-170	5.349E-20	2.5171E-11	-6.06E-163	-1.79E-163	1.641E-15
123	96		21	-279	0	0	5.349E-20	-3.13E-172	-6.23E-170	5.349E-20	2.9451E-11	2.359E-162	6.977E-163	1.92E-15
123	99		22	-278	0	0	6.2633E-20	1.221E-171	2.429E-169	6.2633E-20	2.9451E-11	2.359E-162	6.977E-163	1.92E-15

Figure 47: Track Worksheet Tabulated Output for Temperature and Trainset Results of Analysis, Increment 2 (3 of 3)

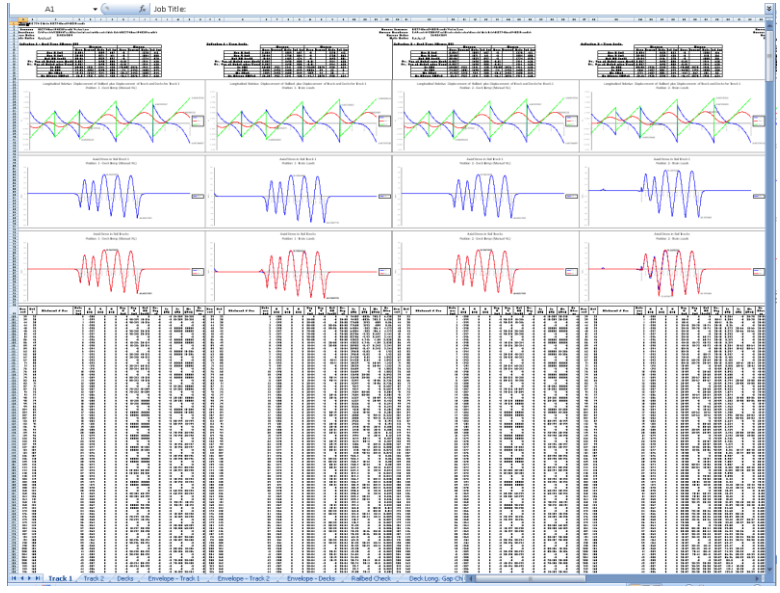


Figure 48: Track Worksheet for Multiple Results Files

If valid basic combinations or envelopes that match the criteria described in Post-processing of automatically defined groups (page 40) 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 49 to Figure 52 show the tabulated and graph output generated for the deck for all of the loading conditions included in the analyses. Figure 53 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.

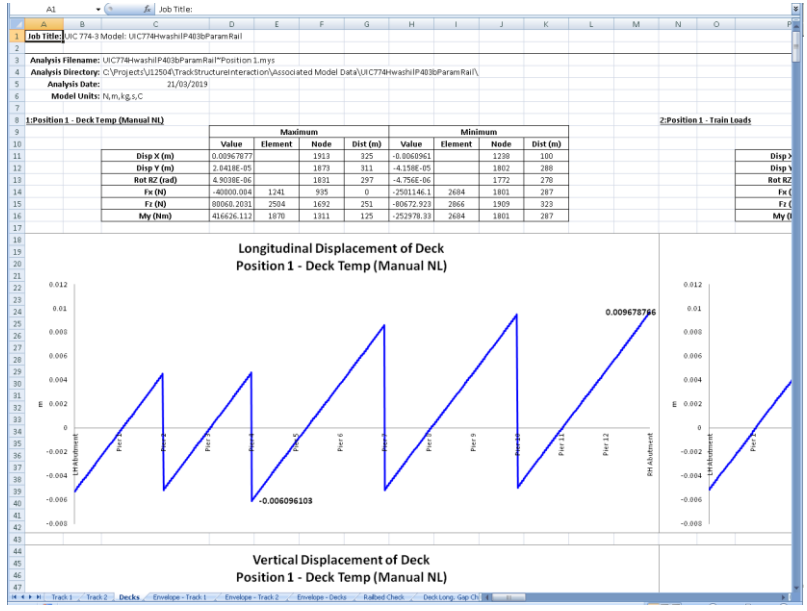


Figure 49: Deck Worksheet Summary and Longitudinal Displacement Graph for Results of Analysis (1 of 4)

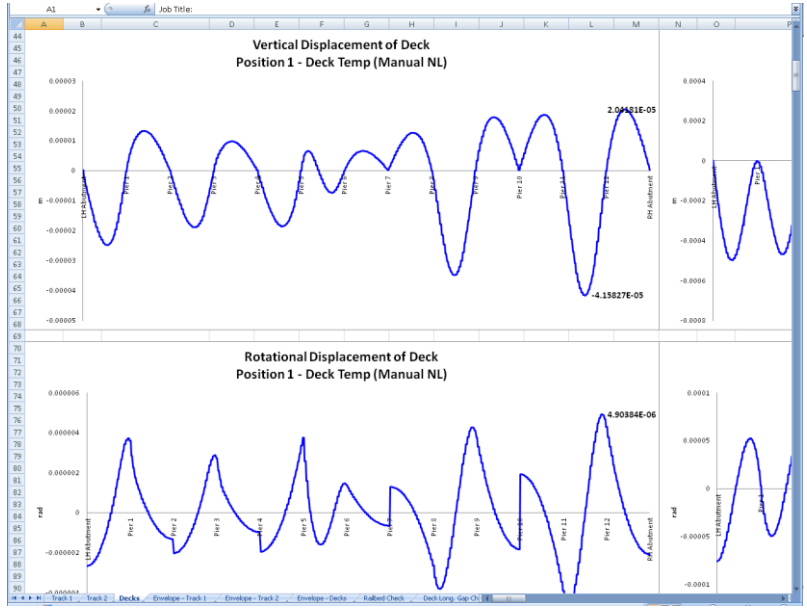


Figure 50: Deck Worksheet Vertical and Rotational Displacement Graphs for Results of Analysis (2 of 4)

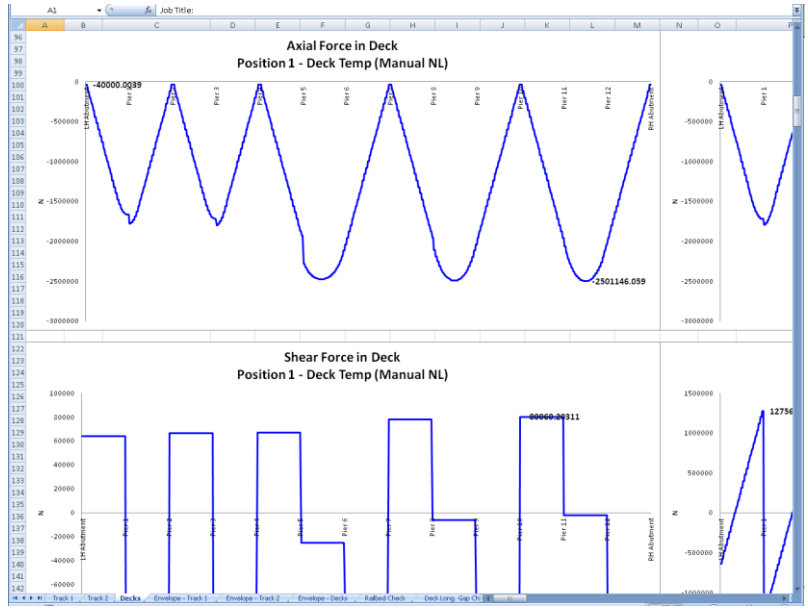
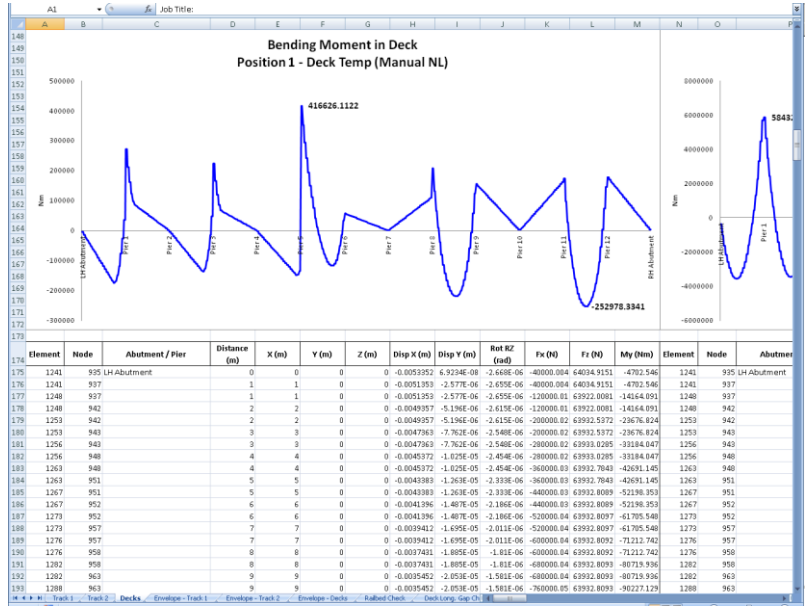


Figure 51: Deck Worksheet Axial and Shear Force Graphs for Results of Analysis (3 of 4)



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

Figure 52: Deck Worksheet Bending Moment Graph and Tabulated Output for Results of Analysis (4 of 4)

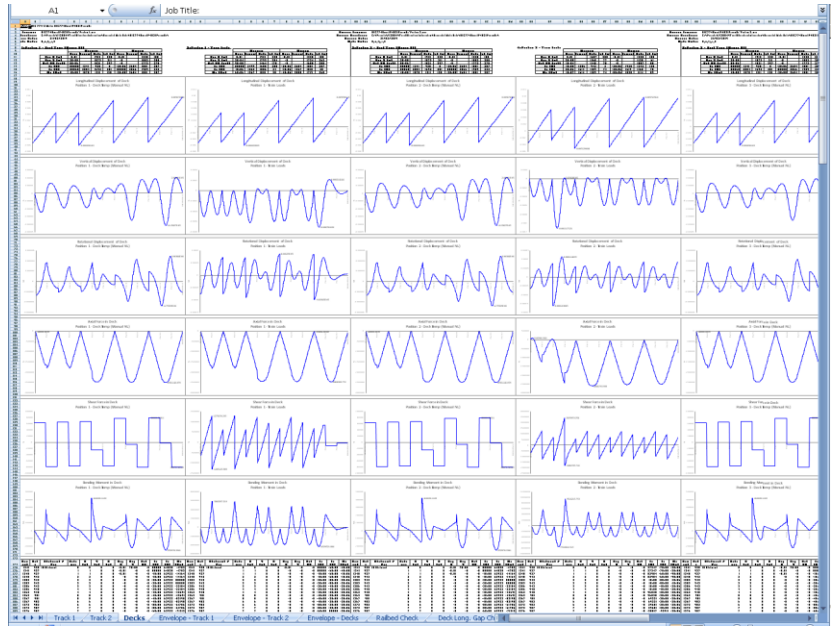


Figure 53: Deck Worksheet for Multiple Results Files

If valid basic combinations or envelopes that match the criteria described in **Post-processing of automatically defined groups** (page 40) 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 40) 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**

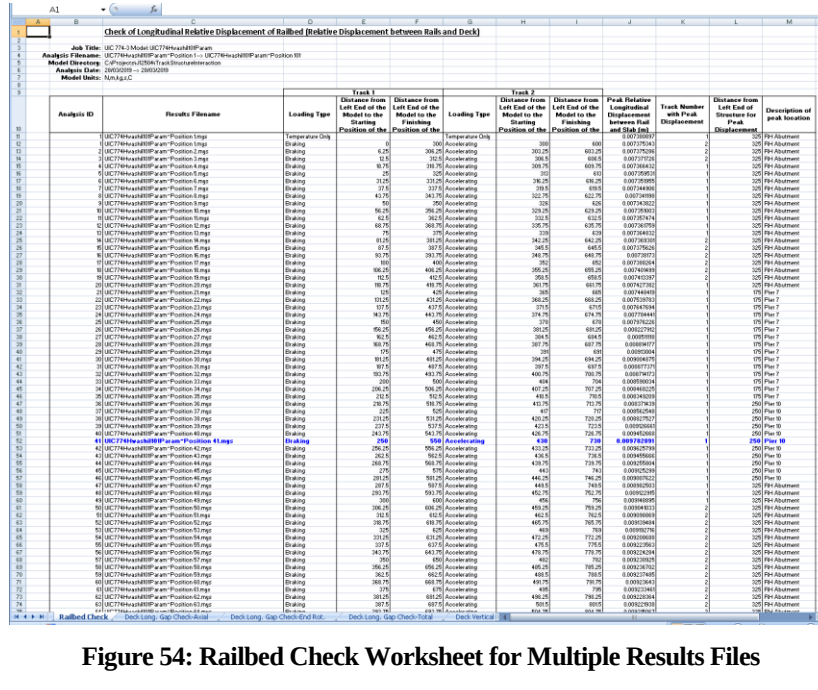
- **Maximum and minimum envelopes for all of the basic combinations defined in the model (if valid basic combinations are present)**
- **Maximum and minimum envelopes for all configurations (an envelope of all of the above results)**

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.



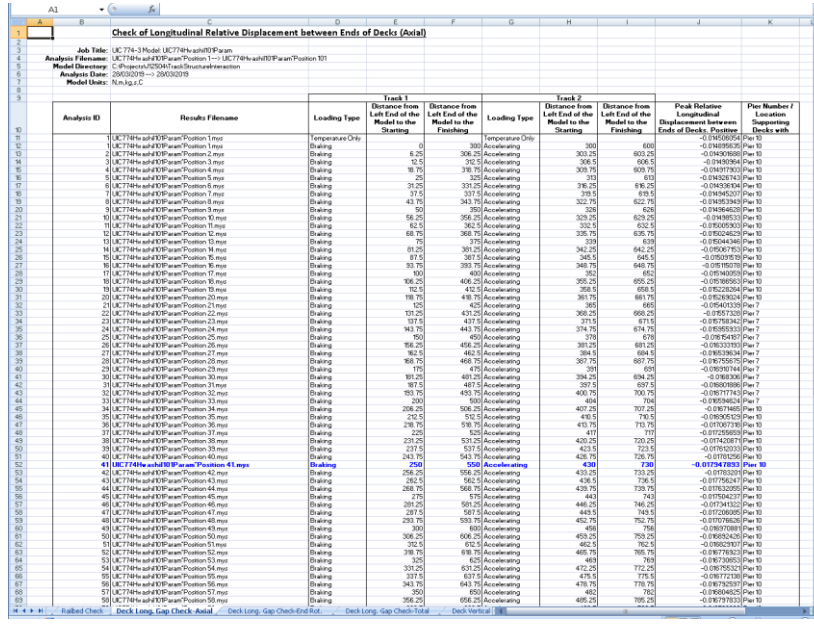
Check of Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)

Job Title: UC774-3 Model: UC774HrushiN01Param
Analysis Filename: UC774HrushiN01Param "Position 1 --> UC774HrushiN01Param "Position 101
Model Directory: C:\Projects\J250N\Track\StructureInteraction
Analysis Date: 29/03/2019 --> 29/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting Position of the	Track 1 Distance from Left End of the Model to the Finishing Position of the	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting Position of the	Track 2 Distance from Left End of the Model to the Finishing Position of the	Peak Relative Longitudinal Displacement between Rail and Slab (m)	Track Number with Peak Displacement	Distance from Left End of Structure for Peak Displacement	Description of peak location
1	UC774HrushiN01Param "Position 1.mys	Temperature Only			Temperature Only			0.007389897	1	325	RH Abutment
1	UC774HrushiN01Param "Position 1.mys	Braking	0	300	Accelerating	300	600	0.007375143	2	325	RH Abutment
2	UC774HrushiN01Param "Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	0.007375286	2	325	RH Abutment
3	UC774HrushiN01Param "Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	0.007375724	2	325	RH Abutment
4	UC774HrushiN01Param "Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	0.007366432	1	325	RH Abutment
5	UC774HrushiN01Param "Position 5.mys	Braking	25	325	Accelerating	310	610	0.007358510	1	325	RH Abutment
6	UC774HrushiN01Param "Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	0.007359585	1	325	RH Abutment
7	UC774HrushiN01Param "Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	0.007344999	1	325	RH Abutment
8	UC774HrushiN01Param "Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	0.007341999	1	325	RH Abutment
9	UC774HrushiN01Param "Position 9.mys	Braking	50	350	Accelerating	326	626	0.007343822	1	325	RH Abutment
10	UC774HrushiN01Param "Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	0.007359301	1	325	RH Abutment
11	UC774HrushiN01Param "Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	0.007357474	1	325	RH Abutment
12	UC774HrushiN01Param "Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	0.007360759	1	325	RH Abutment
13	UC774HrushiN01Param "Position 13.mys	Braking	75	375	Accelerating	339	639	0.007344532	1	325	RH Abutment
14	UC774HrushiN01Param "Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	0.007369301	2	325	RH Abutment
15	UC774HrushiN01Param "Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	0.007379525	2	325	RH Abutment
16	UC774HrushiN01Param "Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	0.007373973	2	325	RH Abutment
17	UC774HrushiN01Param "Position 17.mys	Braking	100	400	Accelerating	352	652	0.007359264	2	325	RH Abutment
18	UC774HrushiN01Param "Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	0.007409493	2	325	RH Abutment
19	UC774HrushiN01Param "Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	0.007403297	2	325	RH Abutment
20	UC774HrushiN01Param "Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	0.007427382	1	325	RH Abutment
21	UC774HrushiN01Param "Position 21.mys	Braking	125	425	Accelerating	365	665	0.007440469	1	175	Pier 7
22	UC774HrushiN01Param "Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	0.007529763	1	175	Pier 7
23	UC774HrushiN01Param "Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	0.007447694	1	175	Pier 7
24	UC774HrushiN01Param "Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	0.007518444	1	175	Pier 7
25	UC774HrushiN01Param "Position 25.mys	Braking	150	450	Accelerating	378	678	0.007576226	1	175	Pier 7
26	UC774HrushiN01Param "Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	0.008227963	1	175	Pier 7
27	UC774HrushiN01Param "Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	0.00851999	1	175	Pier 7
28	UC774HrushiN01Param "Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	0.008819417	1	175	Pier 7
29	UC774HrushiN01Param "Position 29.mys	Braking	175	475	Accelerating	391	691	0.00892984	1	175	Pier 7
30	UC774HrushiN01Param "Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	0.009084675	1	175	Pier 7
31	UC774HrushiN01Param "Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	0.009187371	1	175	Pier 7
32	UC774HrushiN01Param "Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	0.009179071	1	175	Pier 7
33	UC774HrushiN01Param "Position 33.mys	Braking	200	500	Accelerating	404	704	0.009159034	1	175	Pier 7
34	UC774HrushiN01Param "Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	0.009146225	1	175	Pier 7
35	UC774HrushiN01Param "Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	0.009134309	1	175	Pier 7
36	UC774HrushiN01Param "Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	0.009137435	1	250	Pier 10
37	UC774HrushiN01Param "Position 37.mys	Braking	225	525	Accelerating	417	717	0.009162540	1	250	Pier 10
38	UC774HrushiN01Param "Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	0.009127527	1	250	Pier 10
39	UC774HrushiN01Param "Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	0.009092649	1	250	Pier 10
40	UC774HrushiN01Param "Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	0.009152668	1	250	Pier 10
41	**UC774HrushiN01Param "Position 41.mys**	**Braking**	**250**	**550**	**Accelerating**	**430**	**730**	**0.009783893**	**1**	**250**	**Pier 10**
42	UC774HrushiN01Param "Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	0.009625799	1	250	Pier 10
43	UC774HrushiN01Param "Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	0.009495669	1	250	Pier 10
44	UC774HrushiN01Param "Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	0.009255804	1	250	Pier 10
45	UC774HrushiN01Param "Position 45.mys	Braking	275	575	Accelerating	443	743	0.009052929	1	250	Pier 10
46	UC774HrushiN01Param "Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	0.009007622	1	250	Pier 10
47	UC774HrushiN01Param "Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	0.009082583	1	325	RH Abutment
48	UC774HrushiN01Param "Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	0.009022395	1	325	RH Abutment
49	UC774HrushiN01Param "Position 49.mys	Braking	300	600	Accelerating	456	756	0.009148095	1	325	RH Abutment
50	UC774HrushiN01Param "Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	0.009349121	2	325	RH Abutment
51	UC774HrushiN01Param "Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	0.009386869	2	325	RH Abutment
52	UC774HrushiN01Param "Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	0.009139484	2	325	RH Abutment
53	UC774HrushiN01Param "Position 53.mys	Braking	325	625	Accelerating	469	769	0.009092776	2	325	RH Abutment
54	UC774HrushiN01Param "Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	0.009336868	2	325	RH Abutment
55	UC774HrushiN01Param "Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	0.009221563	2	325	RH Abutment
56	UC774HrushiN01Param "Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	0.009224284	2	325	RH Abutment
57	UC774HrushiN01Param "Position 57.mys	Braking	350	650	Accelerating	482	782	0.009230925	2	325	RH Abutment
58	UC774HrushiN01Param "Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	0.009236762	2	325	RH Abutment
59	UC774HrushiN01Param "Position 59.mys	Braking	362.5	662.5	Accelerating	488.5	788.5	0.009237495	2	325	RH Abutment
60	UC774HrushiN01Param "Position 60.mys	Braking	368.75	668.75	Accelerating	491.75	791.75	0.00923643	2	325	RH Abutment
61	UC774HrushiN01Param "Position 61.mys	Braking	375	675	Accelerating	495	795	0.009233461	2	325	RH Abutment
62	UC774HrushiN01Param "Position 62.mys	Braking	381.25	681.25	Accelerating	498.25	798.25	0.009228344	2	325	RH Abutment
63	UC774HrushiN01Param "Position 63.mys	Braking	387.5	687.5	Accelerating	501.5	801.5	0.009227838	2	325	RH Abutment

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

Figure 54: Railbed Check Worksheet for Multiple Results Files



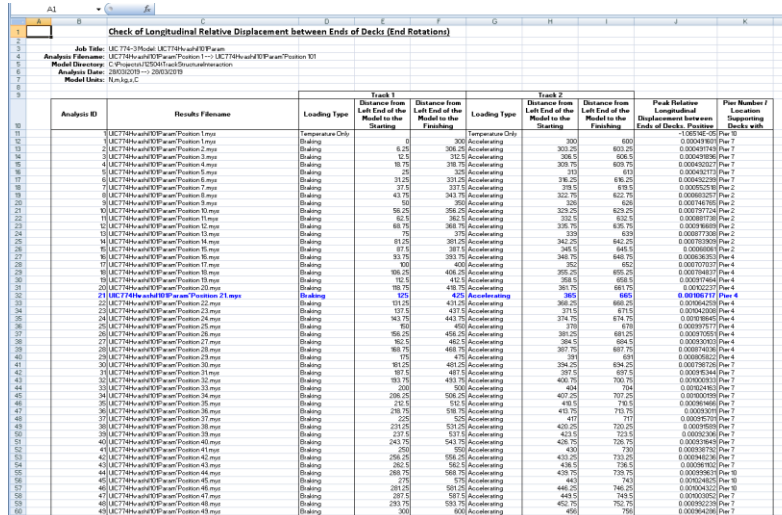
Check of Longitudinal Relative Displacement between Ends of Decks (Axial)

Job Title: UC774-3 Model: UC774HrushiN01Param
Analysis Filename: UC774HrushiN01Param "Position 1 --> UC774HrushiN01Param "Position 101
Model Directory: C:\Projects\J250N\Track\StructureInteraction
Analysis Date: 29/03/2019 --> 29/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting	Track 2 Distance from Left End of the Model to the Finishing	Peak Relative Longitudinal Displacement between Ends of Decks, Positive	Pier Number / Location Supporting Decks with
1	UC774HrushiN01Param "Position 1.mys	Temperature Only			Temperature Only			-0.014506754	Pier 10
1	UC774HrushiN01Param "Position 1.mys	Braking	0	300	Accelerating	300	600	-0.014855635	Pier 10
2	UC774HrushiN01Param "Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	-0.014901688	Pier 10
3	UC774HrushiN01Param "Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	-0.014919764	Pier 10
4	UC774HrushiN01Param "Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-0.014917803	Pier 10
5	UC774HrushiN01Param "Position 5.mys	Braking	25	325	Accelerating	310	610	-0.014928743	Pier 10
6	UC774HrushiN01Param "Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-0.014936104	Pier 10
7	UC774HrushiN01Param "Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-0.014945207	Pier 10
8	UC774HrushiN01Param "Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-0.014953949	Pier 10
9	UC774HrushiN01Param "Position 9.mys	Braking	50	350	Accelerating	326	626	-0.014964628	Pier 10
10	UC774HrushiN01Param "Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	-0.014985533	Pier 10
11	UC774HrushiN01Param "Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	-0.015005903	Pier 10
12	UC774HrushiN01Param "Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	-0.015024629	Pier 10
13	UC774HrushiN01Param "Position 13.mys	Braking	75	375	Accelerating	339	639	-0.015044346	Pier 10
14	UC774HrushiN01Param "Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	-0.01506753	Pier 10
15	UC774HrushiN01Param "Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	-0.015093519	Pier 10
16	UC774HrushiN01Param "Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	-0.015115078	Pier 10
17	UC774HrushiN01Param "Position 17.mys	Braking	100	400	Accelerating	352	652	-0.015140059	Pier 10
18	UC774HrushiN01Param "Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	-0.015186563	Pier 10
19	UC774HrushiN01Param "Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	-0.015228394	Pier 10
20	UC774HrushiN01Param "Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	-0.015269024	Pier 10
21	UC774HrushiN01Param "Position 21.mys	Braking	125	425	Accelerating	365	665	-0.015401335	Pier 7
22	UC774HrushiN01Param "Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	-0.01557328	Pier 7
23	UC774HrushiN01Param "Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	-0.015758342	Pier 7
24	UC774HrushiN01Param "Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	-0.015955333	Pier 7
25	UC774HrushiN01Param "Position 25.mys	Braking	150	450	Accelerating	378	678	-0.01614487	Pier 7
26	UC774HrushiN01Param "Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	-0.016331393	Pier 7
27	UC774HrushiN01Param "Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	-0.016539634	Pier 7
28	UC774HrushiN01Param "Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	-0.016755675	Pier 7
29	UC774HrushiN01Param "Position 29.mys	Braking	175	475	Accelerating	391	691	-0.016981744	Pier 7
30	UC774HrushiN01Param "Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	-0.0168306	Pier 7
31	UC774HrushiN01Param "Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	-0.016808986	Pier 7
32	UC774HrushiN01Param "Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	-0.016717743	Pier 7
33	UC774HrushiN01Param "Position 33.mys	Braking	200	500	Accelerating	404	704	-0.016594624	Pier 7
34	UC774HrushiN01Param "Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	-0.01671465	Pier 10
35	UC774HrushiN01Param "Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	-0.016905125	Pier 10
36	UC774HrushiN01Param "Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	-0.017007716	Pier 10
37	UC774HrushiN01Param "Position 37.mys	Braking	225	525	Accelerating	417	717	-0.017255659	Pier 10
38	UC774HrushiN01Param "Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	-0.017428877	Pier 10
39	UC774HrushiN01Param "Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	-0.017612033	Pier 10
40	UC774HrushiN01Param "Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	-0.01701256	Pier 10
41	**UC774HrushiN01Param "Position 41.mys**	**Braking**	**250**	**550**	**Accelerating**	**430**	**730**	**-0.017347893**	**Pier 10**
42	UC774HrushiN01Param "Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	-0.01783201	Pier 10
43	UC774HrushiN01Param "Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	-0.017758247	Pier 10
44	UC774HrushiN01Param "Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	-0.017632095	Pier 10
45	UC774HrushiN01Param "Position 45.mys	Braking	275	575	Accelerating	443	743	-0.017504237	Pier 10
46	UC774HrushiN01Param "Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	-0.017341322	Pier 10
47	UC774HrushiN01Param "Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-0.017289095	Pier 10
48	UC774HrushiN01Param "Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-0.017076626	Pier 10
49	UC774HrushiN01Param "Position 49.mys	Braking	300	600	Accelerating	456	756	-0.016970889	Pier 10
50	UC774HrushiN01Param "Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	-0.016834426	Pier 10
51	UC774HrushiN01Param "Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	-0.016623107	Pier 10
52	UC774HrushiN01Param "Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	-0.016778763	Pier 10
53	UC774HrushiN01Param "Position 53.mys	Braking	325	625	Accelerating	469	769	-0.016730853	Pier 10
54	UC774HrushiN01Param "Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	-0.016755312	Pier 10
55	UC774HrushiN01Param "Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	-0.016772138	Pier 10
56	UC774HrushiN01Param "Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	-0.016792597	Pier 10
57	UC774HrushiN01Param "Position 57.mys	Braking	350	650	Accelerating	482	782	-0.016804625	Pier 10
58	UC774HrushiN01Param "Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	-0.016797633	Pier 10

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

Figure 55: Longitudinal Deck End Displacement due to Axial Effects Check Worksheet for Multiple Results Files

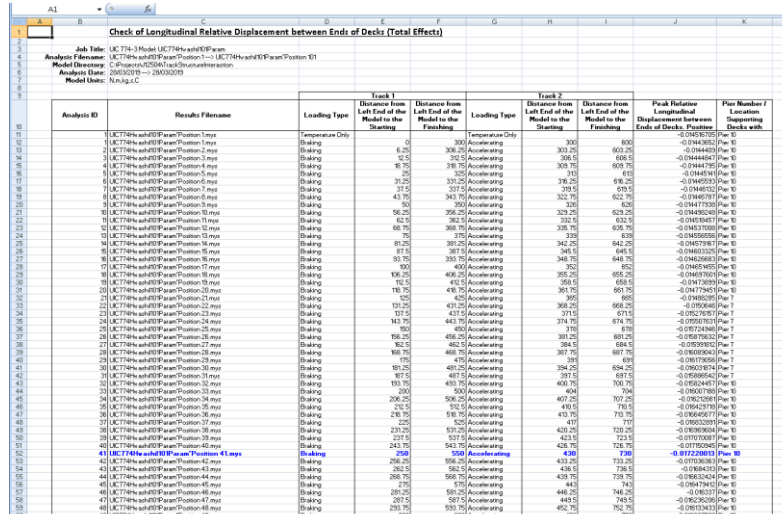


Check of Longitudinal Relative Displacement between Ends of Decks (End Rotations)

Job Title: UC774-3 Model: UC774Hrashid10\Param
Analysis Filename: UC774Hrashid10\Param\Position 1 --> UC774Hrashid10\Param\Position 101
Model Directory: C:\Projects\1250\4Track3\structure\Interaction
Analysis Date: 28/03/2019 --> 29/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting	Track 2 Distance from Left End of the Model to the Finishing	Peak Relative Longitudinal Displacement between Ends of Decks, Positive	Pier Number / Location Supporting Decks with
1	UC774Hrashid10\Param\Position 1.mys	Temperature Only			Temperature Only			-1.0E54E-05	Pier 9
1	UC774Hrashid10\Param\Position 1.mys	Braking	0	300	Accelerating	300	600	0.000491801	Pier 7
2	UC774Hrashid10\Param\Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	0.000497143	Pier 7
3	UC774Hrashid10\Param\Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	0.000491896	Pier 7
4	UC774Hrashid10\Param\Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	0.000492027	Pier 7
5	UC774Hrashid10\Param\Position 5.mys	Braking	25	325	Accelerating	313	613	0.000492171	Pier 7
6	UC774Hrashid10\Param\Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	0.000492299	Pier 7
7	UC774Hrashid10\Param\Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	0.000552516	Pier 2
8	UC774Hrashid10\Param\Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	0.000693257	Pier 2
9	UC774Hrashid10\Param\Position 9.mys	Braking	50	350	Accelerating	326	626	0.000746765	Pier 2
10	UC774Hrashid10\Param\Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	0.000797724	Pier 2
11	UC774Hrashid10\Param\Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	0.000897736	Pier 2
12	UC774Hrashid10\Param\Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	0.000916689	Pier 2
13	UC774Hrashid10\Param\Position 13.mys	Braking	75	375	Accelerating	339	639	0.000977306	Pier 2
14	UC774Hrashid10\Param\Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	0.000763909	Pier 2
15	UC774Hrashid10\Param\Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	0.0006808	Pier 2
16	UC774Hrashid10\Param\Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	0.000636353	Pier 4
17	UC774Hrashid10\Param\Position 17.mys	Braking	100	400	Accelerating	352	652	0.000707037	Pier 4
18	UC774Hrashid10\Param\Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	0.000794837	Pier 4
19	UC774Hrashid10\Param\Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	0.000917464	Pier 4
20	UC774Hrashid10\Param\Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	0.00102237	Pier 4
21	UC774Hrashid10\Param\Position 21.mys	Braking	125	425	Accelerating	365	665	0.00106717	Pier 4
22	UC774Hrashid10\Param\Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	0.00084358	Pier 4
23	UC774Hrashid10\Param\Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	0.00042008	Pier 4
24	UC774Hrashid10\Param\Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	0.00018645	Pier 4
25	UC774Hrashid10\Param\Position 25.mys	Braking	150	450	Accelerating	378	678	0.00009777	Pier 4
26	UC774Hrashid10\Param\Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	0.00097055	Pier 4
27	UC774Hrashid10\Param\Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	0.00093053	Pier 4
28	UC774Hrashid10\Param\Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	0.00087403	Pier 4
29	UC774Hrashid10\Param\Position 29.mys	Braking	175	475	Accelerating	391	691	0.00080682	Pier 4
30	UC774Hrashid10\Param\Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	0.00079726	Pier 7
31	UC774Hrashid10\Param\Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	0.00091534	Pier 7
32	UC774Hrashid10\Param\Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	0.00100033	Pier 7
33	UC774Hrashid10\Param\Position 33.mys	Braking	200	500	Accelerating	404	704	0.00102483	Pier 7
34	UC774Hrashid10\Param\Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	0.00100095	Pier 7
35	UC774Hrashid10\Param\Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	0.00096466	Pier 7
36	UC774Hrashid10\Param\Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	0.00093095	Pier 7
37	UC774Hrashid10\Param\Position 37.mys	Braking	225	525	Accelerating	417	717	0.00095709	Pier 7
38	UC774Hrashid10\Param\Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	0.00091699	Pier 7
39	UC774Hrashid10\Param\Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	0.00092306	Pier 7
40	UC774Hrashid10\Param\Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	0.00093843	Pier 7
41	UC774Hrashid10\Param\Position 41.mys	Braking	250	550	Accelerating	430	730	0.00093875	Pier 7
42	UC774Hrashid10\Param\Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	0.00094625	Pier 10
43	UC774Hrashid10\Param\Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	0.00096162	Pier 7
44	UC774Hrashid10\Param\Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	0.00093963	Pier 10
45	UC774Hrashid10\Param\Position 45.mys	Braking	275	575	Accelerating	443	743	0.00104625	Pier 10
46	UC774Hrashid10\Param\Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	0.00104322	Pier 10
47	UC774Hrashid10\Param\Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	0.00103852	Pier 7
48	UC774Hrashid10\Param\Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	0.00093238	Pier 7
49	UC774Hrashid10\Param\Position 49.mys	Braking	300	600	Accelerating	456	756	0.00096286	Pier 7
50	UC774Hrashid10\Param\Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	0.00093744	Pier 10
51	UC774Hrashid10\Param\Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	0.00094585	Pier 10
52	UC774Hrashid10\Param\Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	0.0009532	Pier 10
53	UC774Hrashid10\Param\Position 53.mys	Braking	325	625	Accelerating	469	769	0.00095026	Pier 10
54	UC774Hrashid10\Param\Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	0.00095425	Pier 10
55	UC774Hrashid10\Param\Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	0.0009539	Pier 10
56	UC774Hrashid10\Param\Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	0.00095197	Pier 10
57	UC774Hrashid10\Param\Position 57.mys	Braking	350	650	Accelerating	482	782	0.00094873	Pier 10
58	UC774Hrashid10\Param\Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	0.00094429	Pier 10

Figure 56: Longitudinal Deck End Displacement due to End Rotation Effects Check Worksheet for Multiple Results Files

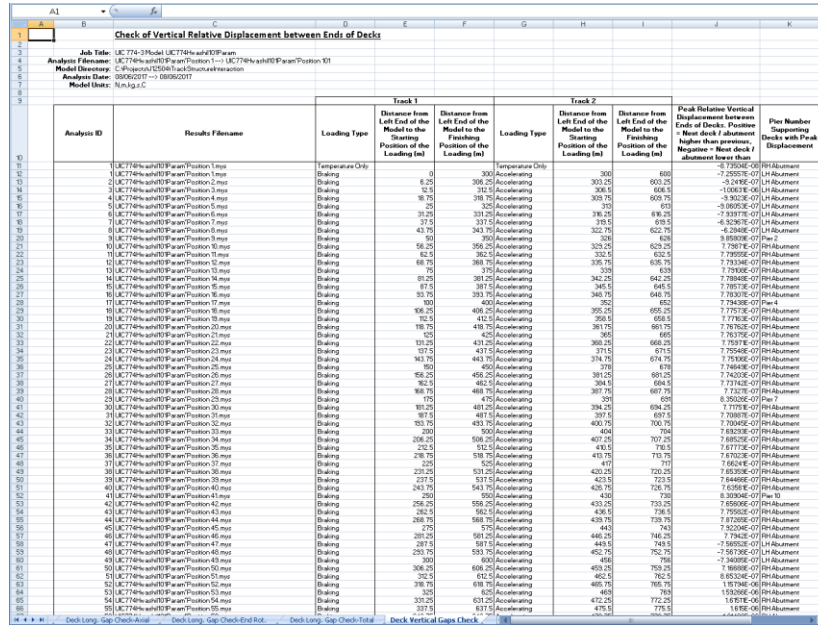


Check of Longitudinal Relative Displacement between Ends of Decks (Total Effects)

Job Title: UC774-3 Model: UC774Hrashid10\Param
Analysis Filename: UC774Hrashid10\Param\Position 1 --> UC774Hrashid10\Param\Position 101
Model Directory: C:\Projects\1250\4Track3\structure\Interaction
Analysis Date: 28/03/2019 --> 29/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting	Track 2 Distance from Left End of the Model to the Finishing	Peak Relative Longitudinal Displacement between Ends of Decks, Positive	Pier Number / Location Supporting Decks with
1	UC774Hrashid10\Param\Position 1.mys	Temperature Only			Temperature Only			-0.0145E705	Pier 10
1	UC774Hrashid10\Param\Position 1.mys	Braking	0	300	Accelerating	300	600	-0.0144361	Pier 10
2	UC774Hrashid10\Param\Position 2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	-0.0144403	Pier 10
3	UC774Hrashid10\Param\Position 3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	-0.0144447	Pier 10
4	UC774Hrashid10\Param\Position 4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-0.0144795	Pier 10
5	UC774Hrashid10\Param\Position 5.mys	Braking	25	325	Accelerating	313	613	-0.0144914	Pier 10
6	UC774Hrashid10\Param\Position 6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-0.0144593	Pier 10
7	UC774Hrashid10\Param\Position 7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-0.0144532	Pier 10
8	UC774Hrashid10\Param\Position 8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-0.0144578	Pier 10
9	UC774Hrashid10\Param\Position 9.mys	Braking	50	350	Accelerating	326	626	-0.0144771	Pier 10
10	UC774Hrashid10\Param\Position 10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	-0.0144362	Pier 10
11	UC774Hrashid10\Param\Position 11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	-0.0145165	Pier 10
12	UC774Hrashid10\Param\Position 12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	-0.0145315	Pier 10
13	UC774Hrashid10\Param\Position 13.mys	Braking	75	375	Accelerating	339	639	-0.0145165	Pier 10
14	UC774Hrashid10\Param\Position 14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	-0.0145798	Pier 10
15	UC774Hrashid10\Param\Position 15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	-0.0146033	Pier 10
16	UC774Hrashid10\Param\Position 16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	-0.0146266	Pier 10
17	UC774Hrashid10\Param\Position 17.mys	Braking	100	400	Accelerating	352	652	-0.0146546	Pier 10
18	UC774Hrashid10\Param\Position 18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	-0.0146976	Pier 10
19	UC774Hrashid10\Param\Position 19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	-0.0147385	Pier 10
20	UC774Hrashid10\Param\Position 20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	-0.0147945	Pier 10
21	UC774Hrashid10\Param\Position 21.mys	Braking	125	425	Accelerating	365	665	-0.0148035	Pier 7
22	UC774Hrashid10\Param\Position 22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	-0.0150846	Pier 7
23	UC774Hrashid10\Param\Position 23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	-0.0152765	Pier 7
24	UC774Hrashid10\Param\Position 24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	-0.0155076	Pier 7
25	UC774Hrashid10\Param\Position 25.mys	Braking	150	450	Accelerating	378	678	-0.0157246	Pier 7
26	UC774Hrashid10\Param\Position 26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	-0.0158796	Pier 7
27	UC774Hrashid10\Param\Position 27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	-0.0159816	Pier 7
28	UC774Hrashid10\Param\Position 28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	-0.0160806	Pier 7
29	UC774Hrashid10\Param\Position 29.mys	Braking	175	475	Accelerating	391	691	-0.0161736	Pier 7
30	UC774Hrashid10\Param\Position 30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	-0.0160385	Pier 7
31	UC774Hrashid10\Param\Position 31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	-0.0158856	Pier 7
32	UC774Hrashid10\Param\Position 32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	-0.0162445	Pier 7
33	UC774Hrashid10\Param\Position 33.mys	Braking	200	500	Accelerating	404	704	-0.0160078	Pier 10
34	UC774Hrashid10\Param\Position 34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	-0.0162126	Pier 10
35	UC774Hrashid10\Param\Position 35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	-0.0162478	Pier 10
36	UC774Hrashid10\Param\Position 36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	-0.0164577	Pier 10
37	UC774Hrashid10\Param\Position 37.mys	Braking	225	525	Accelerating	417	717	-0.0165328	Pier 10
38	UC774Hrashid10\Param\Position 38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	-0.0163636	Pier 10
39	UC774Hrashid10\Param\Position 39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	-0.0157006	Pier 10
40	UC774Hrashid10\Param\Position 40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	-0.0175035	Pier 10
41	UC774Hrashid10\Param\Position 41.mys	Braking	250	550	Accelerating	430	730	-0.0172208	Pier 10
42	UC774Hrashid10\Param\Position 42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	-0.0170363	Pier 10
43	UC774Hrashid10\Param\Position 43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	-0.0168433	Pier 10
44	UC774Hrashid10\Param\Position 44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	-0.0163424	Pier 10
45	UC774Hrashid10\Param\Position 45.mys	Braking	275	575	Accelerating	443	743	-0.0164794	Pier 10
46	UC774Hrashid10\Param\Position 46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	-0.016317	Pier 10
47	UC774Hrashid10\Param\Position 47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-0.0162362	Pier 10
48	UC774Hrashid10\Param\Position 48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-0.0161134	Pier 10
49	UC774Hrashid10\Param\Position 49.mys	Braking	300	600	Accelerating	456	756	-0.0160373	Pier 10
50	UC774Hrashid10\Param\Position 50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	-0.0159532	Pier 10
51	UC774Hrashid10\Param\Position 51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	-0.0158639	Pier 10
52	UC774Hrashid10\Param\Position 52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	-0.0158237	Pier 10
53	UC774Hrashid10\Param\Position 53.mys	Braking	325	625	Accelerating	469	769	-0.0157796	Pier 10
54	UC774Hrashid10\Param\Position 54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	-0.0158016	Pier 10
55	UC774Hrashid10\Param\Position 55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	-0.0158138	Pier 10
56	UC774Hrashid10\Param\Position 56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	-0.0158494	Pier 10
57	UC774Hrashid10\Param\Position 57.mys	Braking	350	650	Accelerating	482	782	-0.0158852	Pier 10
58	UC774Hrashid10\Param\Position 58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	-0.0158535	Pier 10

Figure 57: Longitudinal Deck End Displacement due to Total Effects Check Worksheet for Multiple Results Files



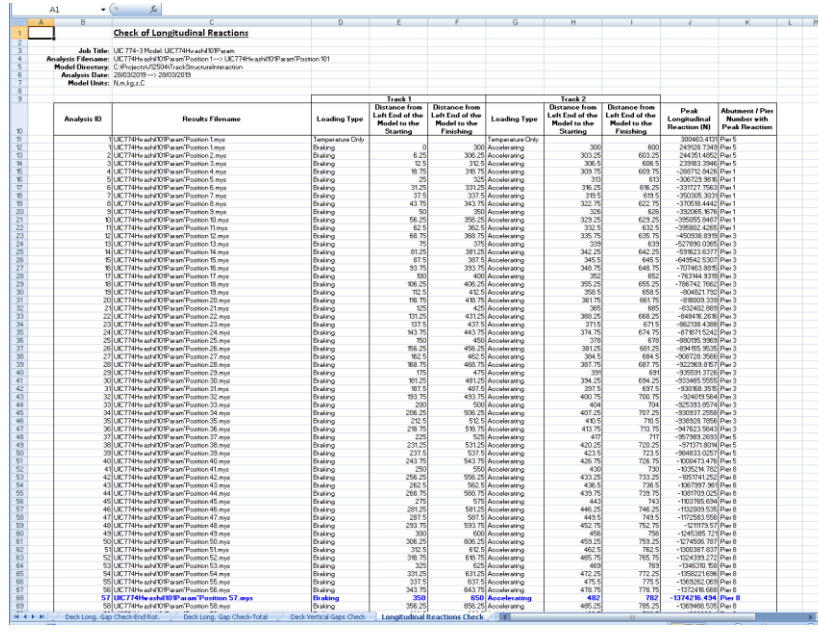
Check of Vertical Relative Displacement between Ends of Decks

Job Title: UIC774-3Model: UIC774Hvashf10?Param
Analysis Filename: UIC774Hvashf10?Param?Position.1~~0 UIC774Hvashf10?Param?Position.101
Model Directory: C:\Projects\T2504\Track\StructureInteraction
Analysis Date: 09/06/2017 ~~ 09/06/2017
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting Position of the Loading (m)	Track 1 Distance from Left End of the Model to the Finishing Position of the Loading (m)	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting Position of the Loading (m)	Track 2 Distance from Left End of the Model to the Finishing Position of the Loading (m)	Peak Relative Vertical Displacement between Ends of Decks. Positive = Next deck / abutment higher than previous., Negative = Next deck / abutment lower than	Pier Number Supporting Decks with Peak Displacement
1	UIC774Hvashf10?Param?Position.1.mys	Temperature Only			Temperature Only			-6.73504E-06	RH Abutment
1	UIC774Hvashf10?Param?Position.1.mys	Braking	0	300	Accelerating	300	600	-7.25557E-07	LH Abutment
2	UIC774Hvashf10?Param?Position.2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	-3.2419E-07	LH Abutment
3	UIC774Hvashf10?Param?Position.3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	-1.00631E-06	LH Abutment
4	UIC774Hvashf10?Param?Position.4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-5.9023E-07	LH Abutment
5	UIC774Hvashf10?Param?Position.5.mys	Braking	25	325	Accelerating	313	613	-3.08053E-07	LH Abutment
6	UIC774Hvashf10?Param?Position.6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-7.33977E-07	LH Abutment
7	UIC774Hvashf10?Param?Position.7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-6.92367E-07	LH Abutment
8	UIC774Hvashf10?Param?Position.8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-6.2846E-07	LH Abutment
9	UIC774Hvashf10?Param?Position.9.mys	Braking	50	350	Accelerating	326	626	9.85809E-07	Pier 2
10	UIC774Hvashf10?Param?Position.10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	7.7987E-07	RH Abutment
11	UIC774Hvashf10?Param?Position.11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	7.79555E-07	RH Abutment
12	UIC774Hvashf10?Param?Position.12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	7.79334E-07	RH Abutment
13	UIC774Hvashf10?Param?Position.13.mys	Braking	75	375	Accelerating	339	639	7.79306E-07	RH Abutment
14	UIC774Hvashf10?Param?Position.14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	7.78948E-07	RH Abutment
15	UIC774Hvashf10?Param?Position.15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	7.78573E-07	RH Abutment
16	UIC774Hvashf10?Param?Position.16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	7.78307E-07	RH Abutment
17	UIC774Hvashf10?Param?Position.17.mys	Braking	100	400	Accelerating	352	652	7.79438E-07	Pier 4
18	UIC774Hvashf10?Param?Position.18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	7.77573E-07	RH Abutment
19	UIC774Hvashf10?Param?Position.19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	7.77163E-07	RH Abutment
20	UIC774Hvashf10?Param?Position.20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	7.76762E-07	RH Abutment
21	UIC774Hvashf10?Param?Position.21.mys	Braking	125	425	Accelerating	365	665	7.76375E-07	RH Abutment
22	UIC774Hvashf10?Param?Position.22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	7.7597E-07	RH Abutment
23	UIC774Hvashf10?Param?Position.23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	7.75548E-07	RH Abutment
24	UIC774Hvashf10?Param?Position.24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	7.75183E-07	RH Abutment
25	UIC774Hvashf10?Param?Position.25.mys	Braking	150	450	Accelerating	378	678	7.74643E-07	RH Abutment
26	UIC774Hvashf10?Param?Position.26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	7.74203E-07	RH Abutment
27	UIC774Hvashf10?Param?Position.27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	7.77142E-07	RH Abutment
28	UIC774Hvashf10?Param?Position.28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	7.7327E-07	RH Abutment
29	UIC774Hvashf10?Param?Position.29.mys	Braking	175	475	Accelerating	391	691	8.35928E-07	Pier 7
30	UIC774Hvashf10?Param?Position.30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	7.7175E-07	RH Abutment
31	UIC774Hvashf10?Param?Position.31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	7.70987E-07	RH Abutment
32	UIC774Hvashf10?Param?Position.32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	7.70045E-07	RH Abutment
33	UIC774Hvashf10?Param?Position.33.mys	Braking	200	500	Accelerating	404	704	7.63293E-07	RH Abutment
34	UIC774Hvashf10?Param?Position.34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	7.68525E-07	RH Abutment
35	UIC774Hvashf10?Param?Position.35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	7.67773E-07	RH Abutment
36	UIC774Hvashf10?Param?Position.36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	7.67023E-07	RH Abutment
37	UIC774Hvashf10?Param?Position.37.mys	Braking	225	525	Accelerating	417	717	7.66241E-07	RH Abutment
38	UIC774Hvashf10?Param?Position.38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	7.65359E-07	RH Abutment
39	UIC774Hvashf10?Param?Position.39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	7.64466E-07	RH Abutment
40	UIC774Hvashf10?Param?Position.40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	7.63561E-07	RH Abutment
41	UIC774Hvashf10?Param?Position.41.mys	Braking	250	550	Accelerating	430	730	8.30394E-07	Pier 8
42	UIC774Hvashf10?Param?Position.42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	7.65606E-07	RH Abutment
43	UIC774Hvashf10?Param?Position.43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	7.75552E-07	RH Abutment
44	UIC774Hvashf10?Param?Position.44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	7.87265E-07	RH Abutment
45	UIC774Hvashf10?Param?Position.45.mys	Braking	275	575	Accelerating	443	743	7.92204E-07	RH Abutment
46	UIC774Hvashf10?Param?Position.46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	7.7942E-07	RH Abutment
47	UIC774Hvashf10?Param?Position.47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-7.58552E-07	LH Abutment
48	UIC774Hvashf10?Param?Position.48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-7.56736E-07	LH Abutment
49	UIC774Hvashf10?Param?Position.49.mys	Braking	300	600	Accelerating	456	756	-7.34085E-07	LH Abutment
50	UIC774Hvashf10?Param?Position.50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	7.16668E-07	RH Abutment
51	UIC774Hvashf10?Param?Position.51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	8.65324E-07	RH Abutment
52	UIC774Hvashf10?Param?Position.52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	1.15794E-06	RH Abutment
53	UIC774Hvashf10?Param?Position.53.mys	Braking	325	625	Accelerating	469	769	1.51926E-06	RH Abutment
54	UIC774Hvashf10?Param?Position.54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	1.61E-06	RH Abutment
55	UIC774Hvashf10?Param?Position.55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	1.61E-06	RH Abutment
56	UIC774Hvashf10?Param?Position.56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	1.61E-06	RH Abutment
57	UIC774Hvashf10?Param?Position.57.mys	Braking	350	650	Accelerating	482	782	-1.13742E-06	Pier 8
58	UIC774Hvashf10?Param?Position.58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	-1.06946E-06	RH Abutment

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

Figure 58: Vertical Deck End Displacement Check Worksheet for Multiple Results Files



Check of Longitudinal Reactions

Job Title: UIC774-3Model: UIC774Hvashf10?Param
Analysis Filename: UIC774Hvashf10?Param?Position.1~~0 UIC774Hvashf10?Param?Position.101
Model Directory: C:\Projects\T2504\Track\StructureInteraction
Analysis Date: 28/03/2018 ~~ 28/03/2018
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting	Track 2 Distance from Left End of the Model to the Finishing	Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction
1	UIC774Hvashf10?Param?Position.1.mys	Temperature Only			Temperature Only			309463.4131	Pier 5
1	UIC774Hvashf10?Param?Position.1.mys	Braking	0	300	Accelerating	300	600	243928.7349	Pier 5
2	UIC774Hvashf10?Param?Position.2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	244261.4952	Pier 5
3	UIC774Hvashf10?Param?Position.3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	239183.3946	Pier 5
4	UIC774Hvashf10?Param?Position.4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-266702.0426	Pier 1
5	UIC774Hvashf10?Param?Position.5.mys	Braking	25	325	Accelerating	313	613	-306729.3616	Pier 1
6	UIC774Hvashf10?Param?Position.6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-337127.7563	Pier 1
7	UIC774Hvashf10?Param?Position.7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-350305.3031	Pier 1
8	UIC774Hvashf10?Param?Position.8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-370518.4442	Pier 1
9	UIC774Hvashf10?Param?Position.9.mys	Braking	50	350	Accelerating	326	626	-392085.8076	Pier 1
10	UIC774Hvashf10?Param?Position.10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	-395055.9467	Pier 1
11	UIC774Hvashf10?Param?Position.11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	-395862.4265	Pier 1
12	UIC774Hvashf10?Param?Position.12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	-450938.8919	Pier 3
13	UIC774Hvashf10?Param?Position.13.mys	Braking	75	375	Accelerating	339	639	-527890.0365	Pier 3
14	UIC774Hvashf10?Param?Position.14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	-591623.6377	Pier 3
15	UIC774Hvashf10?Param?Position.15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	-648542.5307	Pier 3
16	UIC774Hvashf10?Param?Position.16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	-707463.8915	Pier 3
17	UIC774Hvashf10?Param?Position.17.mys	Braking	100	400	Accelerating	352	652	-763144.3319	Pier 3
18	UIC774Hvashf10?Param?Position.18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	-798742.7662	Pier 3
19	UIC774Hvashf10?Param?Position.19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	-804821.792	Pier 3
20	UIC774Hvashf10?Param?Position.20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	-818809.3391	Pier 3
21	UIC774Hvashf10?Param?Position.21.mys	Braking	125	425	Accelerating	365	665	-832402.089	Pier 3
22	UIC774Hvashf10?Param?Position.22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	-848476.2576	Pier 3
23	UIC774Hvashf10?Param?Position.23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	-862108.4388	Pier 3
24	UIC774Hvashf10?Param?Position.24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	-876715.242	Pier 3
25	UIC774Hvashf10?Param?Position.25.mys	Braking	150	450	Accelerating	378	678	-892095.9963	Pier 3
26	UIC774Hvashf10?Param?Position.26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	-894155.9535	Pier 3
27	UIC774Hvashf10?Param?Position.27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	-908728.3566	Pier 3
28	UIC774Hvashf10?Param?Position.28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	-922368.8157	Pier 3
29	UIC774Hvashf10?Param?Position.29.mys	Braking	175	475	Accelerating	391	691	-935531.3726	Pier 3
30	UIC774Hvashf10?Param?Position.30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	-933485.9955	Pier 3
31	UIC774Hvashf10?Param?Position.31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	-930168.3515	Pier 3
32	UIC774Hvashf10?Param?Position.32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	-924619.564	Pier 3
33	UIC774Hvashf10?Param?Position.33.mys	Braking	200	500	Accelerating	404	704	-925393.8574	Pier 3
34	UIC774Hvashf10?Param?Position.34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	-930837.2658	Pier 3
35	UIC774Hvashf10?Param?Position.35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	-938928.7656	Pier 3
36	UIC774Hvashf10?Param?Position.36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	-947623.5643	Pier 3
37	UIC774Hvashf10?Param?Position.37.mys	Braking	225	525	Accelerating	417	717	-957389.2693	Pier 3
38	UIC774Hvashf10?Param?Position.38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	-971371.8014	Pier 5
39	UIC774Hvashf10?Param?Position.39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	-984833.0257	Pier 5
40	UIC774Hvashf10?Param?Position.40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	-1000473.476	Pier 5
41	UIC774Hvashf10?Param?Position.41.mys	Braking	250	550	Accelerating	430	730	-1005214.782	Pier 8
42	UIC774Hvashf10?Param?Position.42.mys	Braking	256.25	556.25	Accelerating	433.25	733.25	-1011741.252	Pier 8
43	UIC774Hvashf10?Param?Position.43.mys	Braking	262.5	562.5	Accelerating	436.5	736.5	-1067397.961	Pier 8
44	UIC774Hvashf10?Param?Position.44.mys	Braking	268.75	568.75	Accelerating	439.75	739.75	-1061929.025	Pier 8
45	UIC774Hvashf10?Param?Position.45.mys	Braking	275	575	Accelerating	443	743	-1103765.694	Pier 8
46	UIC774Hvashf10?Param?Position.46.mys	Braking	281.25	581.25	Accelerating	446.25	746.25	-1102933.535	Pier 8
47	UIC774Hvashf10?Param?Position.47.mys	Braking	287.5	587.5	Accelerating	449.5	749.5	-1172583.556	Pier 8
48	UIC774Hvashf10?Param?Position.48.mys	Braking	293.75	593.75	Accelerating	452.75	752.75	-1211179.57	Pier 8
49	UIC774Hvashf10?Param?Position.49.mys	Braking	300	600	Accelerating	456	756	-1245385.726	Pier 8
50	UIC774Hvashf10?Param?Position.50.mys	Braking	306.25	606.25	Accelerating	459.25	759.25	-1274596.787	Pier 8
51	UIC774Hvashf10?Param?Position.51.mys	Braking	312.5	612.5	Accelerating	462.5	762.5	-1300397.637	Pier 8
52	UIC774Hvashf10?Param?Position.52.mys	Braking	318.75	618.75	Accelerating	465.75	765.75	-1324393.272	Pier 8
53	UIC774Hvashf10?Param?Position.53.mys	Braking	325	625	Accelerating	469	769	-1346370.156	Pier 8
54	UIC774Hvashf10?Param?Position.54.mys	Braking	331.25	631.25	Accelerating	472.25	772.25	-1358221.696	Pier 8
55	UIC774Hvashf10?Param?Position.55.mys	Braking	337.5	637.5	Accelerating	475.5	775.5	-1369282.065	Pier 8
56	UIC774Hvashf10?Param?Position.56.mys	Braking	343.75	643.75	Accelerating	478.75	778.75	-1372418.668	Pier 8
57	UIC774Hvashf10?Param?Position.57.mys	Braking	350	650	Accelerating	482	782	-1374216.434	Pier 8
58	UIC774Hvashf10?Param?Position.58.mys	Braking	356.25	656.25	Accelerating	485.25	785.25	-1369466.535	Pier 8

Deck Long. Gap Check-End Rot. | Deck Long. Gap Check-Total | Deck Vertical Gaps Check | Longitudinal Reactions Check

Figure 59: Longitudinal Reaction Check Worksheet for Multiple Results Files

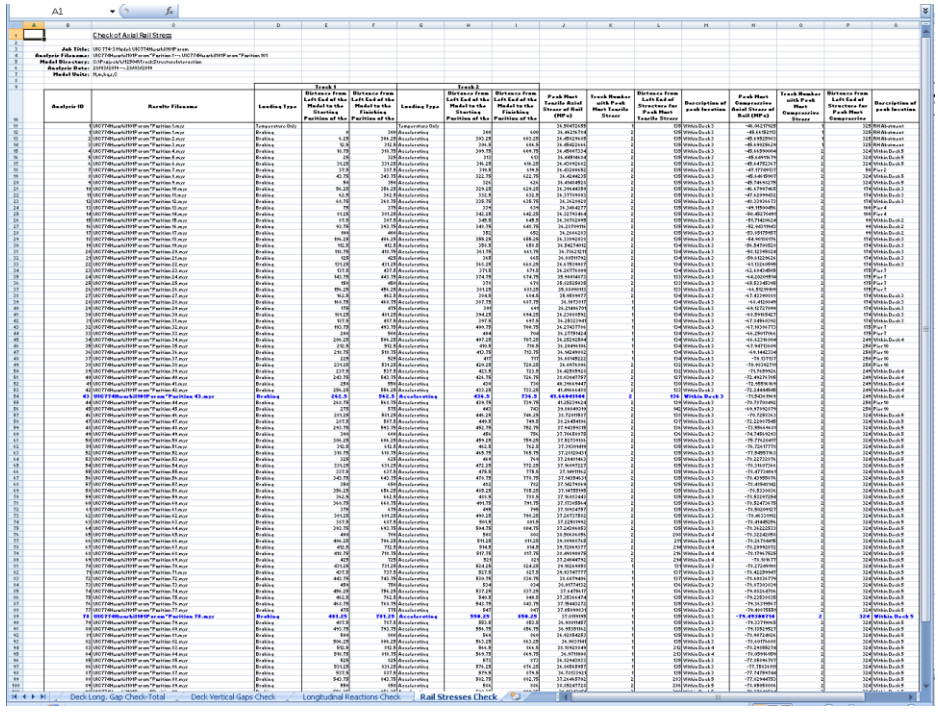


Figure 60: Axial Rail Stress Check Worksheet for Multiple Results Files

If valid basic combinations or envelopes that match the criteria described in **Post-processing of automatically defined groups** (page 40) are present in the model then additional results for these will be tabulated into the Microsoft Excel summary worksheets underneath the results for the temperature only and combined temperature and trainset rail loading results. A separate set of the peak results within these basic combinations will be highlighted in bold blue text as illustrated in the figures below for the railbed displacement and reaction results for a model that includes valid basic combinations.

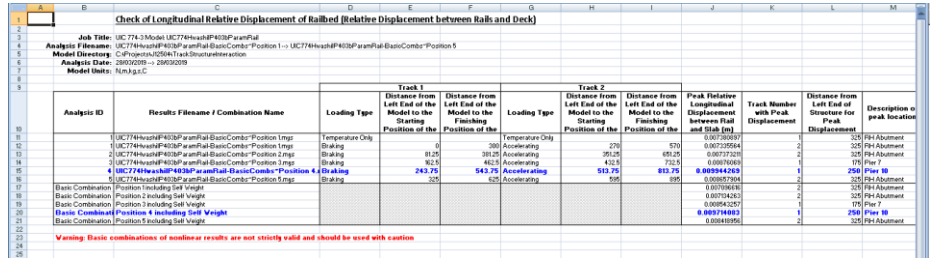
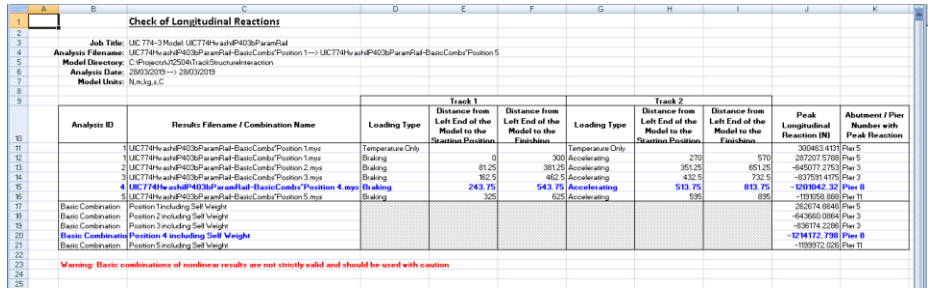


Figure 61: Railbed Check Worksheet for Rail Track Analysis Results and Basic Combinations of these Results



Check of Longitudinal Reactions

Job Title: UIC 774-3 Model: UIC774HvashP403bParamRail
Analysis Filename: UIC774HvashP403bParamRail-BasicCombs\"Position 1 --> UIC774HvashP403bParamRail-BasicCombs\"Position 5
Model Directory: C:\Projects\7250\4Track\StructureInteraction
Analysis Date: 28/03/2019 --> 28/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename / Combination Name	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting Position	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting Position	Track 2 Distance from Left End of the Model to the Finishing	Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction
1	UIC774HvashP403bParamRail-BasicCombs\"Position 1.mys	Temperature Only			Temperature Only			300483.4131	Pier 5
1	UIC774HvashP403bParamRail-BasicCombs\"Position 1.mys	Braking	0	300	Accelerating	270	570	287207.5788	Pier 5
2	UIC774HvashP403bParamRail-BasicCombs\"Position 2.mys	Braking	81.25	381.25	Accelerating	351.25	651.25	-645077.2753	Pier 3
3	UIC774HvashP403bParamRail-BasicCombs\"Position 3.mys	Braking	162.5	462.5	Accelerating	432.5	732.5	-637591.4175	Pier 3
4	**UIC774HvashP403bParamRail-BasicCombs\"Position 4.mys**	**Braking**	**243.75**	**543.75**	**Accelerating**	**513.75**	**813.75**	**-1201042.32**	**Pier 8**
5	UIC774HvashP403bParamRail-BasicCombs\"Position 5.mys	Braking	325	625	Accelerating	595	895	-1191058.888	Pier 11
Basic Combination	Position 1 including Self Weight							-252674.9646	Pier 5
Basic Combination	Position 2 including Self Weight							-642660.0864	Pier 3
Basic Combination	Position 3 including Self Weight							-636174.2266	Pier 3
Basic Combinatio	**Position 4 including Self Weight**							**-1214172.738**	**Pier 8**
Basic Combination	Position 5 including Self Weight							-1199372.026	Pier 11

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

Figure 62: 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 ones 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 63: 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.

This is illustrated in the figures below which illustrate the process. Select **File>Manage Results Files...** to bring up the results management dialog shown in Figure 64. Uncheck the "Let LUSAS manage results files (recommended)" checkbox – this will cause a warning to be issued which can be ignored. Within this dialog, deselect the opening of results files which are to be excluded from the post-processing (Positions 2 and 4 are deselected in the figure) and click OK. The automatic post-processor can now be run (with or without the enveloping in Microsoft Excel) but it will bring up the information message shown in Figure 65 indicating that insufficient results files are loaded for the analyses in the model. Click on OK since we know why this is the case. The automatic post-processor will continue with the extraction of results but with the deselected positions / results files omitted as indicated in Figure 66.

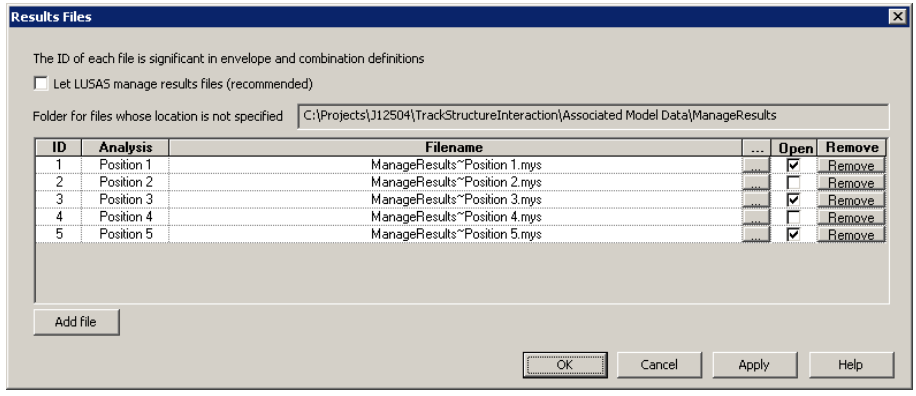


Figure 64: Turning Off LUSAS Management of Results Files

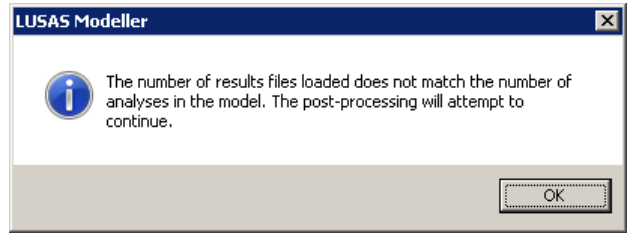
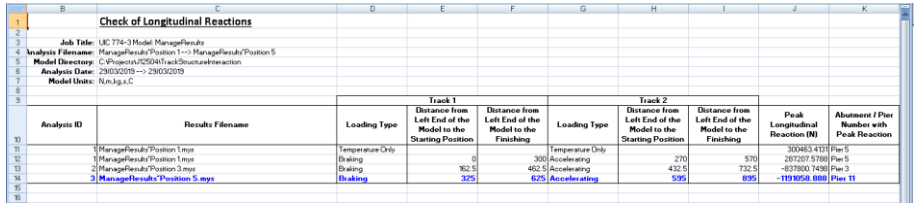


Figure 65: Post-Processor Information Message About Loaded Results



Check of Longitudinal Reactions

Job Title: UIC 774-3 Model: ManageResults
Analysis Filename: ManageResults\Position 1~~> ManageResults\Position 5
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 29/03/2019 ~~> 29/03/2019
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting Position	Track 1 Distance from Left End of the Model to the Finishing	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting Position	Track 2 Distance from Left End of the Model to the Finishing	Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction
1	ManageResults\Position 1.mys	Temperature Only			Temperature Only			300463.4131	Pier 5
1	ManageResults\Position 1.mys	Braking	0	300	Accelerating	270	570	287207.5788	Pier 5
2	ManageResults\Position 2.mys	Braking	162.5	462.5	Accelerating	432.5	732.5	-637800.7498	Pier 3
3	ManageResults\Position 5.mys	Braking	325	625	Accelerating	595	895	-1191058.888	Pier 11

Figure 66: Longitudinal Reactions for User Managed Results

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 67 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 67: 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 68 and Figure 69 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 69 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 70 and Figure 71 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.

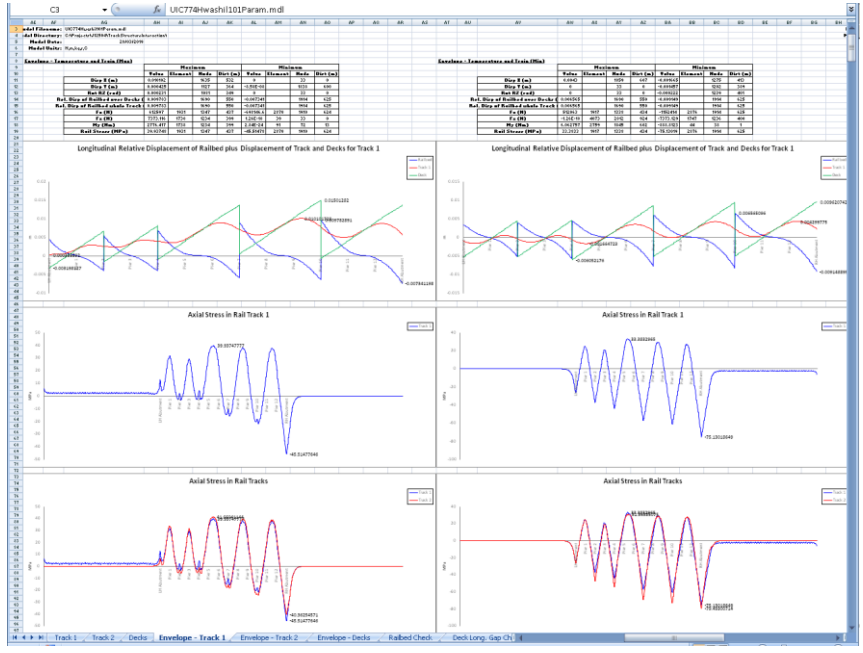


Figure 68: Track Envelopes Performed in Microsoft Excel

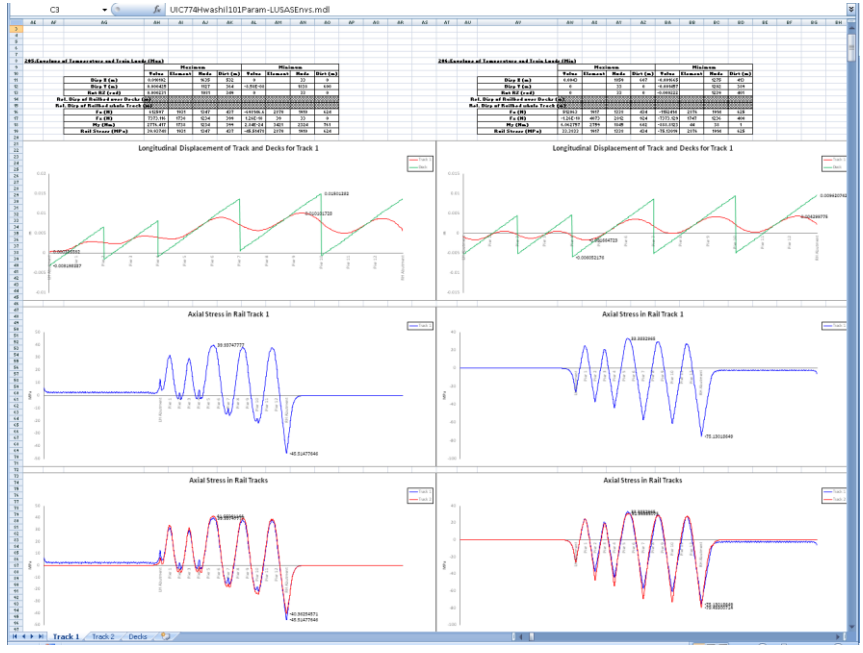


Figure 69: Track Envelopes Performed in Modeller

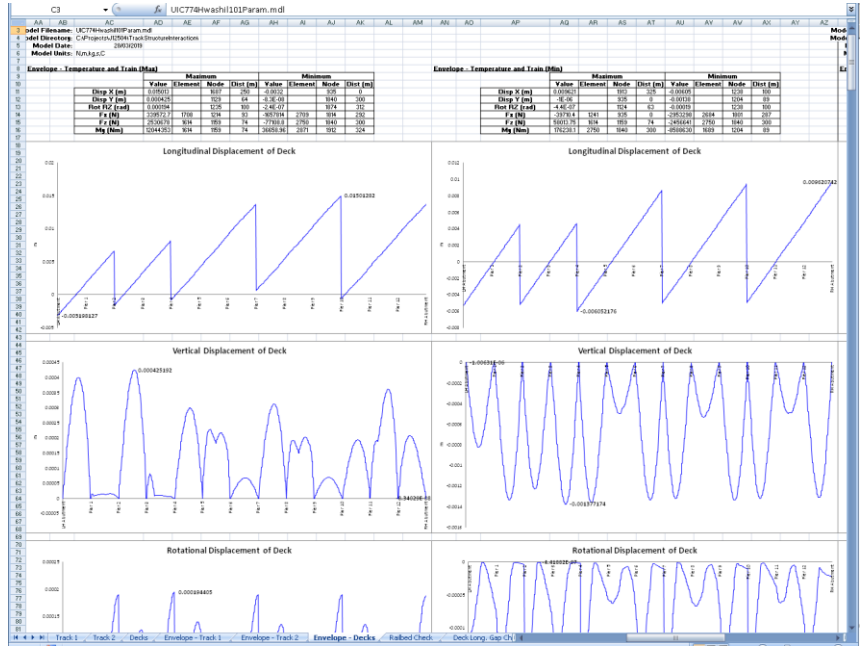


Figure 70: Deck Envelopes Performed in Microsoft Excel

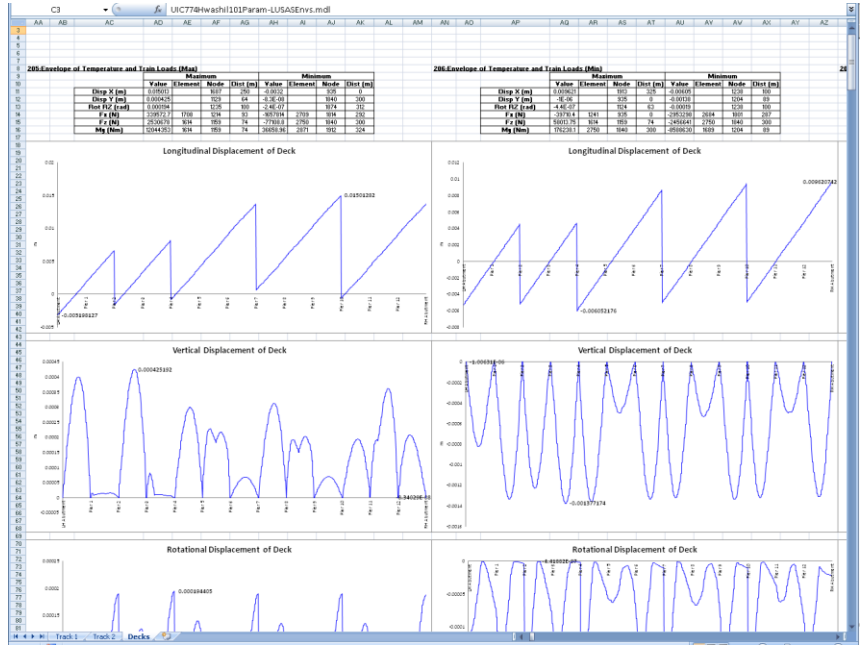
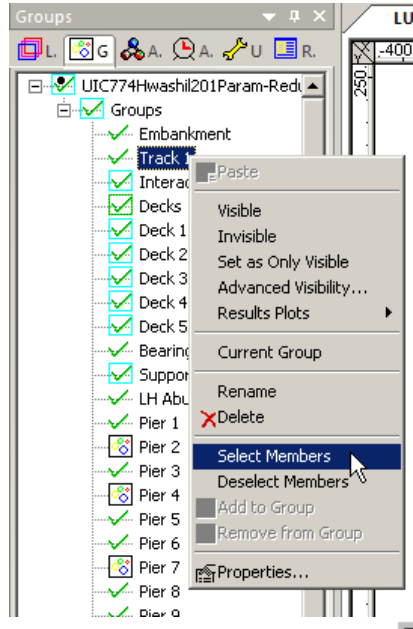


Figure 71: Deck Envelopes Performed in Modeller

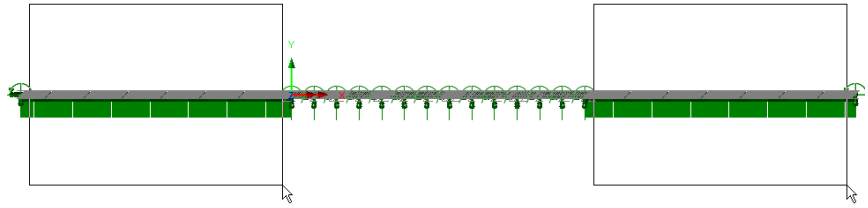
One final option available (that should be used with caution, particularly if there is a possibility for the peak behaviours in the track / railbed being observed over any part of the embankments rather than over the structure) is the reduction of the track/rail groups in the model so that they contain 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:

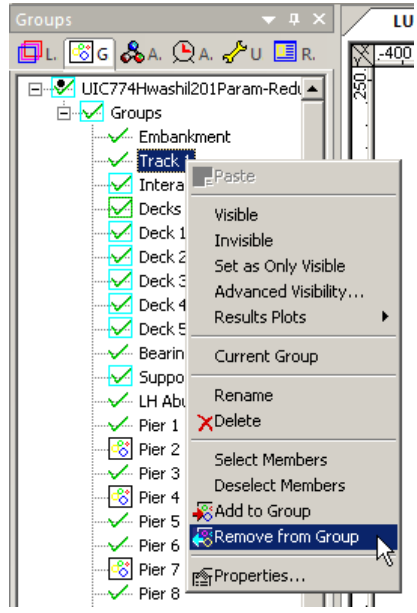
- Ensure the whole model is visible and that the selection allows the selection of any geometry and mesh features with the **Select Any** cursor ,
- In the **Groups Treeview** select all of the members in the **Track 1** group by right-clicking on the **Track 1** group and choosing the **Select Members**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

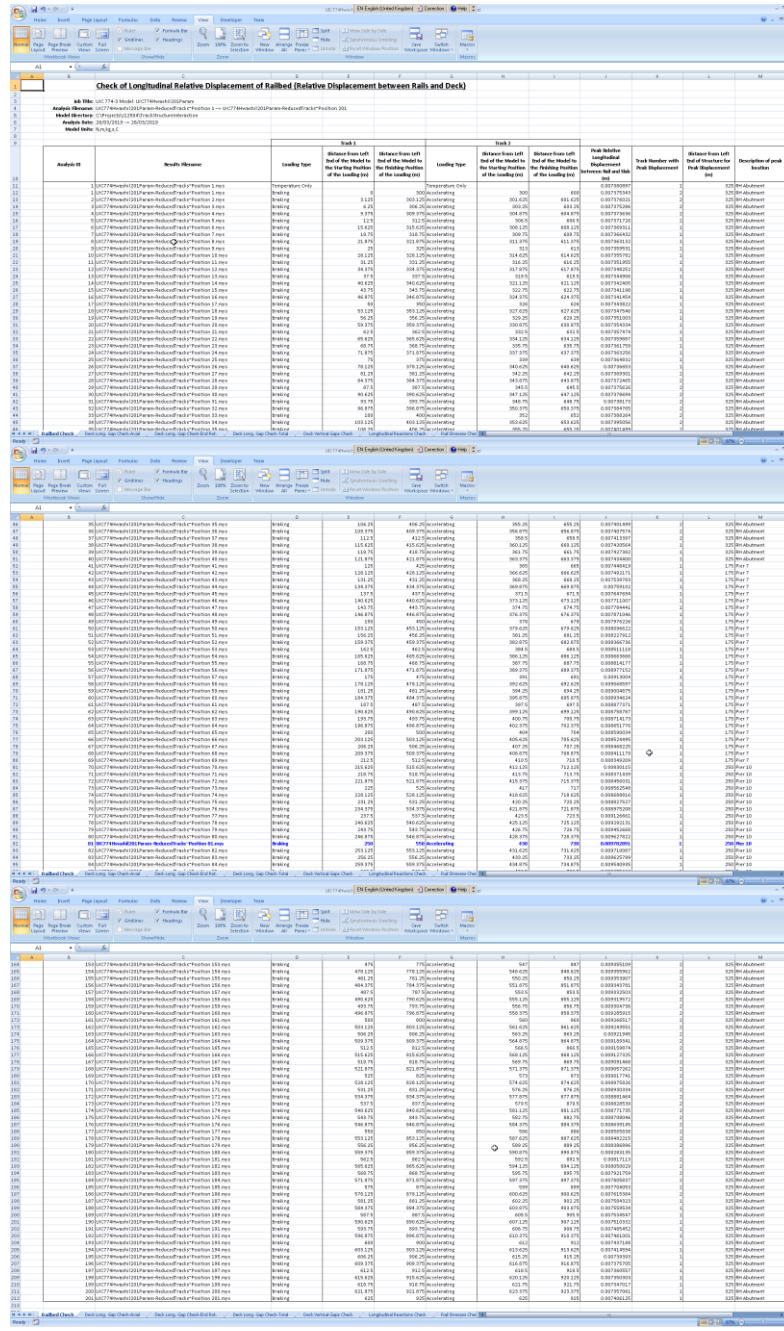
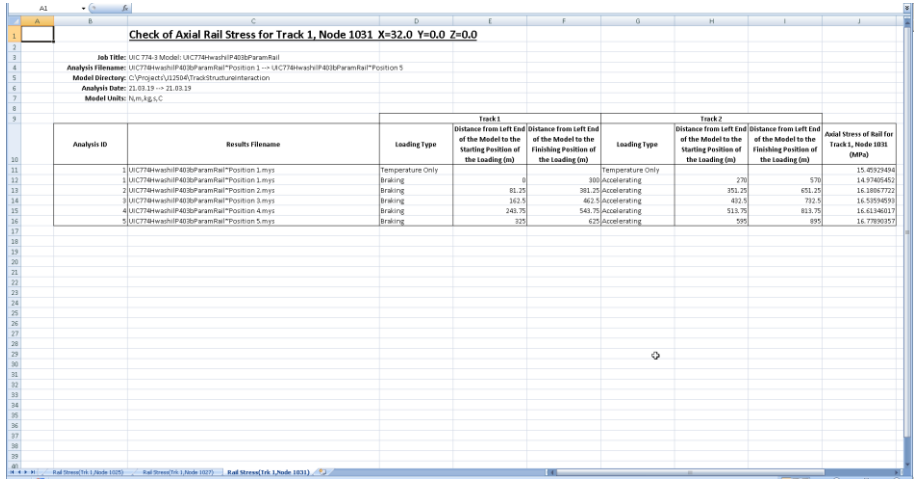


Figure 72: Railbed Enveloped Results for 201 Parametric Trainset Positions in Microsoft Excel

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



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

Job Title: UIC 774-3 Model: UIC774HwashIP403bParamRail
Analysis Filename: UIC774HwashIP403bParamRail"Position 1 --> UIC774HwashIP403bParamRail"Position 5
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 21.03.19 --> 21.03.19
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting Position of the Loading (m)	Track 1 Distance from Left End of the Model to the Finishing Position of the Loading (m)	Track 2 Loading Type	Track 2 Distance from Left End of the Model to the Starting Position of the Loading (m)	Track 2 Distance from Left End of the Model to the Finishing Position of the Loading (m)	Axial Stress of Rail for Track 1, Node 1031 (MPa)
1	UIC774HwashIP403bParamRail"Position 1.mys	Temperature Only			Temperature Only			15.4592949
1	UIC774HwashIP403bParamRail"Position 1.mys	Braking	0	300	Accelerating	270	570	14.97405452
2	UIC774HwashIP403bParamRail"Position 2.mys	Braking	81.25	381.25	Accelerating	351.25	651.25	16.18067722
3	UIC774HwashIP403bParamRail"Position 3.mys	Braking	162.5	462.5	Accelerating	432.5	732.5	16.53594593
4	UIC774HwashIP403bParamRail"Position 4.mys	Braking	243.75	543.75	Accelerating	513.75	813.75	16.61340017
5	UIC774HwashIP403bParamRail"Position 5.mys	Braking	325	625	Accelerating	595	895	16.77890357

Figure 73: Sample Output from an Individual Track/Rail Node

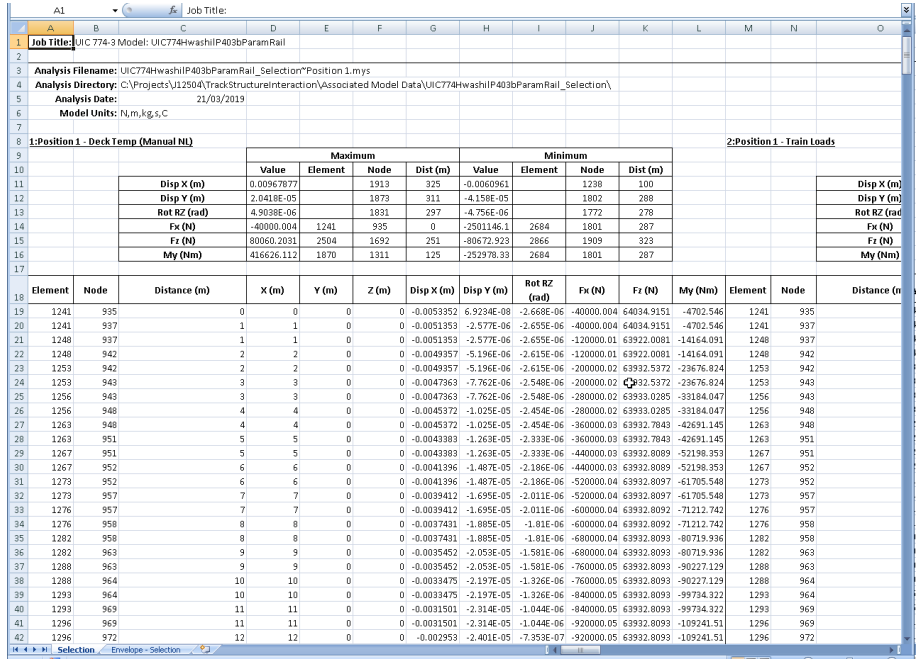
Note. The stresses reported in the track/rail node worksheets are the averaged nodal stresses. The stresses reported previously in the post-processing performed on the UIC774-3 groups is the unaveraged nodal stresses and therefore the values will differ slightly. The averaged nodal stresses can be obtained 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 74 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: UIC774HwashilP403bParamRail

Analysis Filename: UIC774HwashilP403bParamRail_Selection~Position 1.mys
Analysis Directory: C:\Projects\U12504\TrackStructureInteraction\Associated Model Data\UIC774HwashilP403bParamRail_Selection\
Analysis Date: 21/03/2019
Model Units: N,m,kg,s,C

1:Position 1 - Deck Temp (Manual NL)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00967877		1913	325	-0.0060961		1238	100
Disp Y (m)	2.0418E-05		1873	311	-4.158E-05		1802	288
Rot RZ (rad)	4.9038E-06		1831	297	-4.756E-06		1772	278
Fx (N)	-40000.004	1241	935	0	-2501146.1	2684	1801	287
Fz (N)	80060.2031	2504	1692	251	-80672.923	2866	1909	323
My (Nm)	416626.112	1870	1311	125	-252978.33	2684	1801	287

2:Position 1 - Train Loads

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

Element	Node	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Fx (N)	Fz (N)	My (Nm)	Element	Node	Distance (m
1241	935	0	0	0	0	-0.0053352	6.9234E-08	-2.668E-06	-40000.004	64034.9151	-4702.546	1241	935	
1241	937	1	1	0	0	-0.0051353	-2.577E-06	-2.655E-06	-40000.004	64034.9151	-4702.546	1241	937	
1248	937	1	1	0	0	-0.0051353	-2.577E-06	-2.655E-06	-120000.01	63922.0081	-14164.091	1248	937	
1248	942	2	2	0	0	-0.0049357	-5.196E-06	-2.615E-06	-120000.01	63922.0081	-14164.091	1248	942	
1253	942	2	2	0	0	-0.0049357	-5.196E-06	-2.615E-06	-200000.02	63932.5372	-23676.824	1253	942	
1253	943	3	3	0	0	-0.0047363	-7.762E-06	-2.548E-06	-200000.02	63932.5372	-23676.824	1253	943	
1256	943	3	3	0	0	-0.0047363	-7.762E-06	-2.548E-06	-280000.02	63933.0285	-33184.047	1256	943	
1256	948	4	4	0	0	-0.0045372	-1.025E-05	-2.454E-06	-280000.02	63933.0285	-33184.047	1256	948	
1263	948	4	4	0	0	-0.0045372	-1.025E-05	-2.454E-06	-360000.03	63932.7843	-42691.145	1263	948	
1263	951	5	5	0	0	-0.0043383	-1.263E-05	-2.333E-06	-360000.03	63932.7843	-42691.145	1263	951	
1267	951	5	5	0	0	-0.0043383	-1.263E-05	-2.333E-06	-440000.03	63932.8089	-52198.353	1267	951	
1267	952	6	6	0	0	-0.0041396	-1.487E-05	-2.186E-06	-440000.03	63932.8089	-52198.353	1267	952	
1273	952	6	6	0	0	-0.0041396	-1.487E-05	-2.186E-06	-520000.04	63932.8097	-61705.548	1273	952	
1273	957	7	7	0	0	-0.0039412	-1.695E-05	-2.011E-06	-520000.04	63932.8097	-61705.548	1273	957	
1276	957	7	7	0	0	-0.0039412	-1.695E-05	-2.011E-06	-600000.04	63932.8092	-71212.742	1276	957	
1276	958	8	8	0	0	-0.0037431	-1.885E-05	-1.81E-06	-600000.04	63932.8092	-71212.742	1276	958	
1282	958	8	8	0	0	-0.0037431	-1.885E-05	-1.81E-06	-680000.04	63932.8093	-80719.936	1282	958	
1282	963	9	9	0	0	-0.0035452	-2.053E-05	-1.581E-06	-680000.04	63932.8093	-80719.936	1282	963	
1288	963	9	9	0	0	-0.0035452	-2.053E-05	-1.581E-06	-760000.05	63932.8093	-90227.129	1288	963	
1288	964	10	10	0	0	-0.0033475	-2.197E-05	-1.326E-06	-760000.05	63932.8093	-90227.129	1288	964	
1293	964	10	10	0	0	-0.0033475	-2.197E-05	-1.326E-06	-840000.05	63932.8093	-99734.322	1293	964	
1293	969	11	11	0	0	-0.0031501	-2.314E-05	-1.044E-06	-840000.05	63932.8093	-99734.322	1293	969	
1296	969	11	11	0	0	-0.0031501	-2.314E-05	-1.044E-06	-920000.05	63932.8093	-109241.51	1296	969	
1296	972	12	12	0	0	-0.002953	-2.401E-05	-7.353E-07	-920000.05	63932.8093	-109241.51	1296	972	

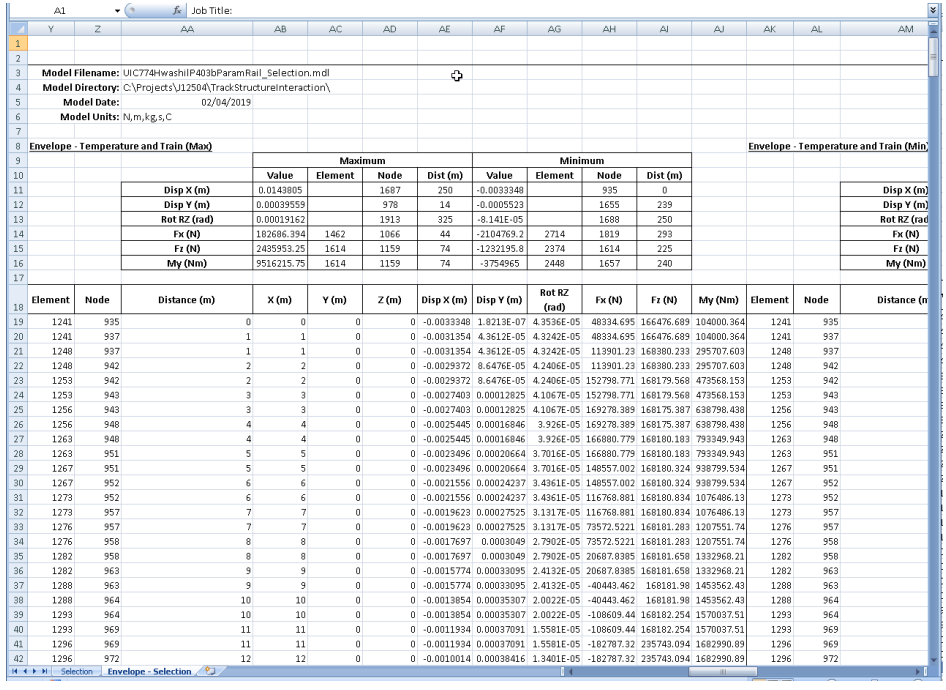
Figure 74: Sample Output from Post-Processing of Selected Lines when the Groups are Missing or Invalid

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 40) 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)**

The following figure illustrates the tabulated enveloped results when selected lines are post-processed if expected model groups are either missing or invalid. No automatic graphing is possible when post-processing with enveloping in Microsoft Excel is carried out on selected lines (since these lines may not be continuous). Should graphs of the results be required then these can either be defined manually within the generated Microsoft Excel spreadsheet or the data can be copied and pasted from the spreadsheet.



Model Filename: UIC774HwashilP403bParamRail_Selection.mdl
Model Directory: C:\Projects\J12504\TrackStructureInteraction\
Model Date: 02/04/2019
Model Units: N,m,kg,s,C

Envelope - Temperature and Train (Max)

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

Envelope - Temperature and Train (Min)

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

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

Figure 75: Sample Output from Post-Processing of Envelopes for Selected Lines when the Groups are Missing or Invalid

Limitations of Use

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

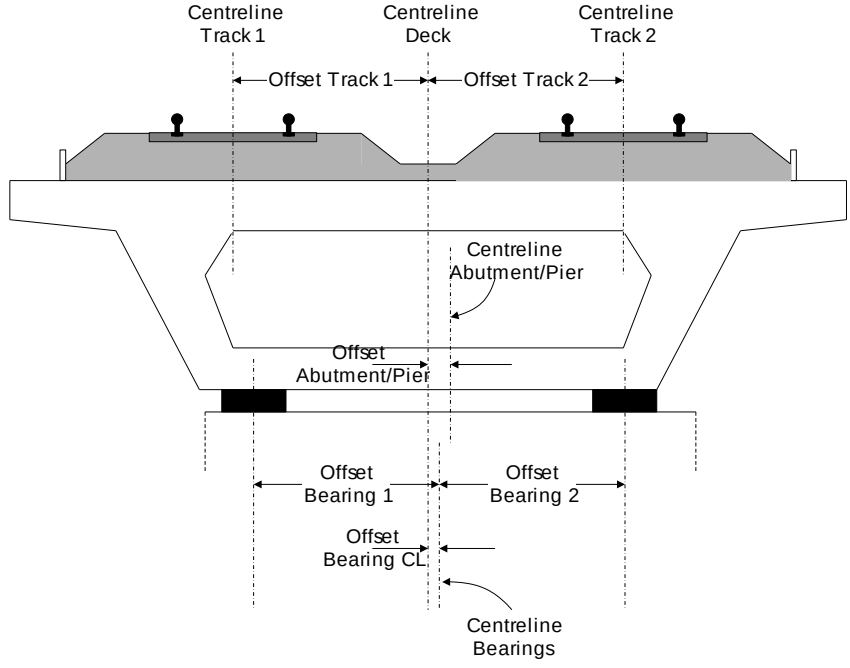


Figure 76: Offsets of Tracks/Bearings/Piers from Centreline Of Deck

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.

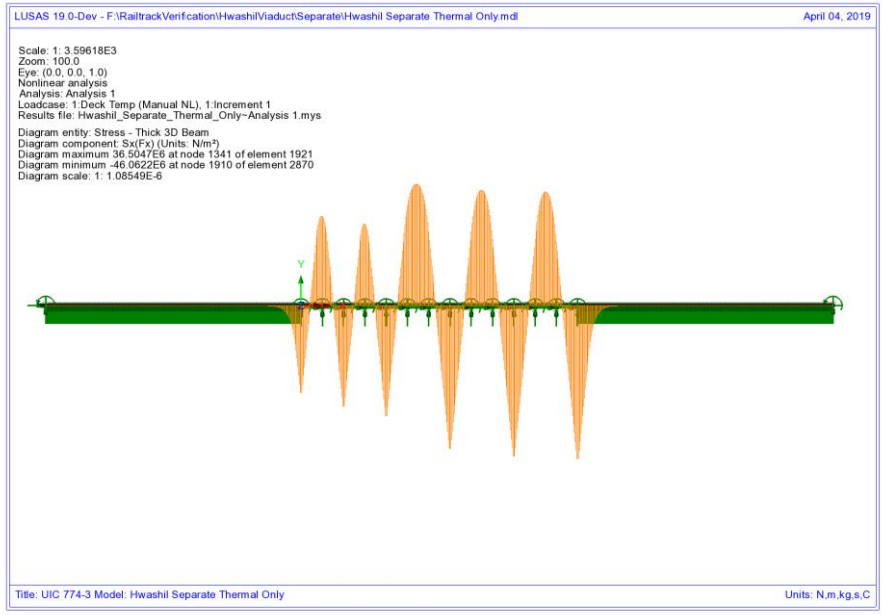


Figure 77: Axial Stress In Rails Due To Thermal Effects Only

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

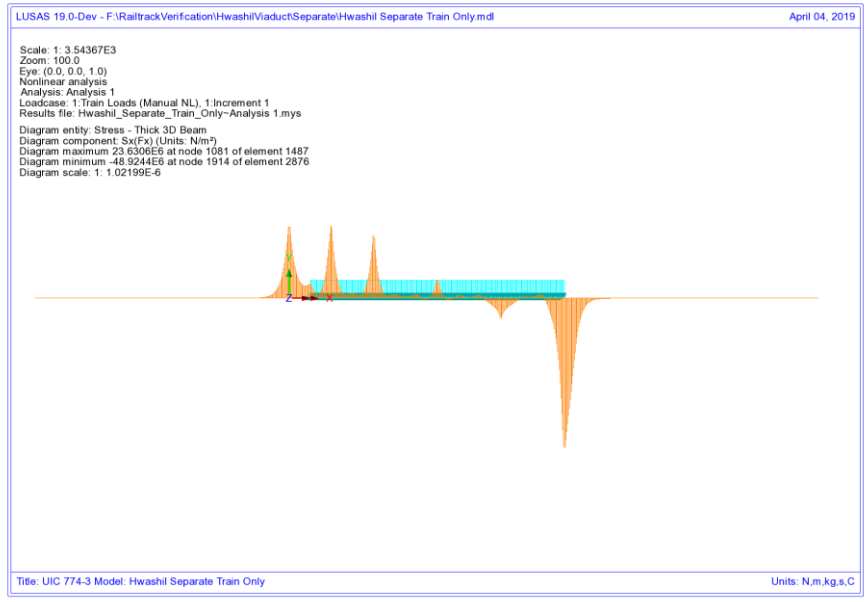


Figure 78: Axial Stress In Rails Due To Braking Train Loads On Track 1

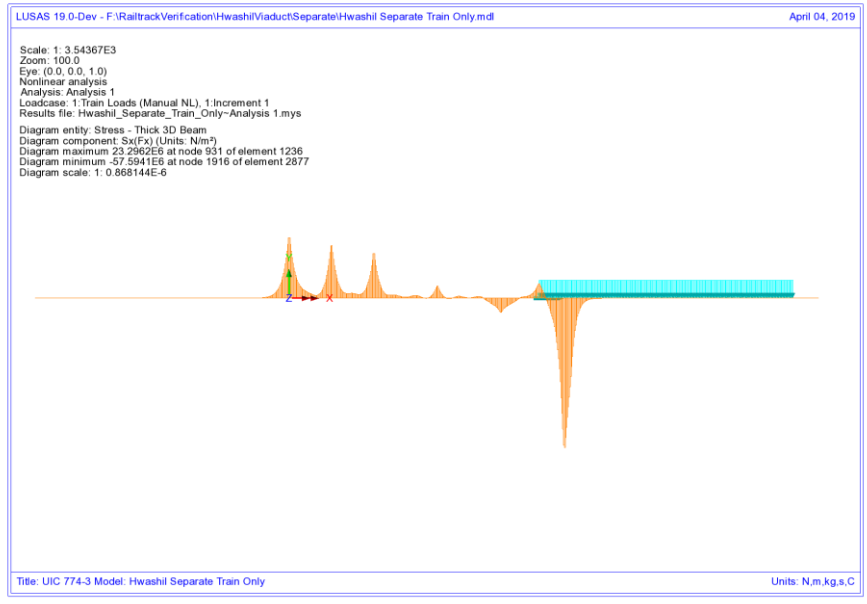


Figure 79: Axial Stress In Rails Due To AcceleratingTrain Loads On Track 2

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

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

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

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

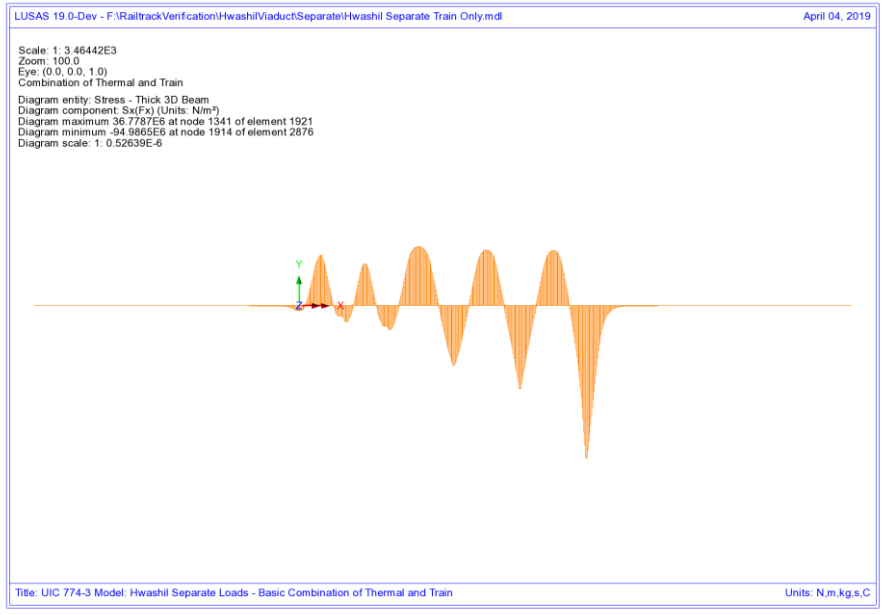


Figure 80: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 1

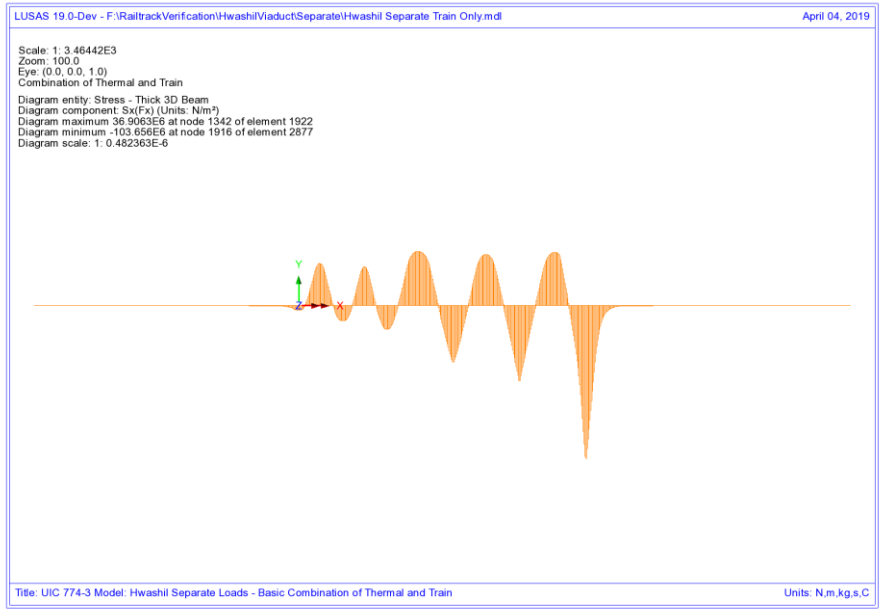


Figure 81: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 2

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 83, 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^{nd} pier from left abutment) the axial stress in the rail over the end of the first deck is equal to a tensile stress of 23.63 N/mm^2 while the axial stress over the start of the second deck is equal to a tensile stress of 22.47 N/mm^2. Like for like comparison of the elements a certain distance from the pier for each deck shows that the second deck is consistently lower and this difference has caused the non-symmetric nature of the combined axial rail stress diagram over the deck transition piers when the axial rail stresses from the train loading are combined with the axial rail stresses from the thermal loading.

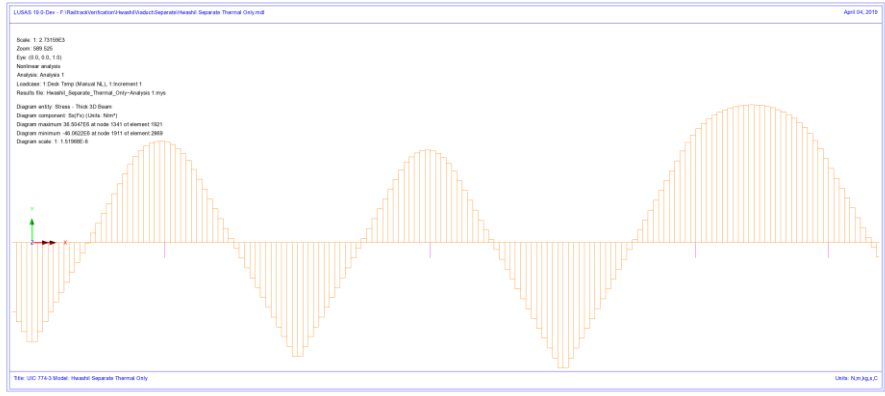


Figure 82: Zoomed Axial Stress In Rails Due To Thermal Effects Only

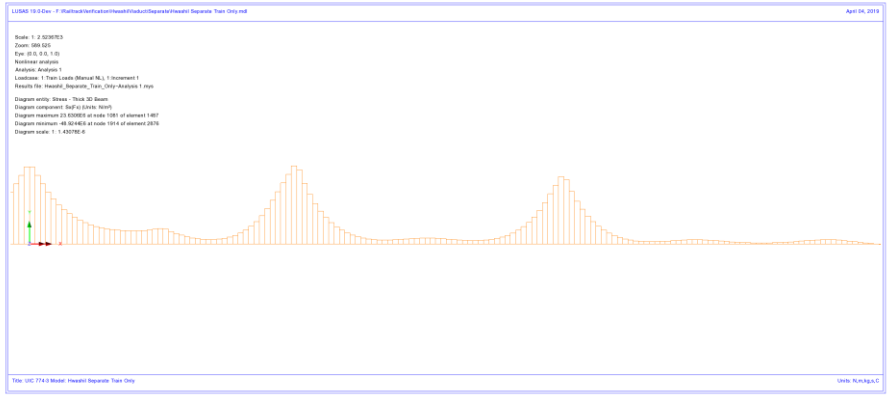


Figure 83: Zoomed Axial Stress In Rails Due To Braking Train Loads On Track 1

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 84, 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.

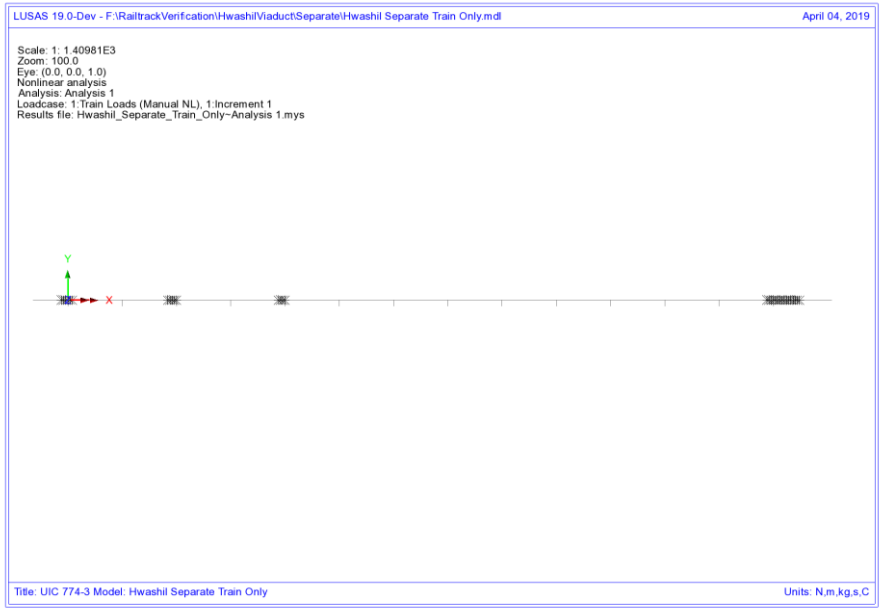


Figure 84: Yield In Track/Bridge Interaction Due To Train Braking Load On Track 1

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.

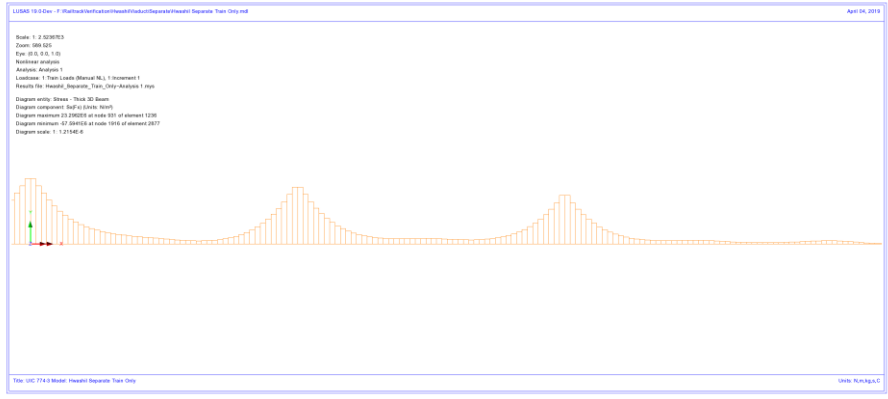


Figure 85: Zoomed Axial Force In Rails Due To Accelerating Train Loads On Track 2

Looking again at the yielding, Figure 86, 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.

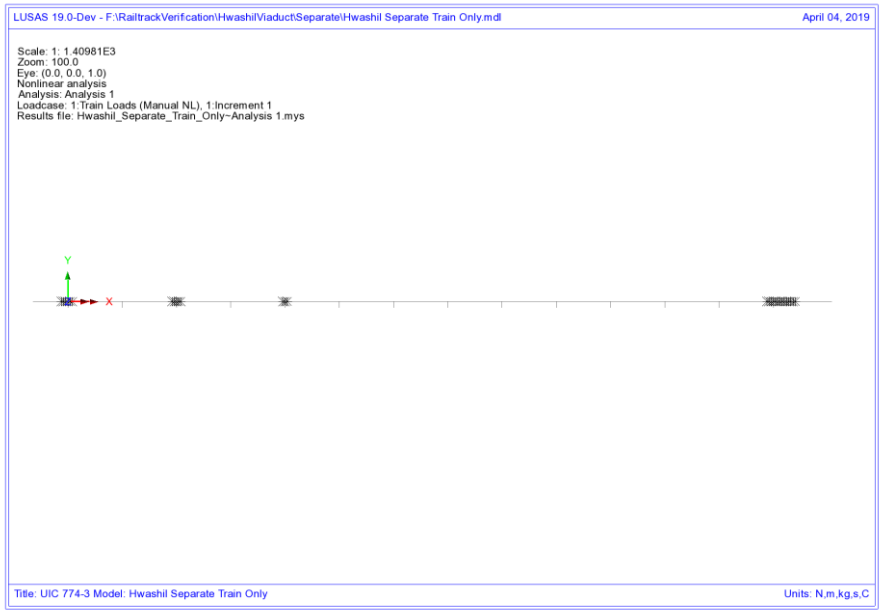


Figure 86: Yield In Track/Bridge Interaction Due To Train Acceleration Load On Track 2

Analysis of Combined Thermal and Rail Loading (One Step)

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

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

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

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

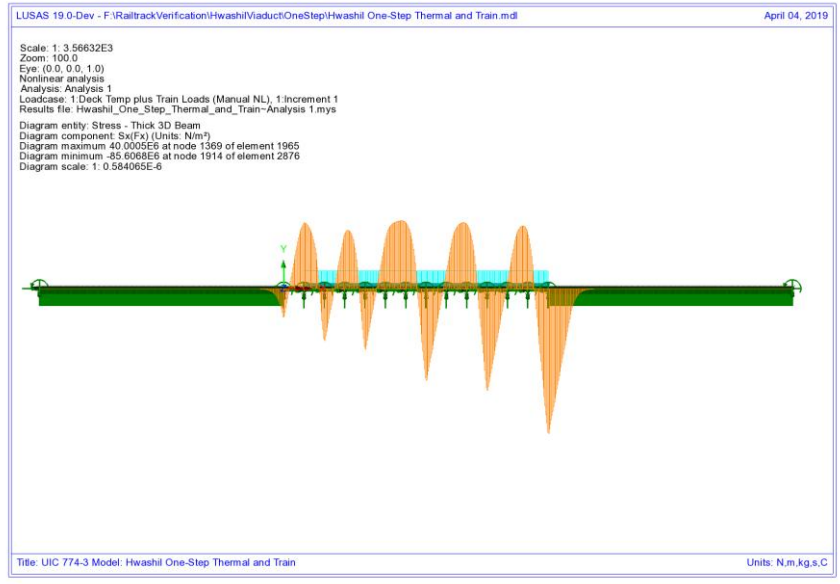


Figure 87: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 1 (One Step)

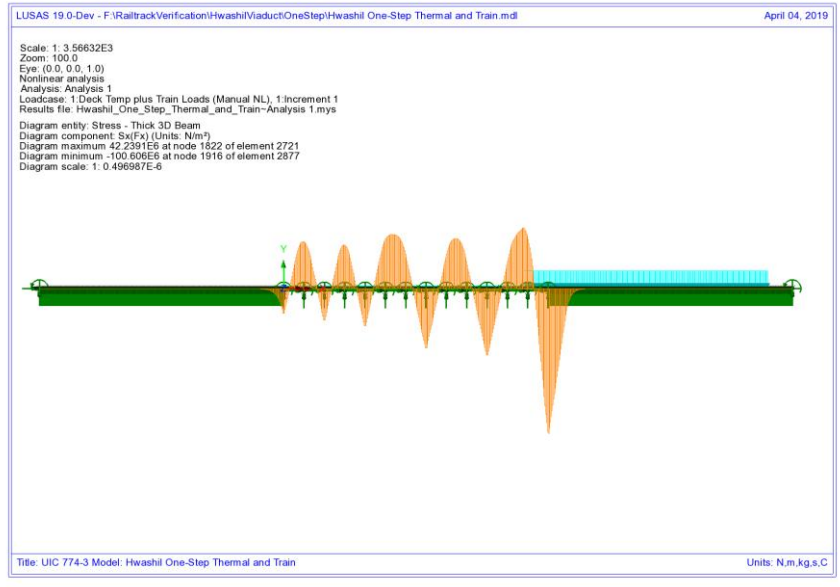


Figure 88: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 2 (One Step)

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

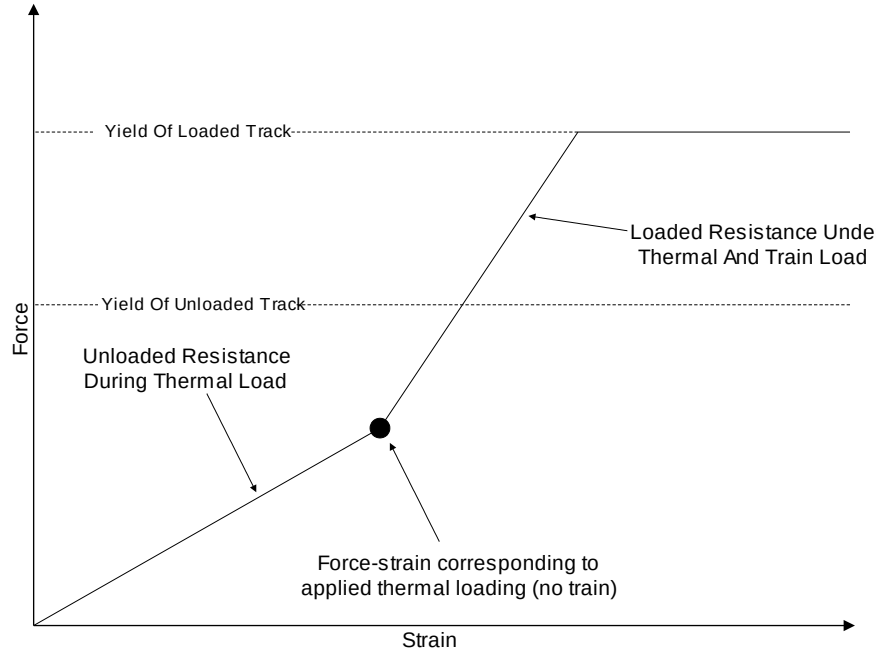


Figure 89: Representation of Transition From Unloaded To Loaded In LUSAS

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

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

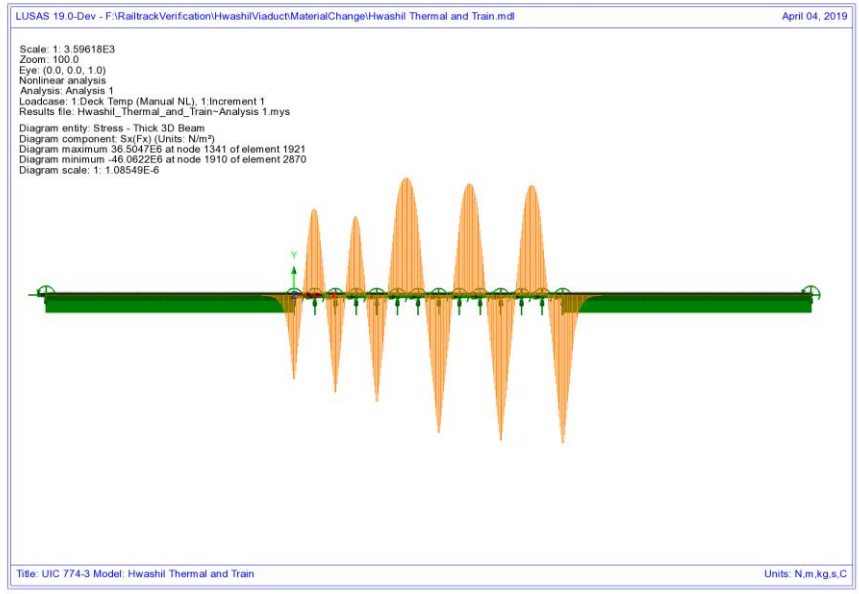


Figure 90: Axial Stress In Rails Due To Thermal Only

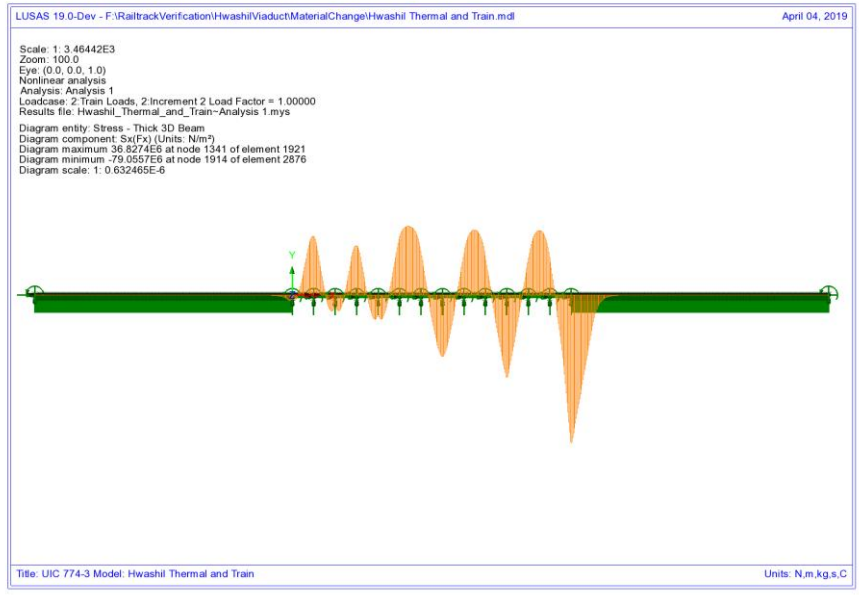


Figure 91: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 1

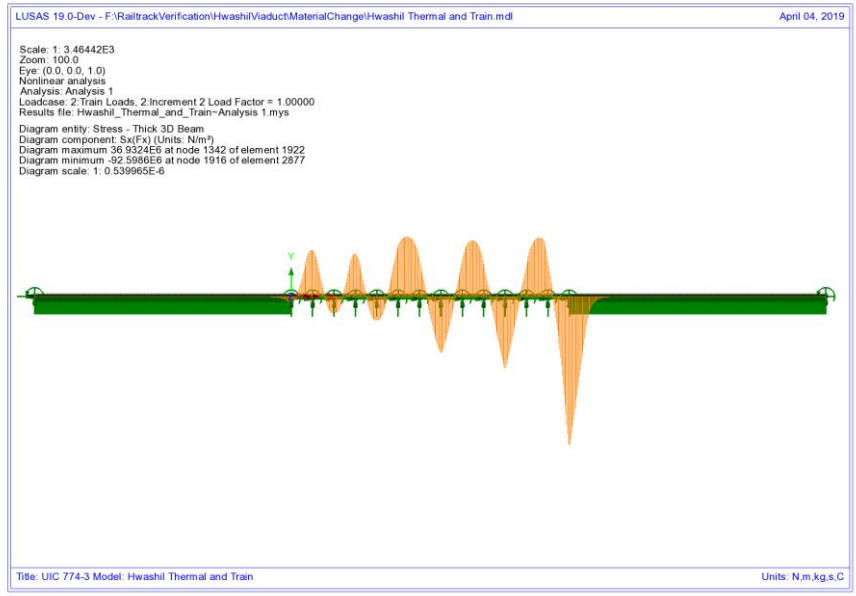


Figure 92: Axial Stress In Rails Due To Combined Thermal And Train Loads In Track 2

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 96) and the concurrent thermal/train loading analysis (Figure 95) shows that the amount of yielding of the interaction joints (ballast) at the right-hand abutment is similar but the yielding diminishes away from the accelerating locomotive at the front of the train which has only just entered the structure at the right-hand abutment in the LUSAS analysis whereas in the concurrent

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

Looking now at the separate analysis, the yield layout for the concurrent thermal/train analysis is comparable to the yield layout for the thermal effects alone (Figure 93). In the separate train loading analysis very little yielding is indicated as being associated with the accelerating train loading analysis (Figure 94). 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.

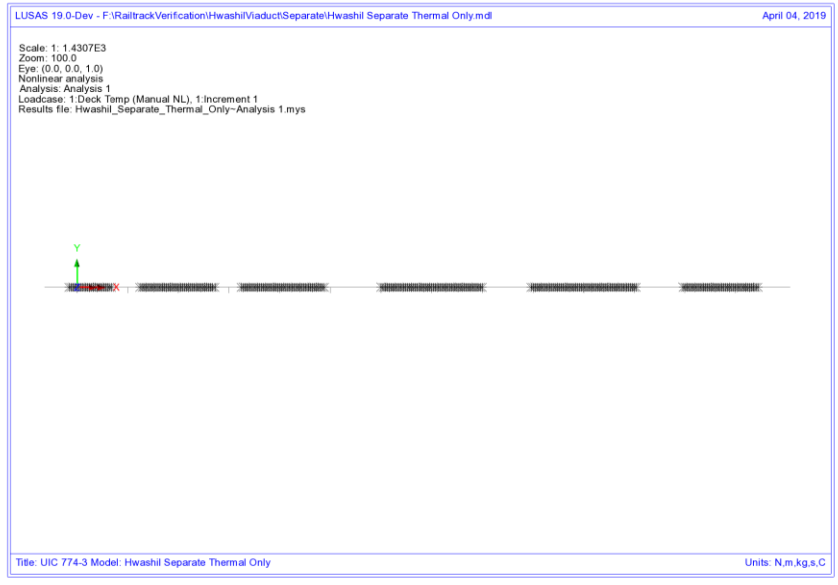


Figure 93: Track/Rail 2 Yield Due To Thermal Load On Track Alone

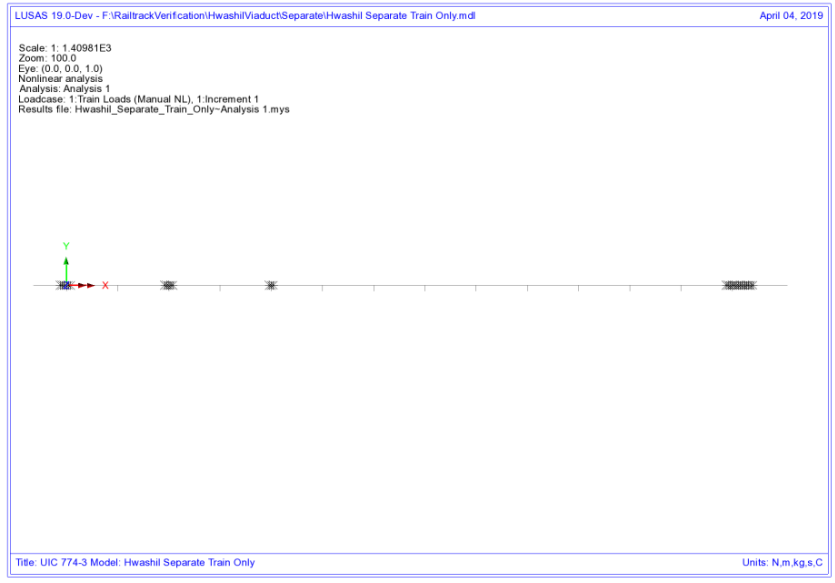


Figure 94: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 – Separate Analysis

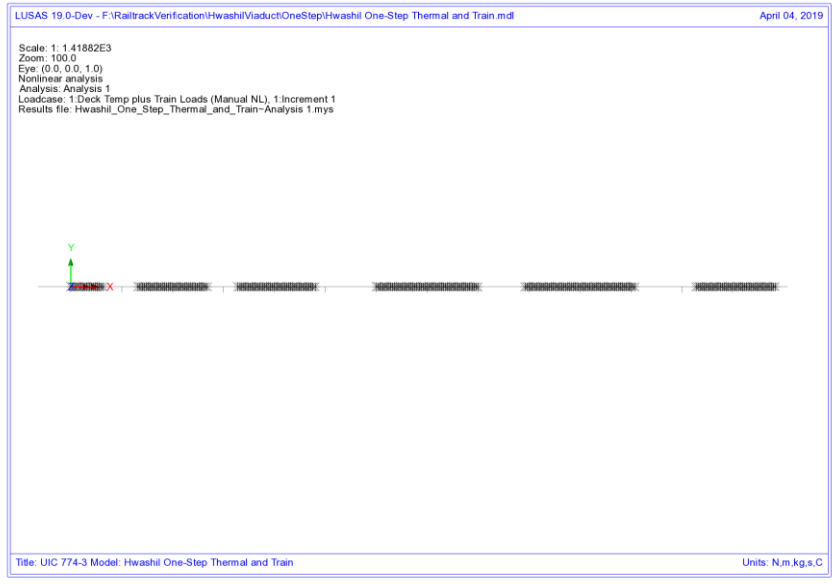


Figure 95: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 - Thermal And Rail Applied Concurrently

Figure 96: 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 97, 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.

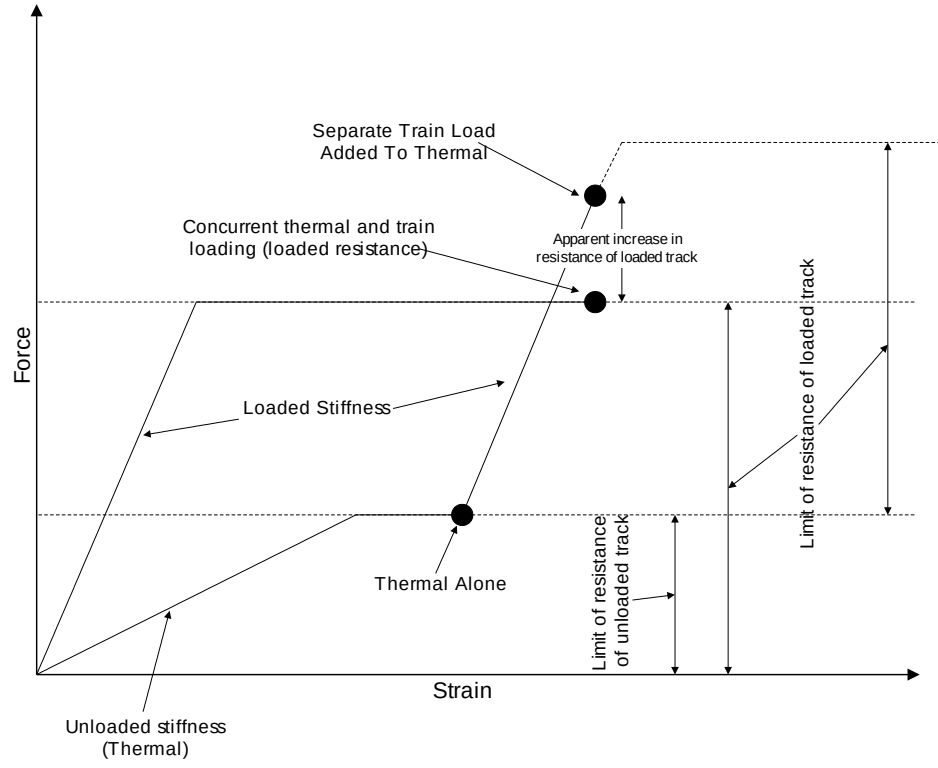


Figure 97: Illustration Of Behaviour Of Separate Analysis Vs. Concurrent Thermal And Rail Loading

Similar comparisons can be made between the separate analysis and the LUSAS analysis - Figure 98. While both of these effectively use the 'Thermal Alone' location as an origin for the loaded resistance curve, the key difference between the two approaches is that the LUSAS analysis enforces the track resistance at which plasticity occurs instead of allowing the potential for an apparent increase in the track resistance equal up to the unloaded plus the loaded track resistance.

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

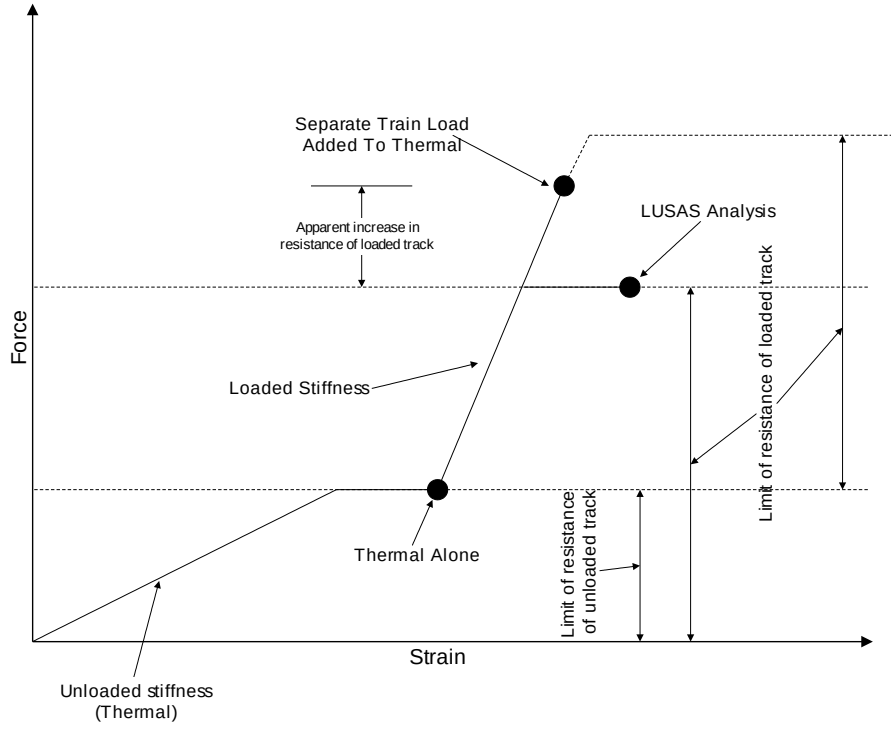


Figure 98: Illustration Of Behaviour Of Separate Analysis Vs. LUSAS Analysis

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 99) shows close similarity to the yielding observed when the thermal and train loading are applied concurrently (Figure 101) – minimal yielding is observed under the action of the train load alone in the separate analysis (Figure 100).

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 100 and Figure 102 where the

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

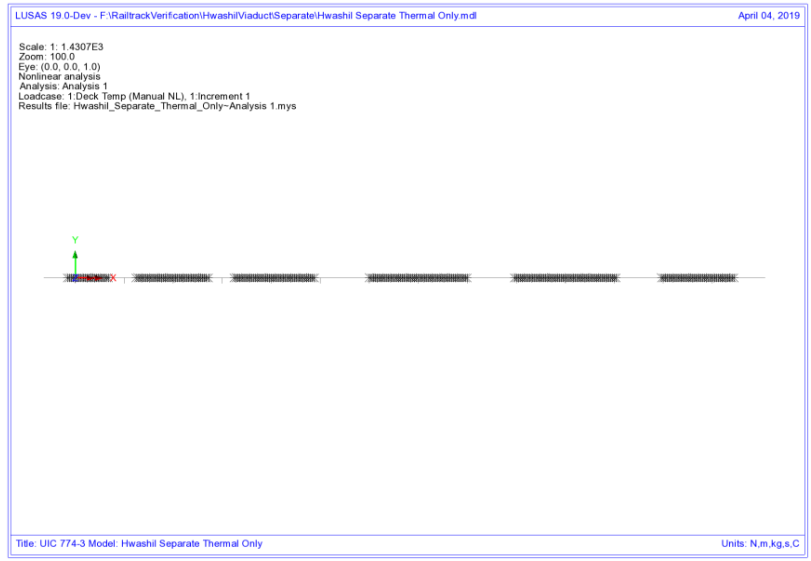


Figure 99: Track/Rail 1 Yield Due To Thermal Load On Track Alone

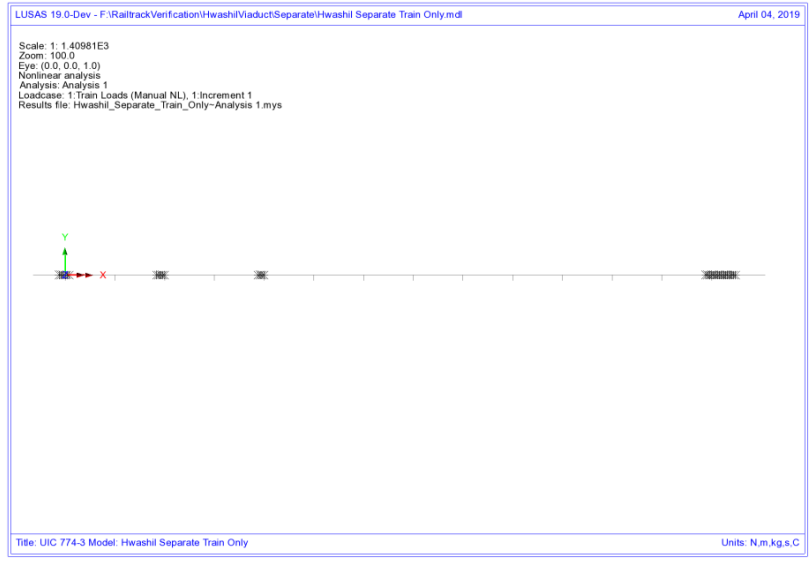


Figure 100: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 – Separate Analysis

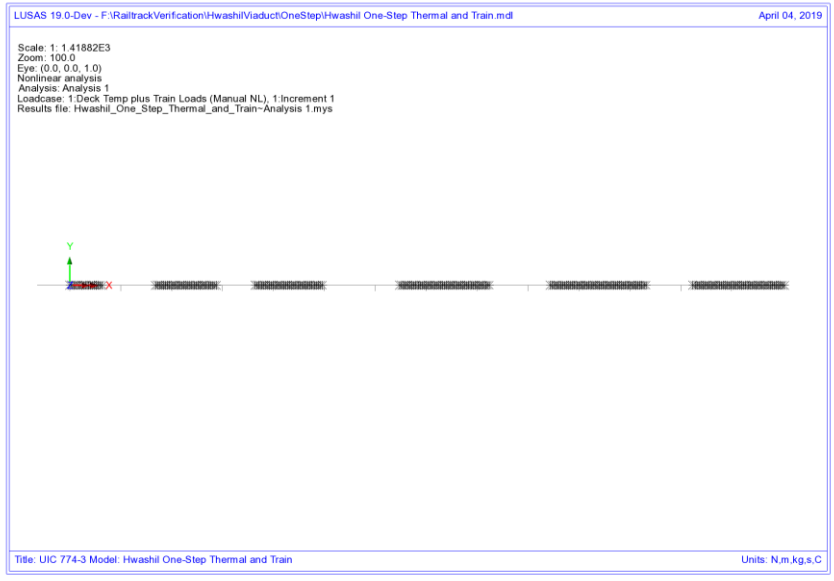


Figure 101: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 - Thermal And Rail Applied Concurrently

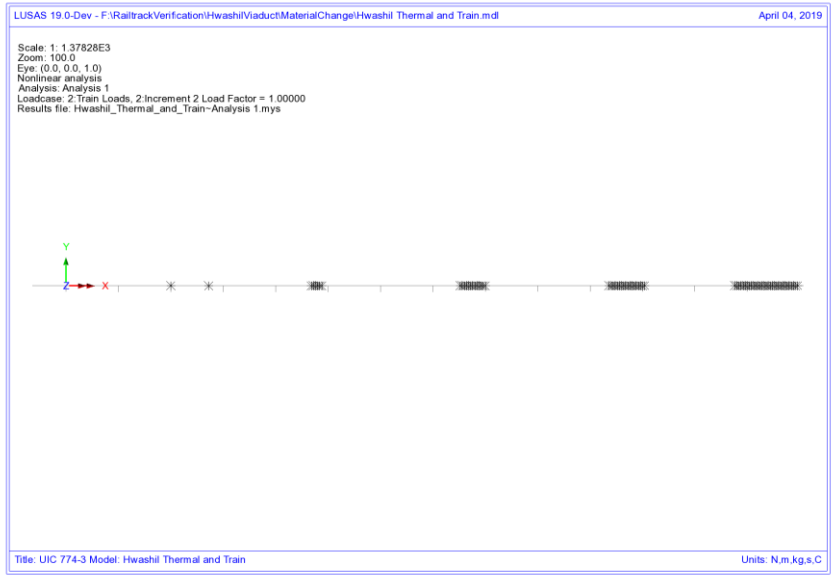


Figure 102: Track/Rail 1 Yield Due To Braking Train Load On Track 1 - LUSAS Combined Analysis

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 103 and Figure 104 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 105.

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.

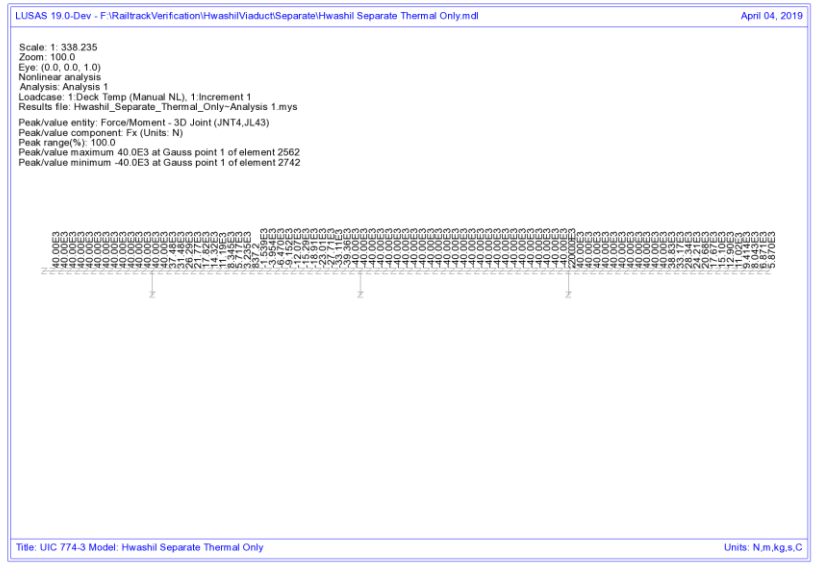


Figure 103: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 – Separate Thermal Loading (N/m length)

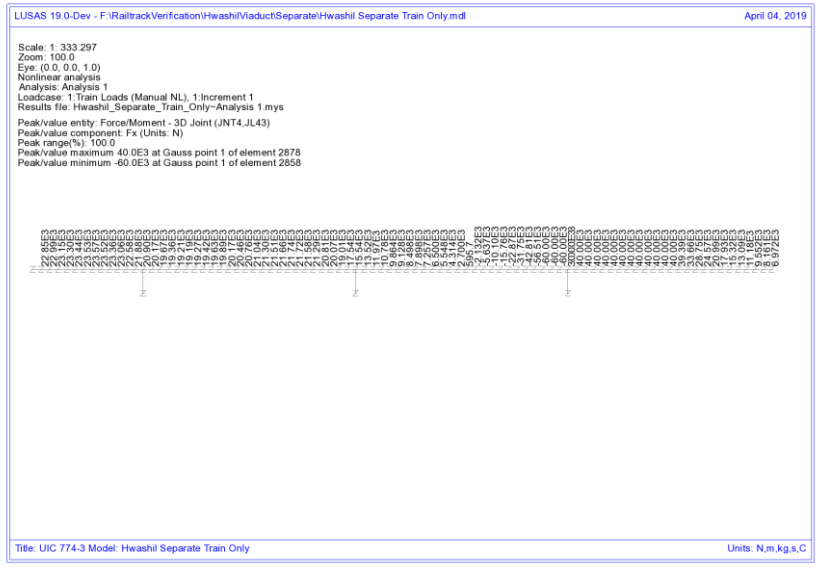


Figure 104: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 - Separate Train Loading (N/m length)

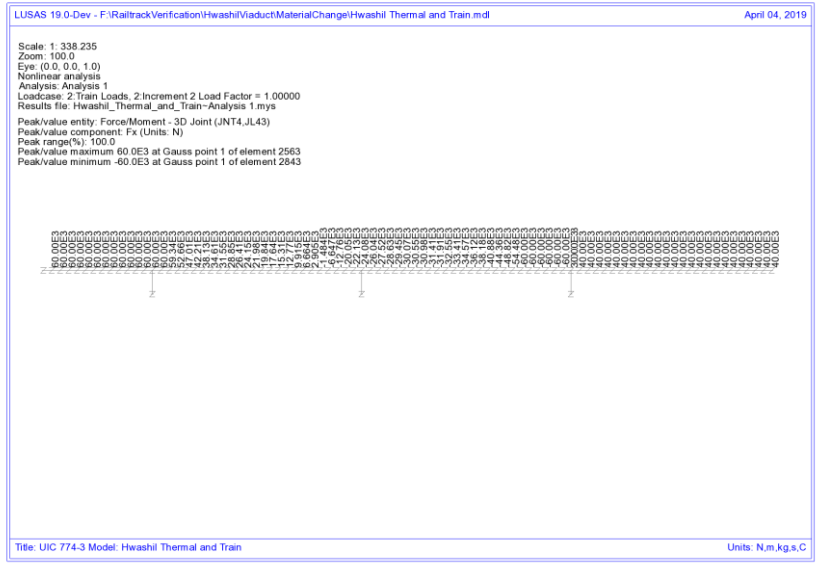


Figure 105: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 – LUSAS Nonlinear (N/m length)

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

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

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

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

Separate Analyses

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

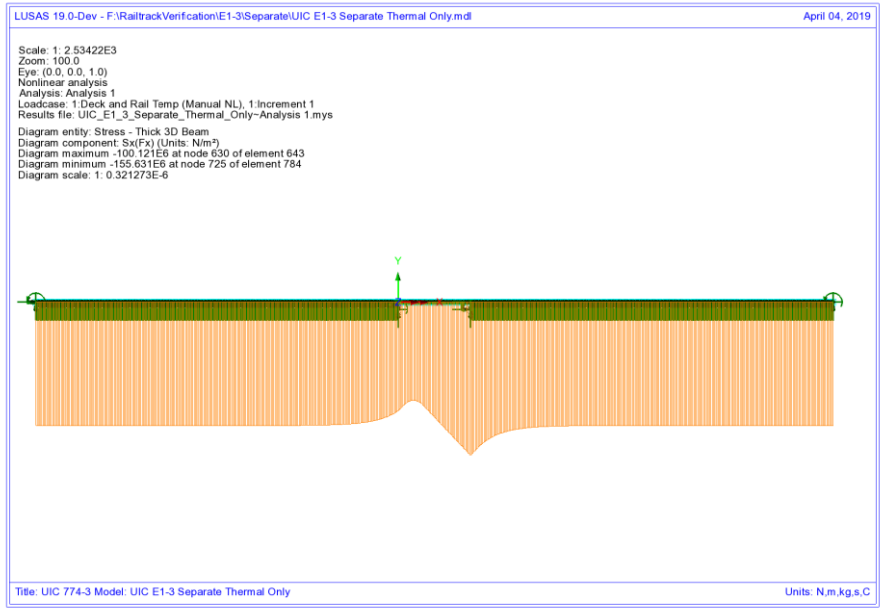


Figure 106: Axial Stress In Rails Due To Temperature In Bridge And Rail

To determine the worst location of the train load for compressive rail stresses the bridge has been analysed with the rail loading at 31 separate locations (starting from the left abutment of the bridge and finishing 90m from the right abutment of the bridge – train moving from left to right) and these results enveloped. The results of this

analysis are presented in the following figure which give a peak compressive rail stress of 40.64 N/mm^2.

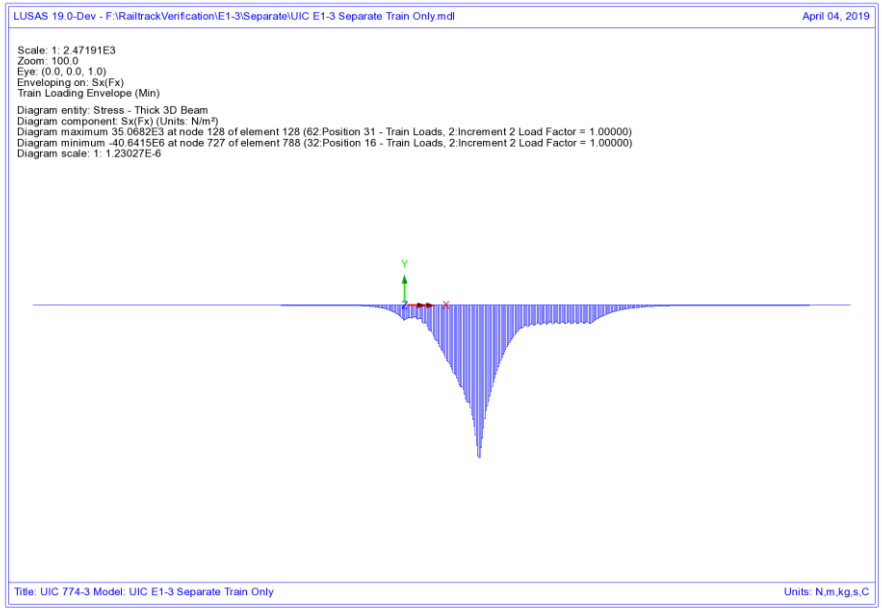


Figure 107: Envelope Of Axial Stress In Rails Due To Rail Loading

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

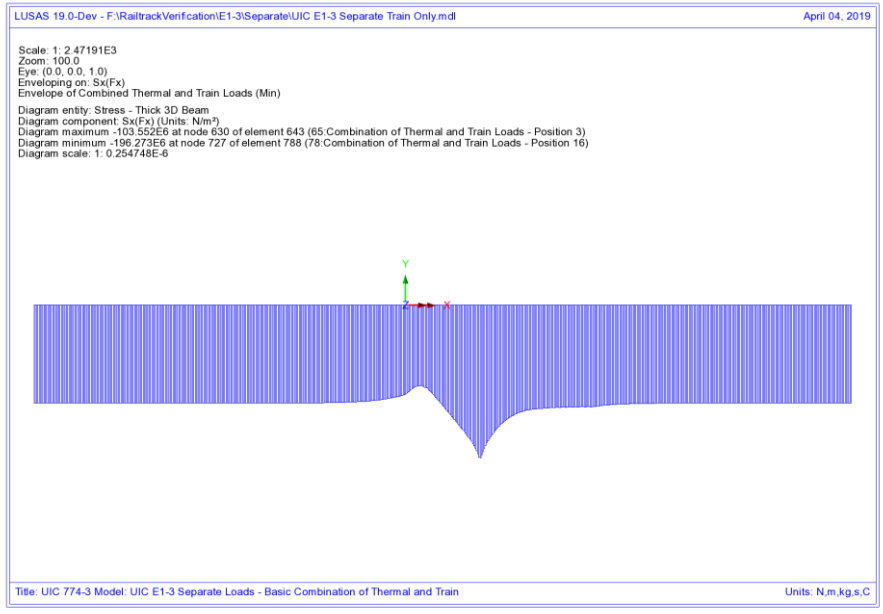


Figure 108: Axial Stress In Rails Due To Combined Temperature And Rail Loading

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

LUSAS Nonlinear Analysis

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

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

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

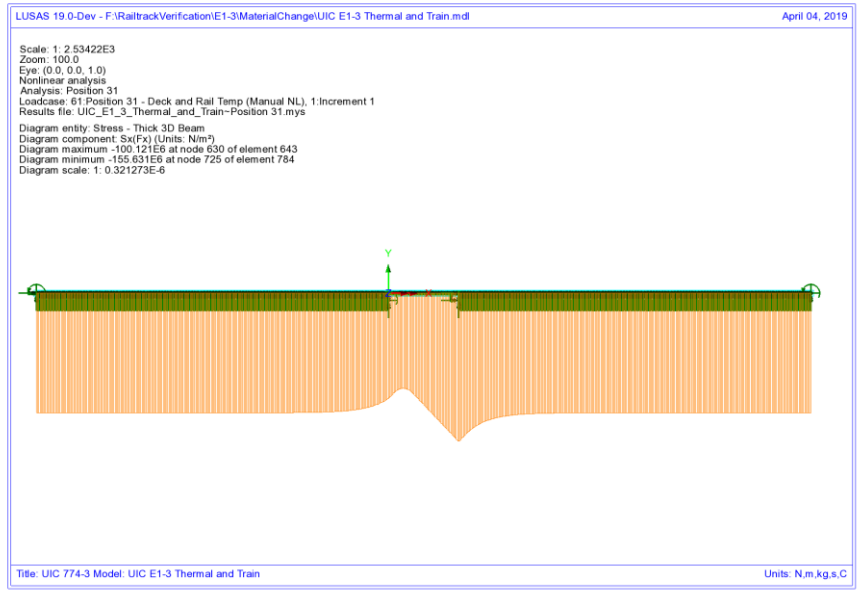


Figure 109: Axial Stress In Rails Due To Temperature In Bridge And Rail

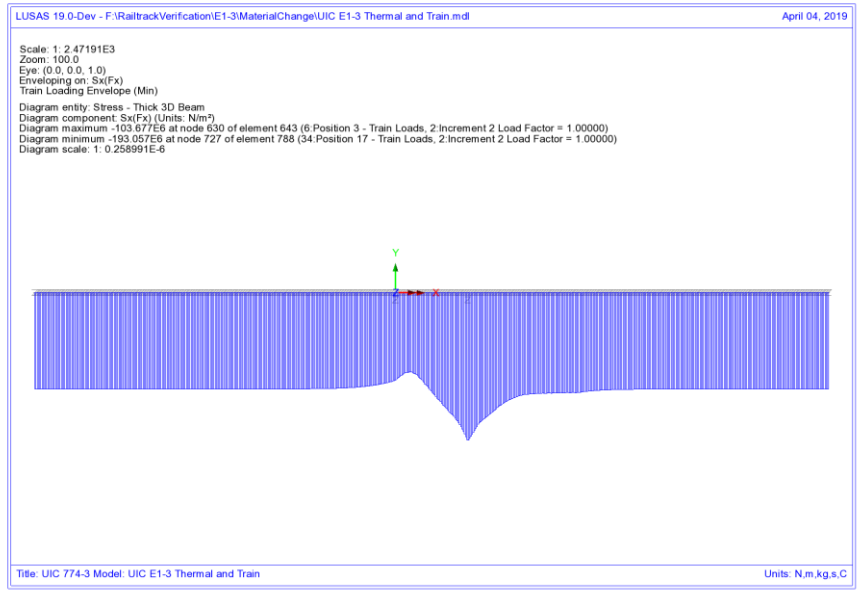


Figure 110: Axial Stress In Rails Due To Combined Temperature And Enveloped Rail Loading

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 111. 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 112 and Figure 113. 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.

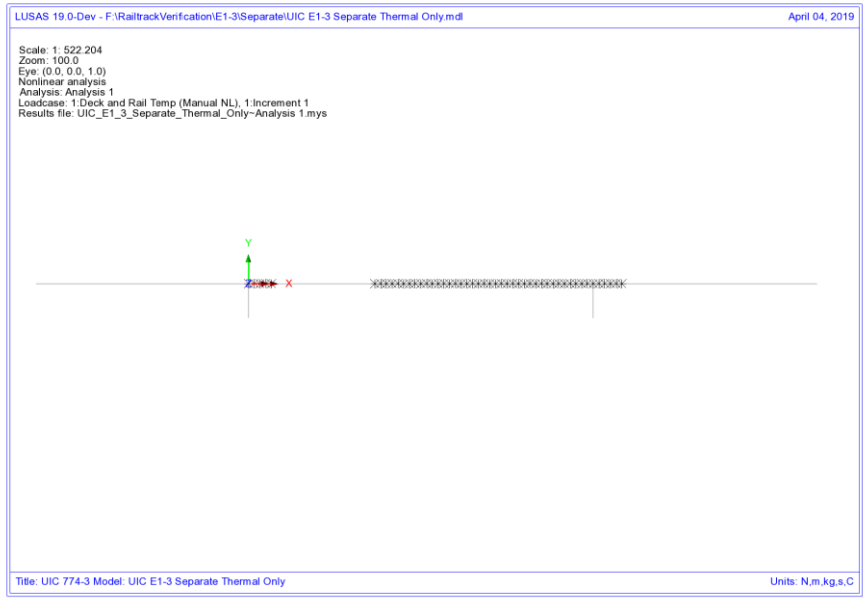


Figure 111: Yield Layout For Thermal Loading Only

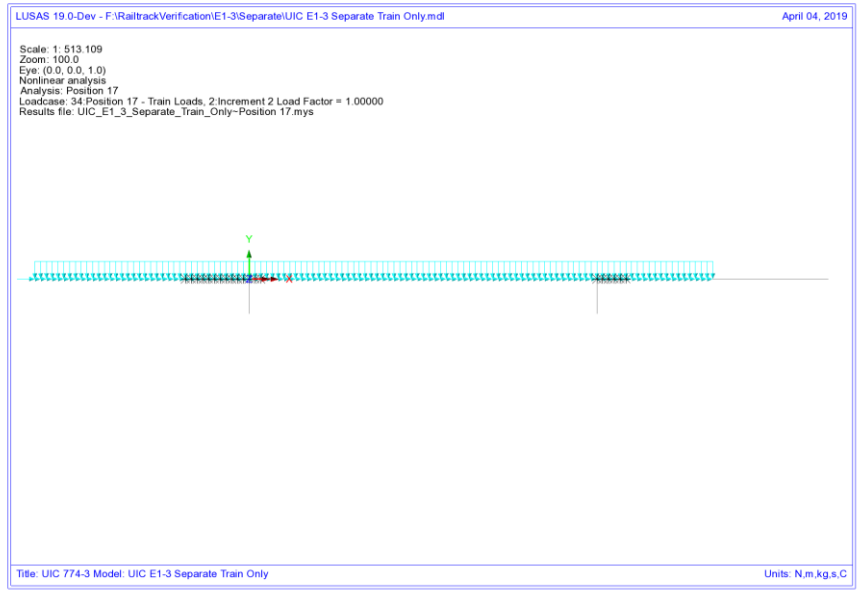


Figure 112: Yield Layout For Train Loading Only From Separate Analysis

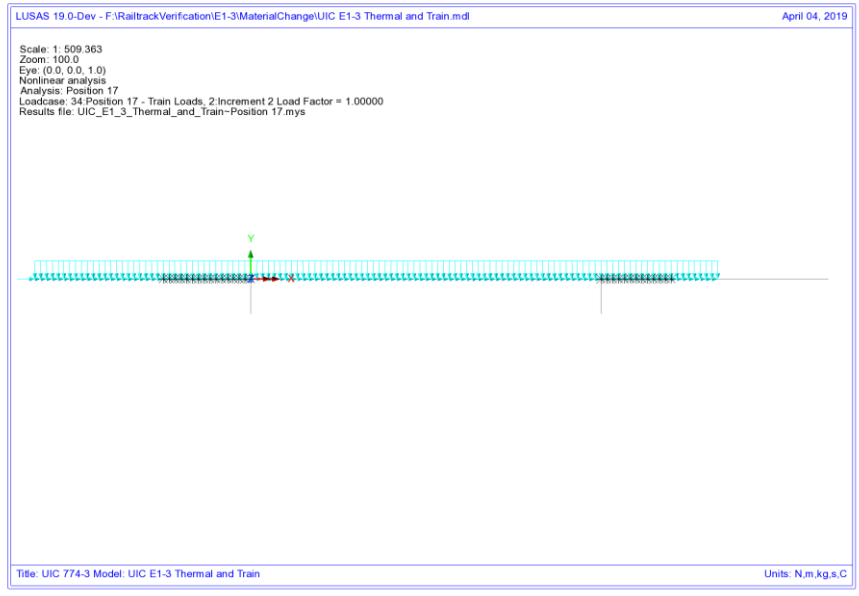
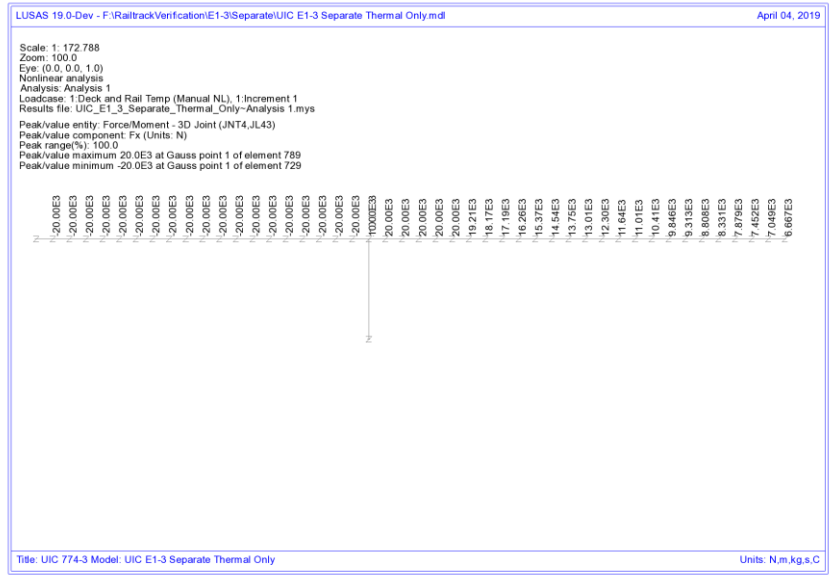


Figure 113: Yield Layout For Combined Thermal And Train Loading From LUSAS Nonlinear Analysis

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 116. 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 117.

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.


LUSAS 19.0-Dev - F:\RailtrackVerification\E1-3\Separate\UIC E1-3 Separate Thermal Only.mdl
April 04, 2019
Scale: 1: 172.788
Zoom: 100.0
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 1:Deck and Rail Temp (Manual NL), 1:Increment 1
Results file: UIC_E1_3_Separate_Thermal_Only~Analysis 1.mys
Peak/value entity: Force/Moment - 3D Joint (JNT4,JL43)
Peak/value component: Fx (Units: N)
Peak range(%): 100.0
Peak/value maximum 20.0E3 at Gauss point 1 of element 789
Peak/value minimum -20.0E3 at Gauss point 1 of element 729
-20.00E3
-20.00E3
-20.00E3

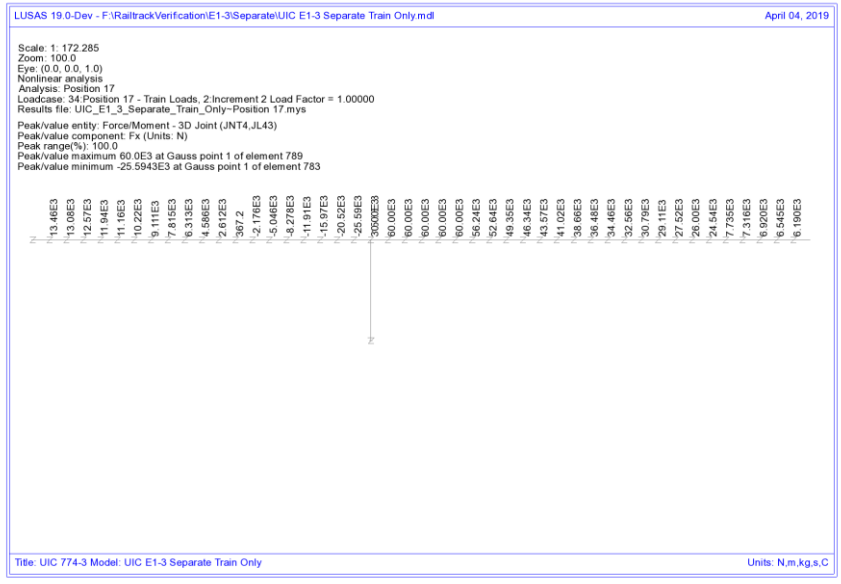


Figure 115: Force Per Metre Length In Interaction From Train Loading - Separate Analysis

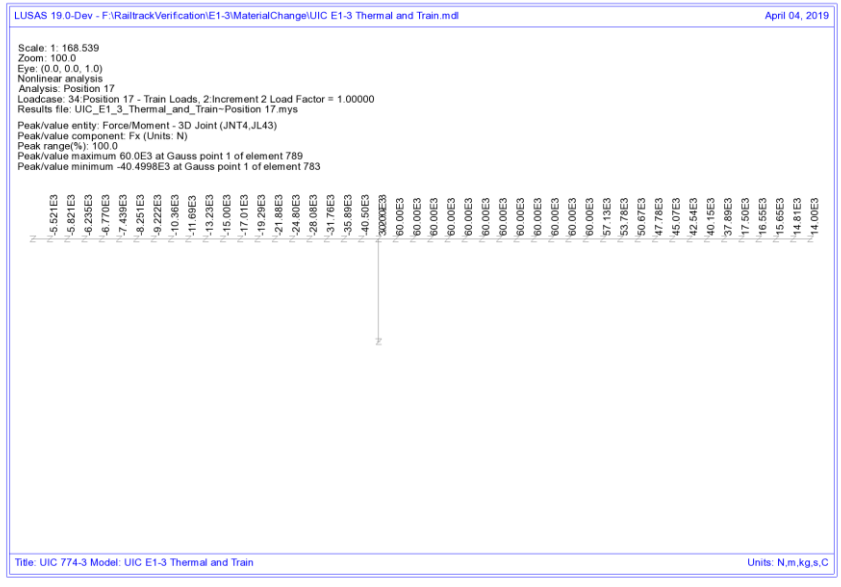


Figure 116: Force Per Metre Length In Interaction From Combined Loading - LUSAS Analysis

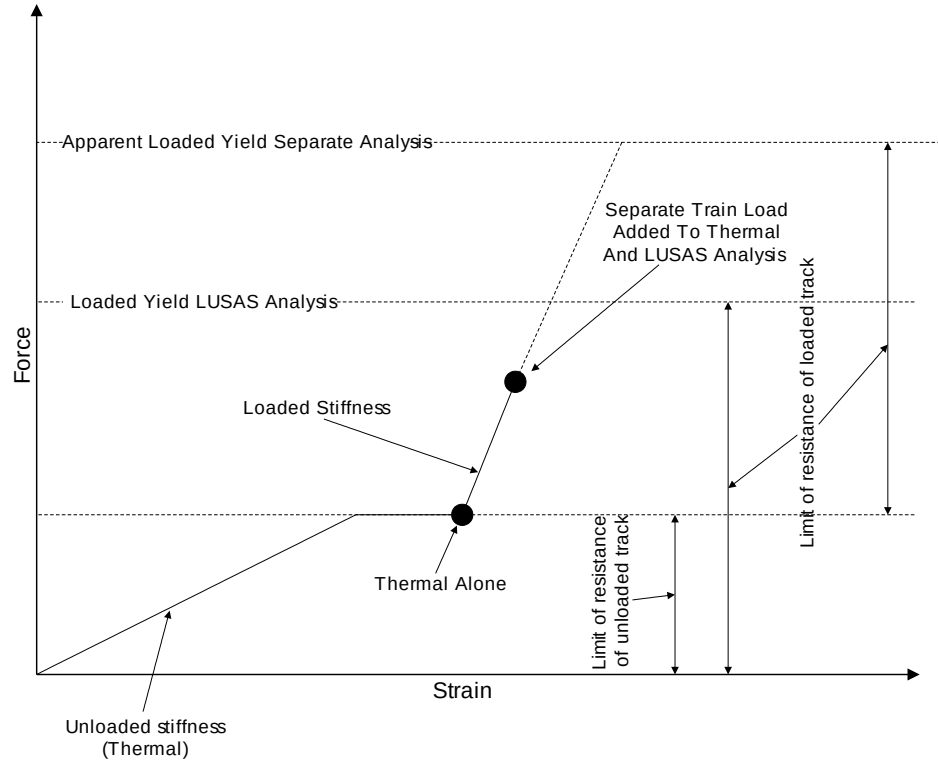


Figure 117: Illustration Of Behvaiour For UIC774-3 Standard Test E1-3 For Separate And LUSAS Analyses

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

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

Separate Analyses

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

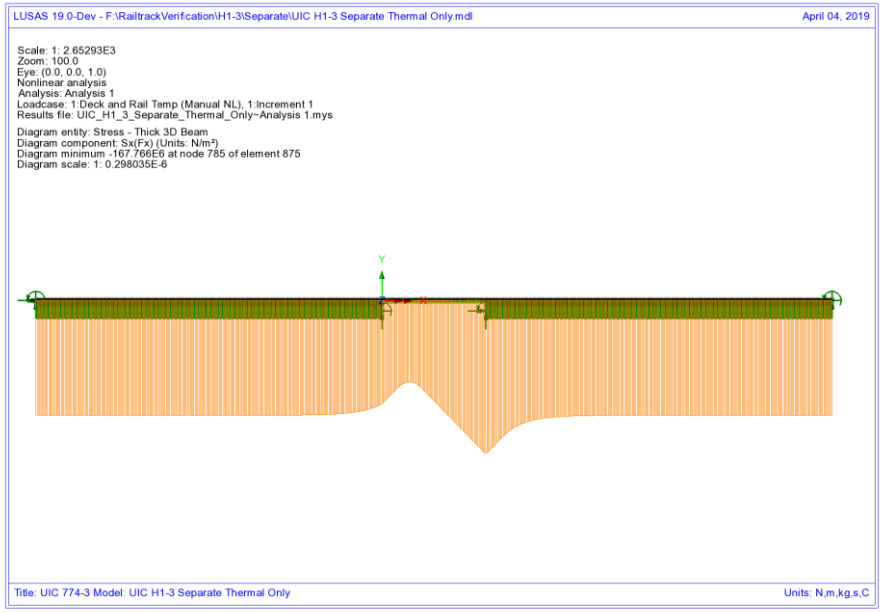


Figure 118: Axial Stress In Rails Due To Temperature In Bridge And Rail

To determine the worst location of the train load for compressive rail stresses the bridge has been analysed with the rail loading at 37 separate locations (starting from the left abutment of the bridge and finishing 90m from the right abutment of the bridge – train moving from left to right) and these results enveloped. The results of this analysis are presented in the following figure which give a peak compressive rail stress of 29.09 N/mm^2.

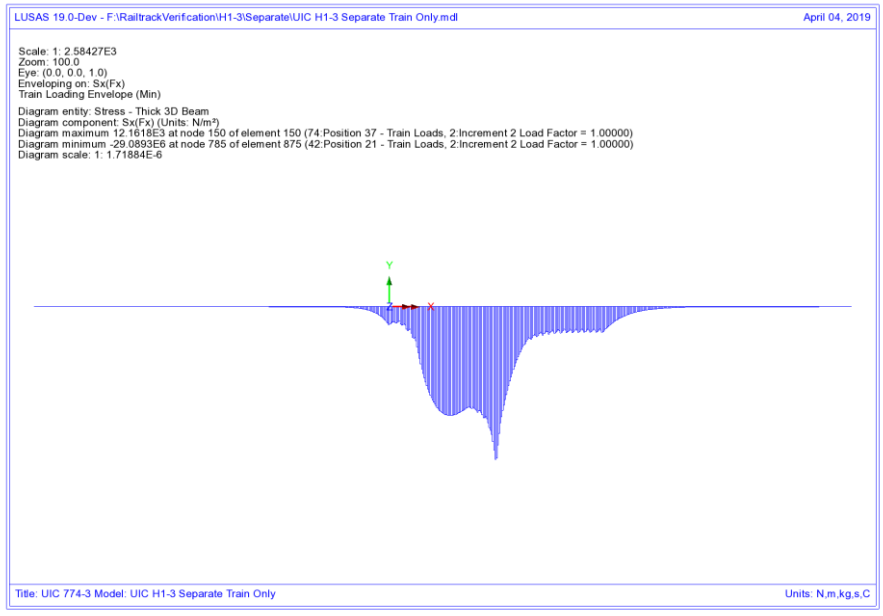


Figure 119: Envelope Of Axial Stress In Rails Due To Rail Loading

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

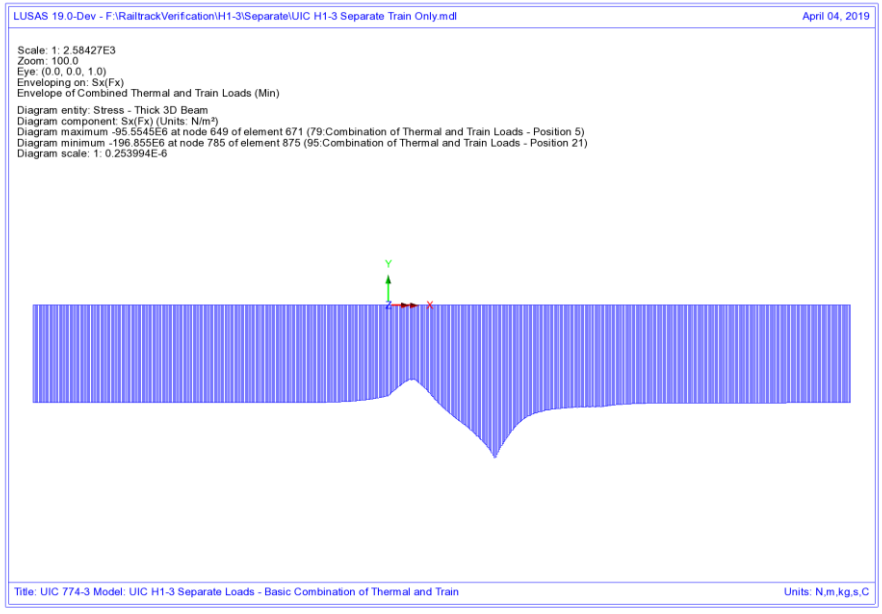


Figure 120: Axial Stress In Rails Due To Combined Temperature And Rail Loading

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

LUSAS Nonlinear Analysis

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

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

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

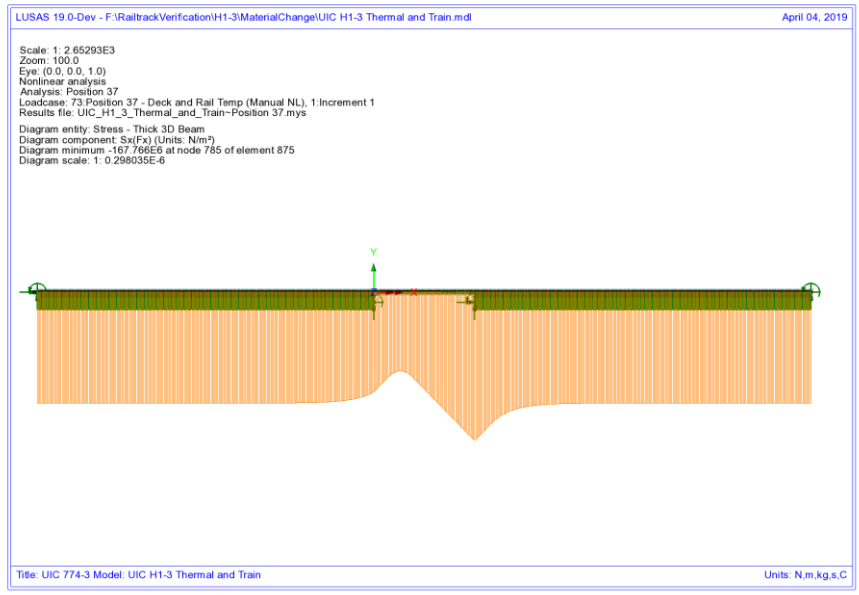


Figure 121: Axial Stress In Rails Due To Temperature In Bridge And Rail

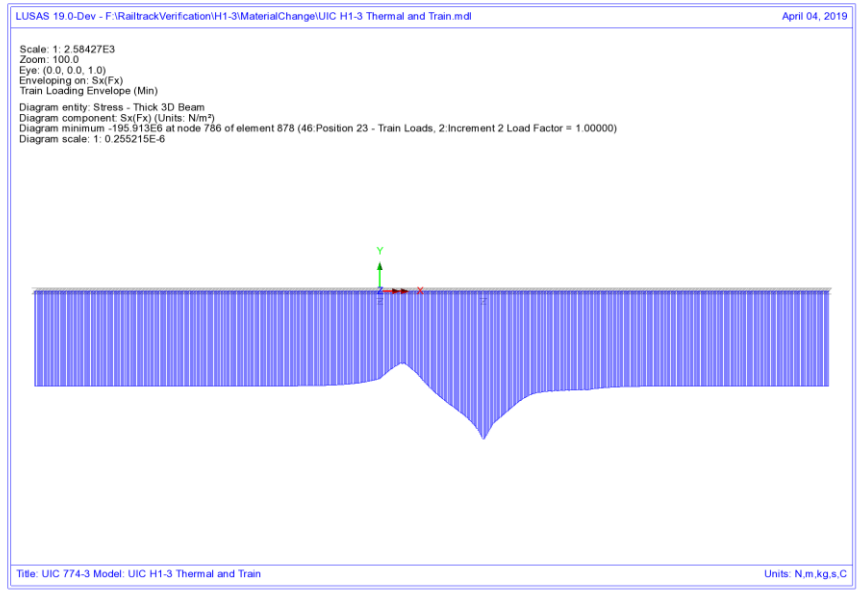


Figure 122: Axial Stress In Rails Due To Combined Temperature And Enveloped Rail Loading

Discussion

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

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

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

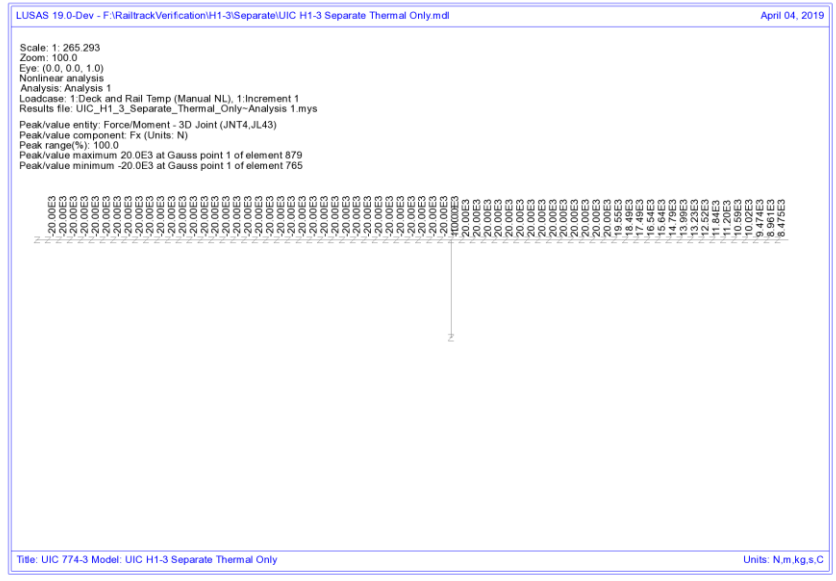


Figure 123: Force Per Metre Length In Interaction From Thermal Loading - Separate Analysis

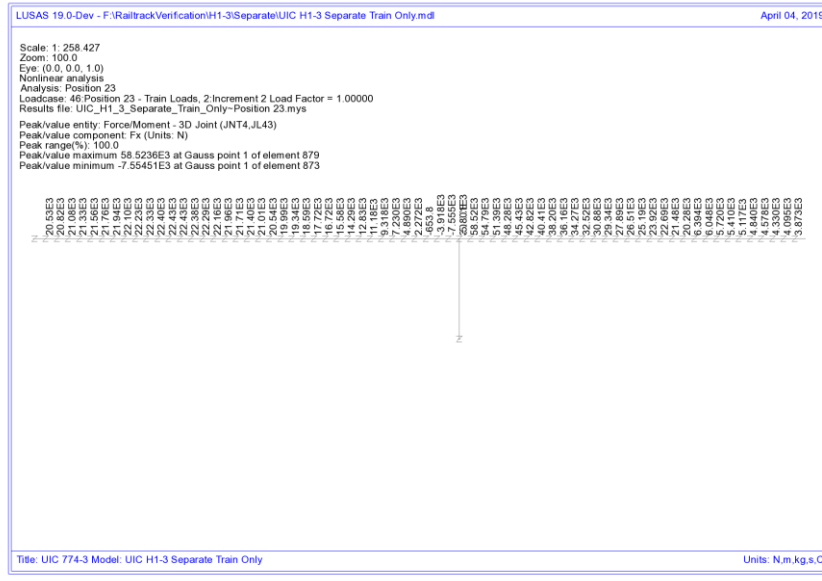


Figure 124: Force Per Metre Length In Interaction From Train Loading - Separate Analysis

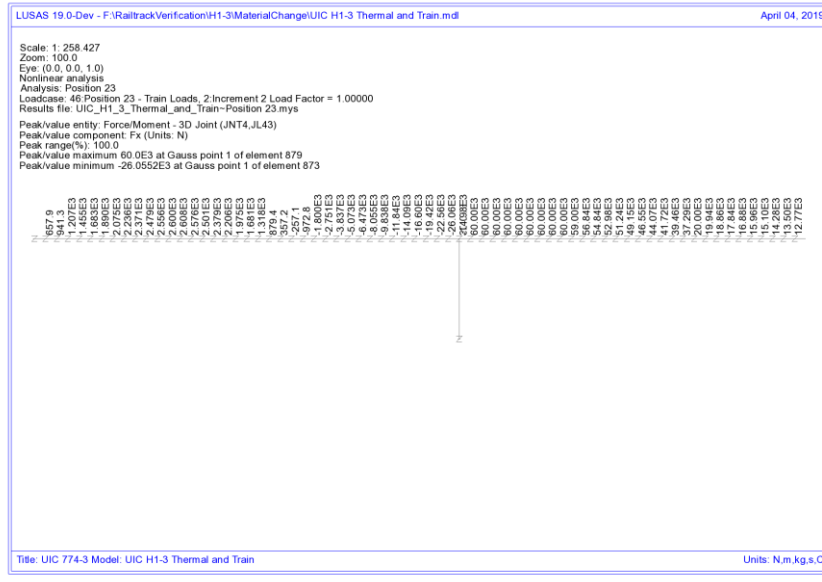


Figure 125: Force Per Metre Length In Interaction From Combined Loading - LUSAS Analysis

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 97 and Figure 98, the key issue with the separate analysis approach is the ability for the track resistance to be overestimated by the combination of the two nonlinear analyses and potentially cause the rail stresses to be overestimated. In the concurrent loading and LUSAS rail option analyses the limit of track resistance is correctly modelled as the value determined from the loaded bilinear curve and therefore this potentially leads to reduced rail stresses observed in the analyses. As the initial movement under pure thermal loading in the concurrent analysis uses the loaded track resistance this will give different results to the LUSAS rail option analysis. Referring back to the Hwashil Viaduct analyses, the rail stresses observed for the three analysis types are:

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

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

Comparison of the results for the separate and LUSAS analyses shows that the peak compressive stress for the separate analysis is 1.2 times that of the LUSAS analysis for track 1 and 1.12 times for track 2. It should be noted however that the separate analysis could be giving an apparent increase in track resistance of up to 1.6 times that of the loaded track due to the combination of the nonlinear results. The concurrent analysis gave results that are between the separate and LUSAS analysis as expected since the correct limit of loaded track resistance is modelled even though the thermal effects are only approximated.

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

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

References

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

Appendix B: Definition of Complex Trainset Configurations

Introduction

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

Definition of Trainset Configurations With UDLs Alone

The UDL loading allows the definition of trainset configurations where the load is spread over lengths of the track as illustrated by the example shown in Figure 126. In this configuration the vertical load varies along the length of the trainset and the acceleration / traction load acts only over the length of the locomotive(s). In the definition the train is accelerating to the left for any structure model it is applied to with the origin of the trainset loading defined at the left-hand extent of the configuration. Any number of UDLs can be used for the definition of the trainsets in the **Loading** worksheet of the input Microsoft Excel spreadsheet to allow more complex configurations to be defined.

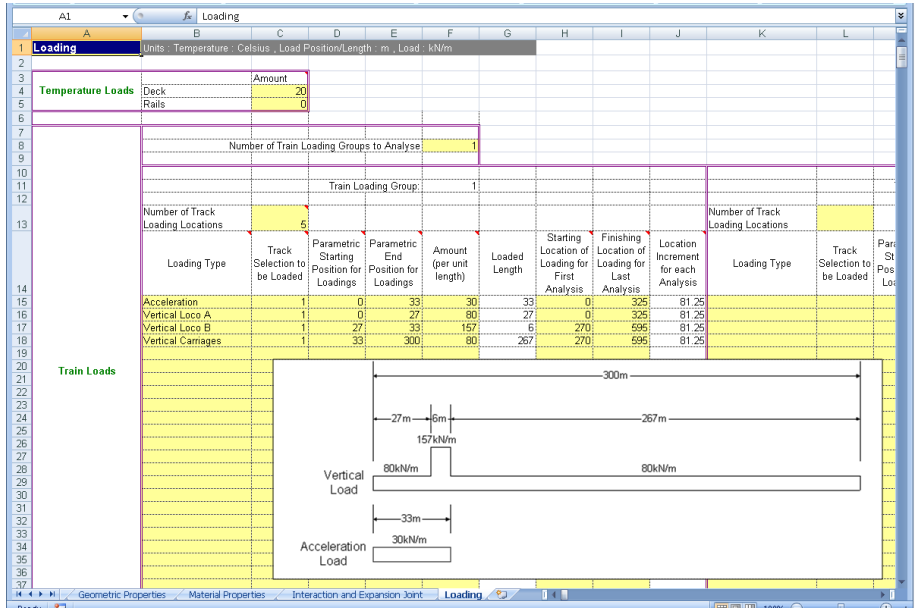


Figure 126: More Complex Train Loading Definition in Spreadsheet

Additional simple examples were illustrated in Figure 34 on page 31 showing the types of loading configurations that can be defined.

EuroCode Load Model SW/0 Loading Configuration

The SW/0 vertical loading pattern is shown in Figure 127 which has two separated UDLs. In addition, Note 1 of Clause 6.5.3 'Actions due to traction and braking' within BS EN 1991-2:2003 states that *'For Load Models SW/0 and SW/2 traction and braking forces need only be applied to those parts of the structure which are loaded according to Figure 6.2 and Table 6.1'* where this figure is equivalent to Figure 127 below. The definition of the SW/0 trainset configuration will therefore be described below according to these conditions.

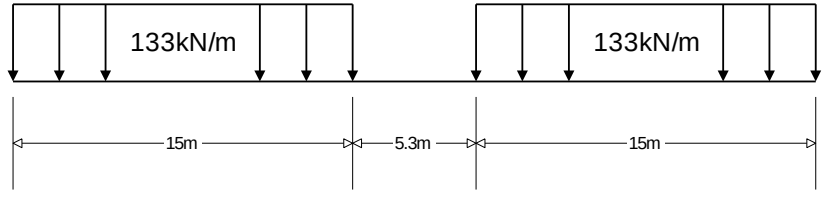


Figure 127: EuroCode Load Model SW/0 Train Vertical Load Pattern

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

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

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

Table 3: SW/0 Parametric Vertical Loading Definition

As stated in BS EN 1991-2:2003 Clause 6.5.3, the braking load from the SW/0 trainset should be defined as a UDL over the parts that are loaded and with a value of 20kN/m (limited to 6000kN total load) in the direction of travel. Assuming that we are defining the SW/0 trainset travelling to the right in the Rail Track Analysis model the loading configuration will be as illustrated in Figure 128 with the loading origin at the centre.

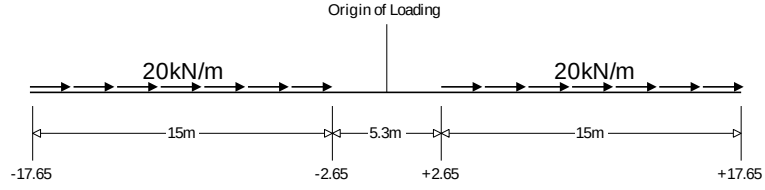


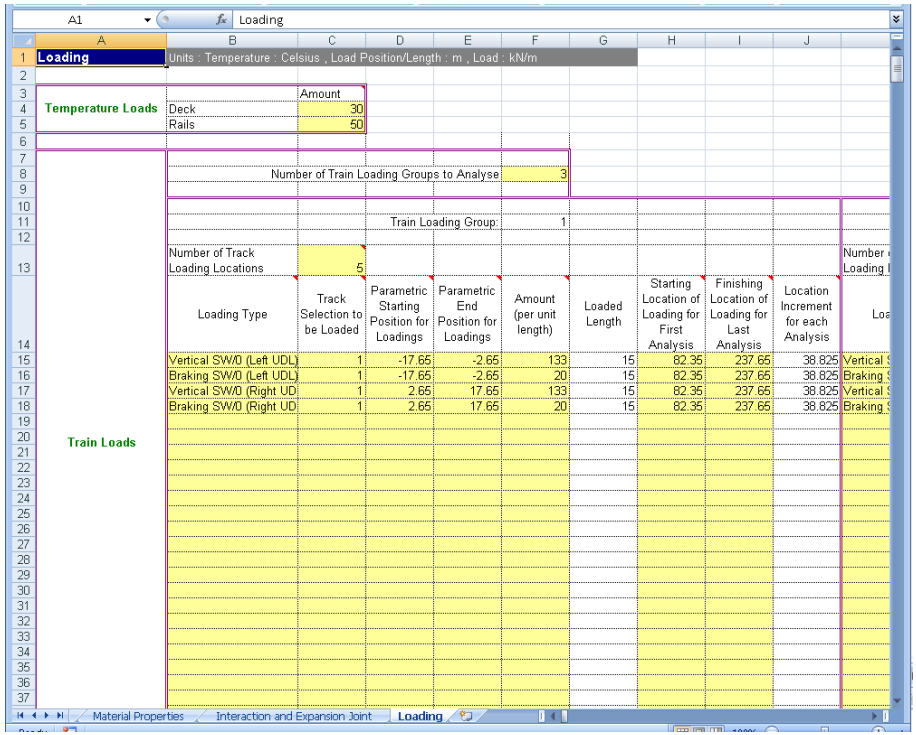
Figure 128: EuroCode SW/0 Train Braking Load Pattern

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

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

Table 4: SW/0 Parametric Braking Loading Definition

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



	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
3			Amount							
4	Temperature Loads	Deck	30							
5		Rails	50							
8		Number of Train Loading Groups to Analyse				3				
11				Train Loading Group		1				
13		Number of Track Loading Locations	5							
14		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
15	Train Loads	Vertical SW/0 (Left UDL)	1	-17.65	-2.65	133	15	82.35	237.65	38.825
16		Braking SW/0 (Left UDL)	1	-17.65	-2.65	20	15	82.35	237.65	38.825
17		Vertical SW/0 (Right UD	1	2.65	17.65	133	15	82.35	237.65	38.825
18		Braking SW/0 (Right UD	1	2.65	17.65	20	15	82.35	237.65	38.825

Figure 129: Complete SW/0 Trainset Configuration

Definition of Trainset Configurations With Concentrated Loads

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

EuroCode Load Model 71 Loading Configuration

The Load Model 71 vertical loading pattern is shown in Figure 130. This trainset load pattern has two UDLs either side and four concentrated loads in the centre. BS EN 1992-2:2003 Clause 6.5.3 ‘Actions due to traction and braking’ describes the

longitudinal braking and traction loads that should be considered with Load Model 71 but these are not considered here. For this example we will only consider the definition of the four 250kN concentrated loads shown in Figure 131 (with the origin of the loading taken at the centre) and how these can be approximated within the Rail Track Analysis tool.

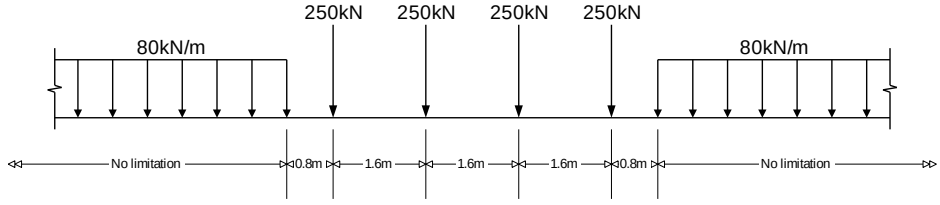


Figure 130: EuroCode Load Model 71 Train Vertical Load Pattern

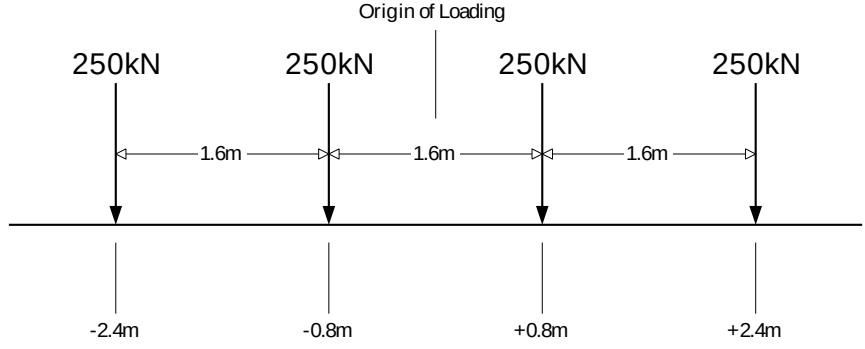


Figure 131: Load Model 71 Concentrated Loads Only

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

Note. The choice of the contact length to be used to define the equivalent UDL to a concentrated load must be decided by the user based on the configuration of the model and the element lengths used for the meshing of that model. The illustration here

should be viewed as a guide on how to incorporate concentrated loads with a trainset definition and not as the de facto contact length to be used for all circumstances.

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

$$\text{UDL} = \text{Conc.Load} / \text{ContactLength} = 250\text{kN} / 0.01\text{m} = 25000\text{kN/m}$$

The definition of the four concentrated loads of Load Model 71 now becomes the four UDLs indicated in Figure 132.

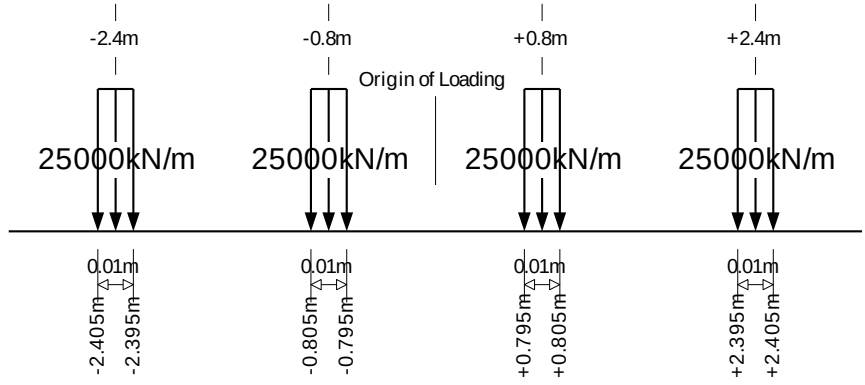
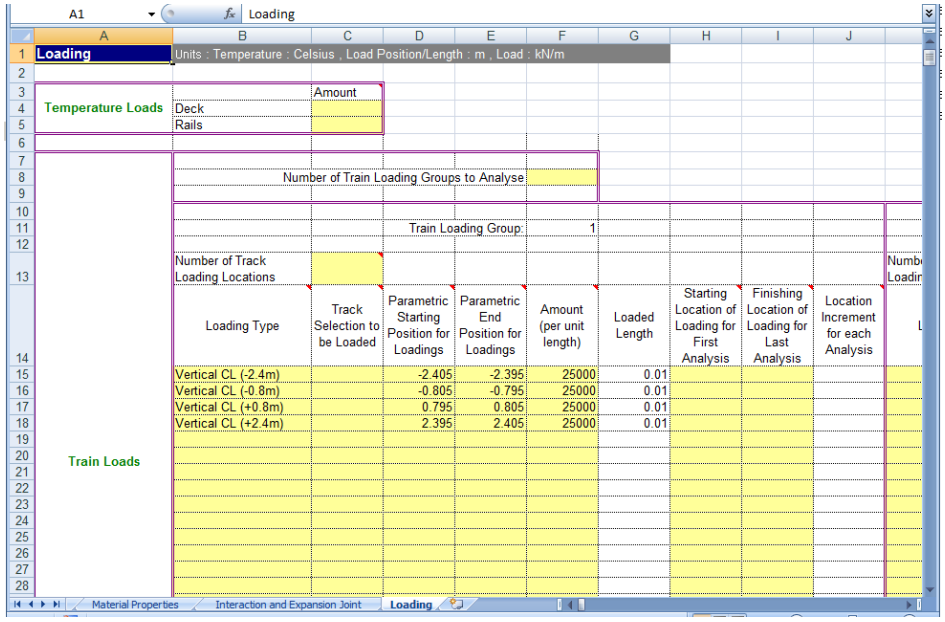


Figure 132: Load Model 71 Equivalent UDLs to Concentrated Loads

This UDL definition of the four concentrated loads of Load Model 71 can now be defined in the **Loading** worksheet of the input Microsoft Excel spreadsheet as illustrated in Figure 133.



	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
2										
3			Amount							
4	Temperature Loads	Deck								
5		Rails								
6										
7										
8			Number of Train Loading Groups to Analyse							
9										
10										
11					Train Loading Group:		1			
12										
13		Number of Track Loading Locations								Numbe Loadir
14		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
15		Vertical CL (-2.4m)		-2.405	-2.395	25000	0.01			
16		Vertical CL (-0.8m)		-0.805	-0.795	25000	0.01			
17		Vertical CL (+0.8m)		0.795	0.805	25000	0.01			
18		Vertical CL (+2.4m)		2.395	2.405	25000	0.01			
19										
20	Train Loads									
21										
22										
23										
24										
25										
26										
27										
28										

Figure 133: Sample Loading Definition for Load Model 71 Concentrated Loads

EuroCode Load Model HSLM-A Loading Configuration

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

The HSLM-A Load Model representing a universal train, Figure 134,consists of multiple concentrated loads with the magnitude and configuration which is dependent upon the universal train type (A1 to A10).

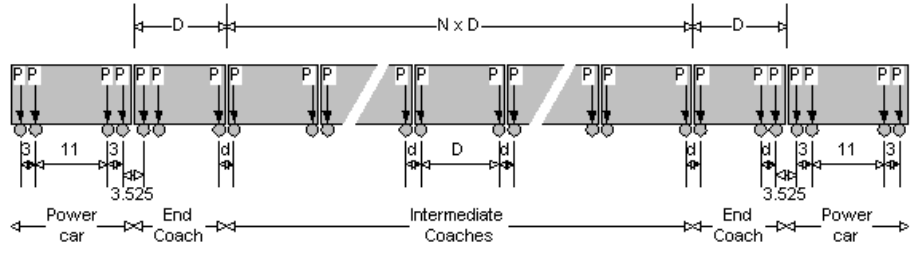
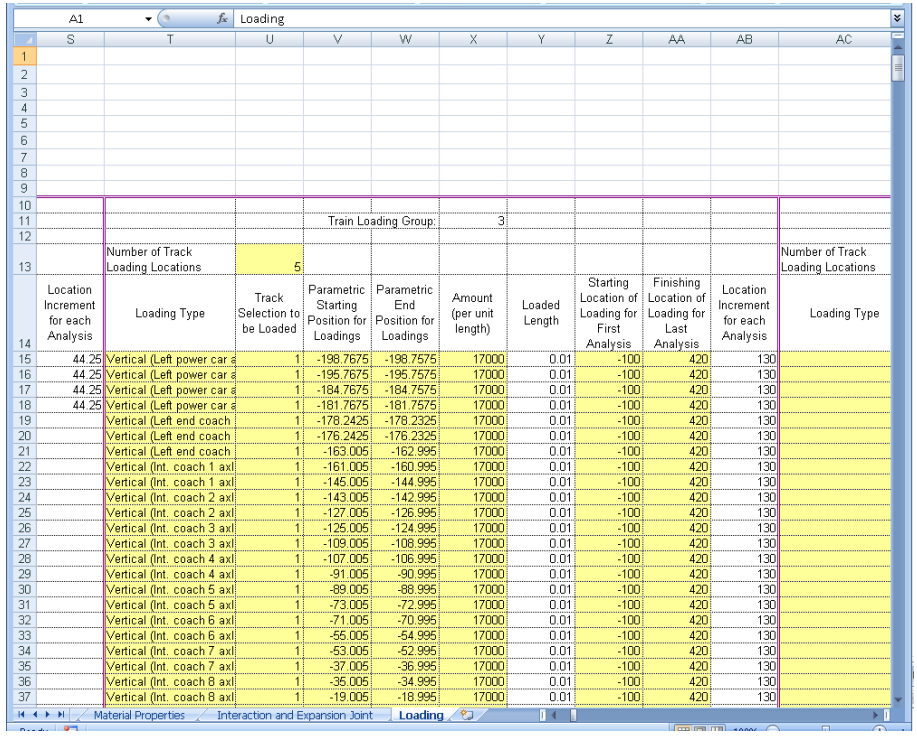


Figure 134: EuroCode Load Model HSLM-A Train Vertical Load Pattern

Figure 135 shows a HSLM-A1 trainset (with braking loads) which has been defined in the **Loading** worksheet using the equivalent UDL approach for the concentrated loads. The input just for the single HSLM-A1 braking trainset requires 51 rows of data input to define all of the axle loads and the braking load.



A1 | Loading

	S	T	U	V	W	X	Y	Z	AA	AB	AC
10											
11				Train Loading Group:		3					
12											
13		Number of Track Loading Locations	5								Number of Track Loading Locations
14	Location Increment for each Analysis	Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis	Loading Type
15	44.25	Vertical (Left power car a	1	-198.7675	-198.7575	17000	0.01	-100	420	130	
16	44.25	Vertical (Left power car a	1	-195.7675	-195.7575	17000	0.01	-100	420	130	
17	44.25	Vertical (Left power car a	1	-184.7675	-184.7575	17000	0.01	-100	420	130	
18	44.25	Vertical (Left power car a	1	-181.7675	-181.7575	17000	0.01	-100	420	130	
19		Vertical (Left end coach	1	-178.2425	-178.2325	17000	0.01	-100	420	130	
20		Vertical (Left end coach	1	-176.2425	-176.2325	17000	0.01	-100	420	130	
21		Vertical (Left end coach	1	-163.005	-162.995	17000	0.01	-100	420	130	
22		Vertical (Int. coach 1 axl	1	-161.005	-160.995	17000	0.01	-100	420	130	
23		Vertical (Int. coach 1 axl	1	-145.005	-144.995	17000	0.01	-100	420	130	
24		Vertical (Int. coach 2 axl	1	-143.005	-142.995	17000	0.01	-100	420	130	
25		Vertical (Int. coach 2 axl	1	-127.005	-126.995	17000	0.01	-100	420	130	
26		Vertical (Int. coach 3 axl	1	-125.005	-124.995	17000	0.01	-100	420	130	
27		Vertical (Int. coach 3 axl	1	-109.005	-108.995	17000	0.01	-100	420	130	
28		Vertical (Int. coach 4 axl	1	-107.005	-106.995	17000	0.01	-100	420	130	
29		Vertical (Int. coach 4 axl	1	-91.005	-90.995	17000	0.01	-100	420	130	
30		Vertical (Int. coach 5 axl	1	-89.005	-88.995	17000	0.01	-100	420	130	
31		Vertical (Int. coach 5 axl	1	-73.005	-72.995	17000	0.01	-100	420	130	
32		Vertical (Int. coach 6 axl	1	-71.005	-70.995	17000	0.01	-100	420	130	
33		Vertical (Int. coach 6 axl	1	-55.005	-54.995	17000	0.01	-100	420	130	
34		Vertical (Int. coach 7 axl	1	-53.005	-52.995	17000	0.01	-100	420	130	
35		Vertical (Int. coach 7 axl	1	-37.005	-36.995	17000	0.01	-100	420	130	
36		Vertical (Int. coach 8 axl	1	-35.005	-34.995	17000	0.01	-100	420	130	
37		Vertical (Int. coach 8 axl	1	-19.005	-18.995	17000	0.01	-100	420	130	

Material Properties | Interaction and Expansion Joint | Loading

Figure 135: HSLM-A1 Trainset Defined In Loading Worksheet

It would take some time (and be prone to errors) to manually input all of the equivalent UDLs for the concentrated loads illustrated above for the HSLM-A trainset configuration. These loads should therefore be defined through an automated method such as another Microsoft Excel spreadsheet which defines the required data or by using the VBScript capabilities of LUSAS Modeller to parametrically define the trainset loads. Such a VBScript has been written as a demonstration for these HSLM-A trainset configurations.

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

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

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

The VBScript is run as follows:

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

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

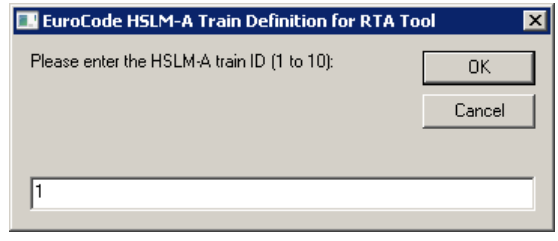


Figure 136: Input of the HSLM-A Train Configuration ID

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

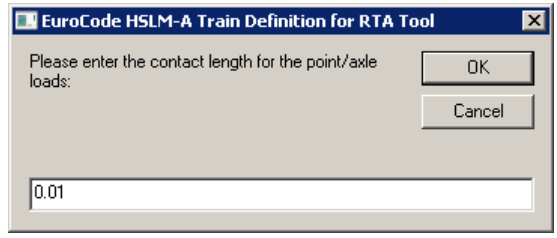


Figure 137: Input of the Contact Length for the UDLs Equivalent to the Concentrated Loads

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

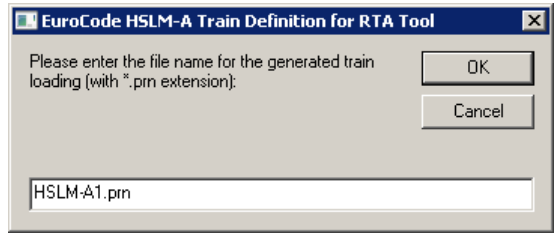


Figure 138: Input of the Filename for the Output of the HSLM-A Train Configuration

On clicking OK the VBScript will now process the HSLM-A loading and generate a TAB delimited text file defining all of the loading for a braking train and an accelerating train as indicated in Figure 139 and Figure 140 (for a HSLM-A1 trainset with 0.01m contact length for the equivalent UDLs).

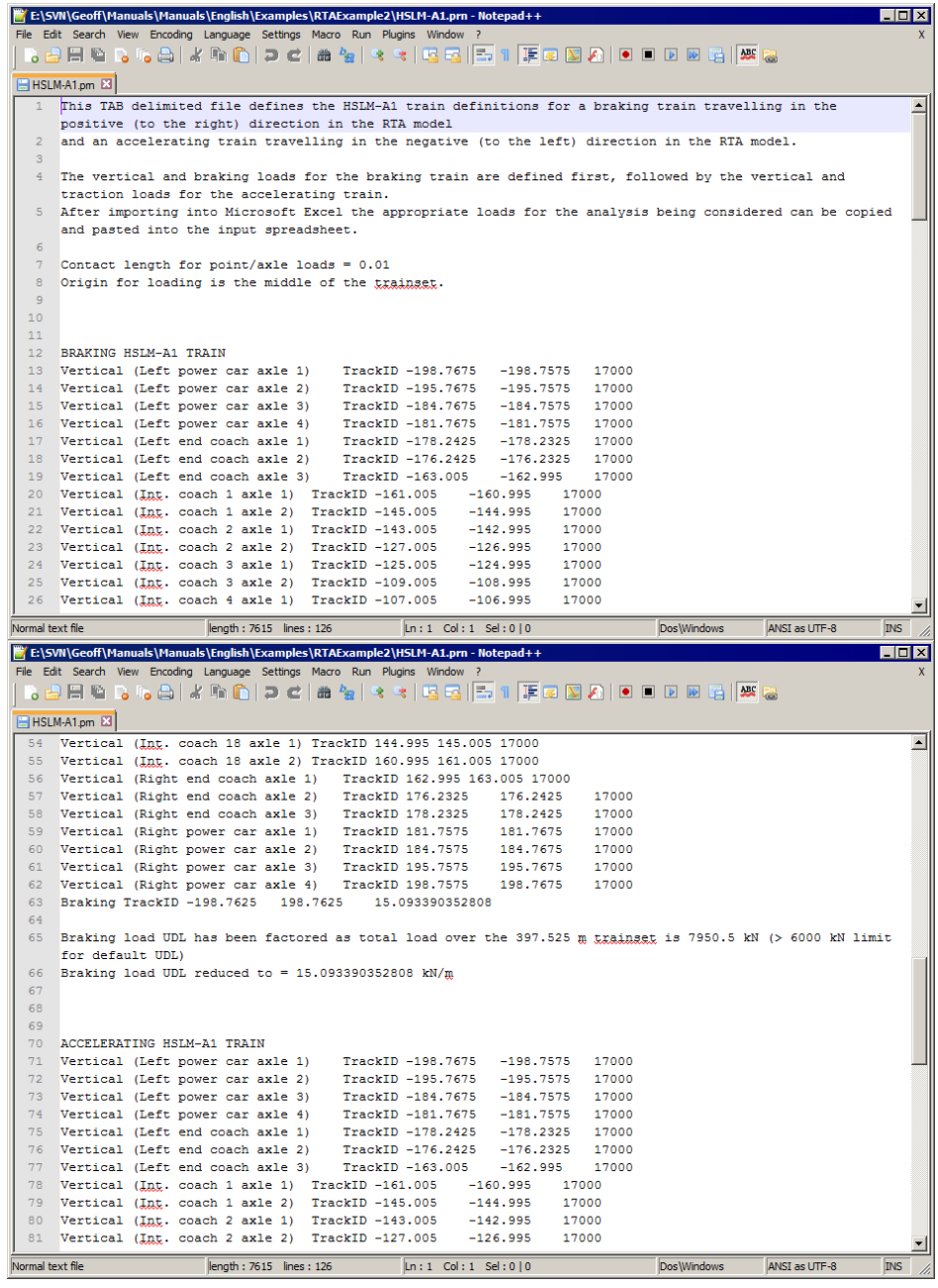


Figure 139: Output for a HSLM-A1 Trainset Configuration (1 of 2)

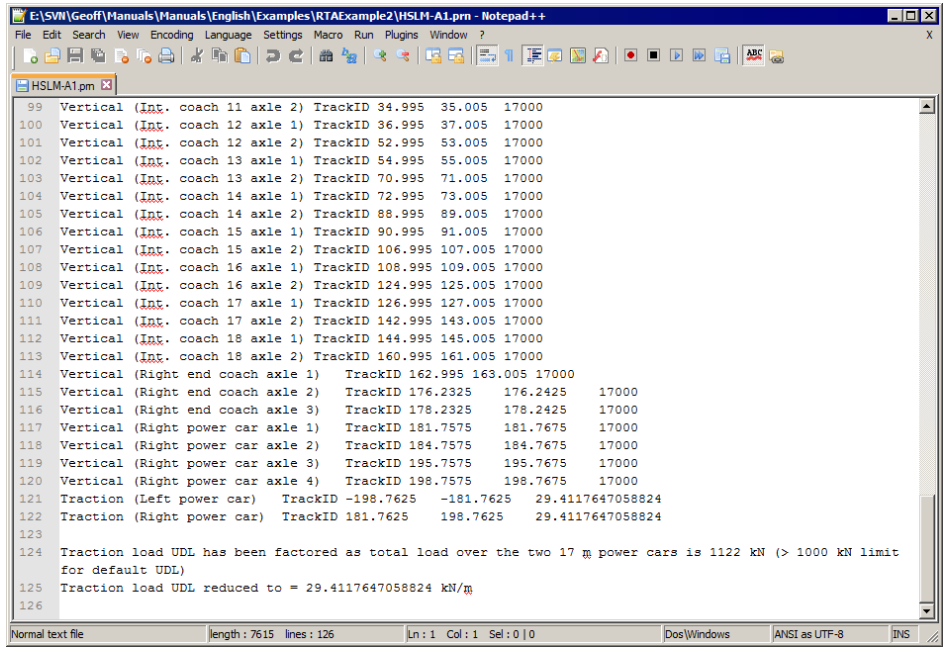
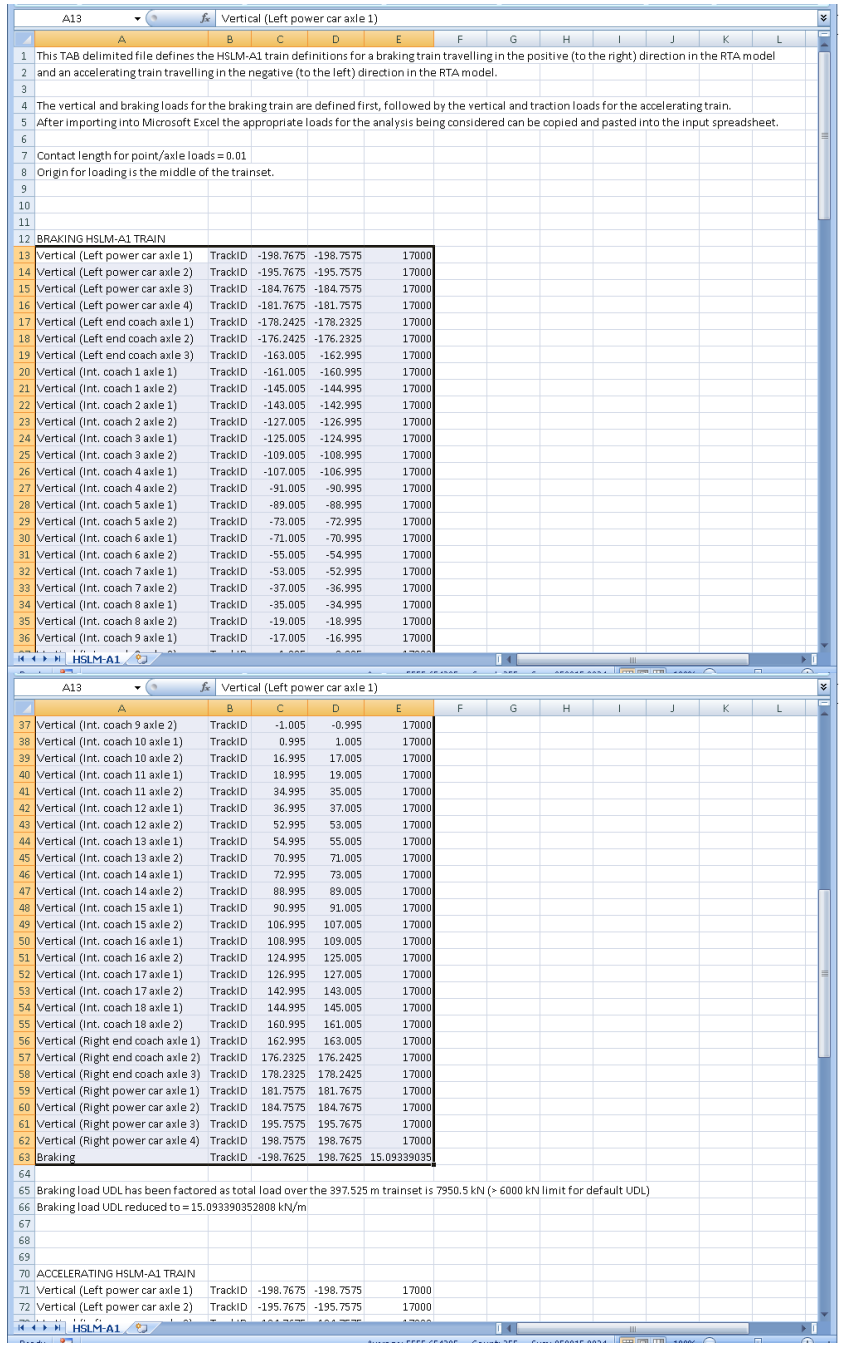


Figure 140: Output for a HSLM-A1 Trainset Configurations (2 of 2)

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

1) Import the TAB delimited file generated above into Microsoft Excel

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



A13 | Vertical (Left power car axle 1)

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

HSLM-A1

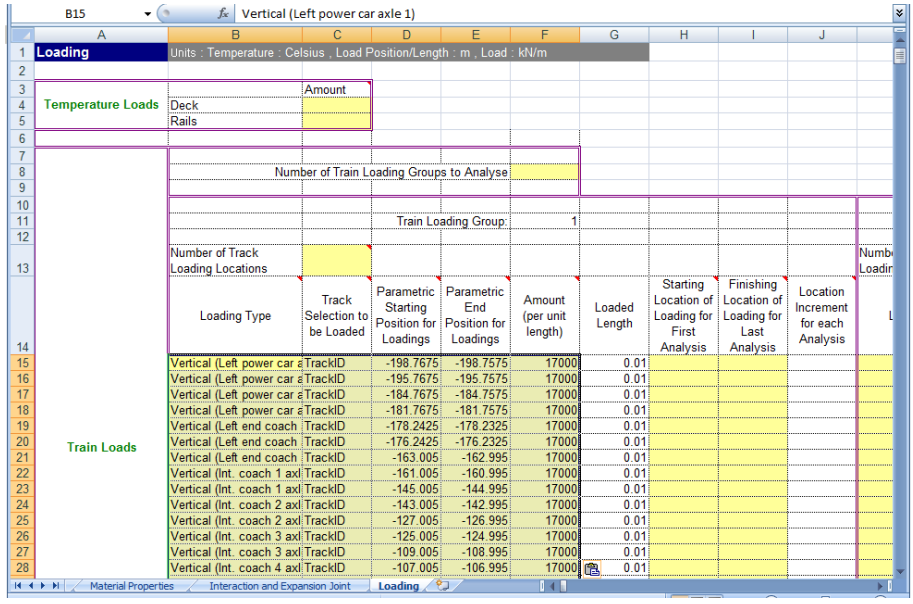
A13 | Vertical (Left power car axle 1)

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

HSLM-A1

Figure 141: Select the Braking (or Acceleration) Loading to be Copied

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



B15 Vertical (Left power car axle 1)

	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
2										
3			Amount							
4	Temperature Loads	Deck								
5		Rails								
6										
7										
8		Number of Train Loading Groups to Analyse								
9										
10										
11		Train Loading Group:				1				
12										
13		Number of Track Loading Locations								Numb Loadir
14		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
15		Vertical (Left power car a	TrackID	-198.7675	-198.7575	17000	0.01			
16		Vertical (Left power car a	TrackID	-195.7675	-195.7575	17000	0.01			
17		Vertical (Left power car a	TrackID	-184.7675	-184.7575	17000	0.01			
18		Vertical (Left power car a	TrackID	-181.7675	-181.7575	17000	0.01			
19		Vertical (Left end coach	TrackID	-178.2425	-178.2325	17000	0.01			
20	Train Loads	Vertical (Left end coach	TrackID	-176.2425	-176.2325	17000	0.01			
21		Vertical (Left end coach	TrackID	-163.005	-162.995	17000	0.01			
22		Vertical (Int. coach 1 axl	TrackID	-161.005	-160.995	17000	0.01			
23		Vertical (Int. coach 1 axl	TrackID	-145.005	-144.995	17000	0.01			
24		Vertical (Int. coach 2 axl	TrackID	-143.005	-142.995	17000	0.01			
25		Vertical (Int. coach 2 axl	TrackID	-127.005	-126.995	17000	0.01			
26		Vertical (Int. coach 3 axl	TrackID	-125.005	-124.995	17000	0.01			
27		Vertical (Int. coach 3 axl	TrackID	-109.005	-108.995	17000	0.01			
28		Vertical (Int. coach 4 axl	TrackID	-107.005	-106.995	17000	0.01			

Material Properties | Interaction and Expansion Joint | Loading

Figure 142: Paste the HSLM-A1 Trainset Definition into the Loading Worksheet

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

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

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

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

loading defined by multiple trainset creation subroutines. This is, however, beyond the scope of this demonstration example.

VBScript Source Code for "Define_HSLM-A_for_RTA.vbs"

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

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

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

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

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

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

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

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

```
    pointForce(3) = 190.0
    pointForce(4) = 170.0
    pointForce(5) = 180.0
    pointForce(6) = 190.0
    pointForce(7) = 190.0
    pointForce(8) = 210.0
    pointForce(9) = 210.0
' Calculate the equivalent UDL for spreading the point/axle load over the contact
length
    equivVertUDL = pointForce(trainID - 1) / contLen
' Determine the number of axles that are required for defining the whole trainset.
' Trainset has 2 powercars + 2 end coaches + N * intermediate coaches
' Power cars have 4 axles each, end coaches have 3 axles each, intermediate coaches
have 2 axles each
    totNumAxles = 2 * (4 + 3) + 2 * nCoaches(trainID - 1)
' Dimension the storage for the axles coordinates and descriptions
    ReDim axleCoord(totNumAxles - 1)
    ReDim axleDesc(totNumAxles - 1)
' Define the left powercar
    axleCoord(0) = 0.0
    axleDesc(0)  = "Left power car axle 1"
    axleCoord(1) = powerCarBog
    axleDesc(1)  = "Left power car axle 2"
    axleCoord(2) = axleCoord(1) + powerCarSpc
    axleDesc(2)  = "Left power car axle 3"
    axleCoord(3) = axleCoord(2) + powerCarBog
    axleDesc(3)  = "Left power car axle 4"
' Define the left end coach
    axleCoord(4) = axleCoord(3) + powerEndSpc
    axleDesc(4)  = "Left end coach axle 1"
    axleCoord(5) = axleCoord(4) + bogieAxle(trainID - 1)
    axleDesc(5)  = "Left end coach axle 2"
    axleCoord(6) = (axleCoord(3) + axleCoord(4)) / 2.0 + coachLen(trainID - 1) -
bogieAxle(trainID - 1) / 2.0
    axleDesc(6)  = "Left end coach axle 3"
    endCoachSpc = axleCoord(6) - axleCoord(5)
' Define the N intermediate coaches
    curAxleID = 7
    For icoach = 1 To nCoaches(trainID - 1)
        curAxleID = curAxleID + 1
        axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + bogieAxle(trainID -
1)
        axleDesc(curAxleID - 1)  = "Int. coach " & CStr(icoach) & " axle 1"
        curAxleID = curAxleID + 1
        axleCoord(curAxleID - 1) = axleCoord(curAxleID - 3) + coachLen(trainID - 1)
        axleDesc(curAxleID - 1)  = "Int. coach " & CStr(icoach) & " axle 2"
    Next
' Define the right end coach
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + bogieAxle(trainID - 1)
    axleDesc(curAxleID - 1)  = "Right end coach axle 1"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + endCoachSpc
    axleDesc(curAxleID - 1)  = "Right end coach axle 2"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + bogieAxle(trainID - 1)
    axleDesc(curAxleID - 1)  = "Right end coach axle 3"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerEndSpc
    axleDesc(curAxleID - 1)  = "Right power car axle 1"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerCarBog
    axleDesc(curAxleID - 1)  = "Right power car axle 2"
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerCarSpc
    axleDesc(curAxleID - 1)  = "Right power car axle 3"
```

```
    curAxleID = curAxleID + 1
    axleCoord(curAxleID - 1) = axleCoord(curAxleID - 2) + powerCarBog
    axleDesc(curAxleID - 1)  = "Right power car axle 4"
' Determine the total length for the braking load and echo the length
    brakLoadLen = axleCoord(totNumAxles - 1)
    Call getTextWindow.writeLine("Braking loads will be defined over a total length
of " & CStr(brakLoadLen) & " (and factored to ensure limit is observed)")
' Determine if the braking load needs to be scaled (most likely)
    brakTotLoad = brakUDL * brakLoadLen
    If brakTotLoad > 6000.0 Then
        brakUDL = brakUDL * 6000.0 / brakTotLoad
        Call getTextWindow.writeLine("Braking load UDL has been factored as " &
CStr(brakTotLoad) & " > 6000 kN for default UDL")
    End If
    Call getTextWindow.writeLine("Braking load UDL = " & CStr(brakUDL) & " kN/m")
' Shift the axles
    Dim shiftAxles
    shiftAxles = axleCoord(totNumAxles - 1) / 2.0
    For iaxle = 0 To totNumAxles - 1
        axleCoord(iaxle) = axleCoord(iaxle) - shiftAxles
    Next
' Determine the coordinates for the power car traction loads and report the lengths
    tracFront = axleCoord(totNumAxles - 1)
    tracBack  = axleCoord(totNumAxles - 4)
    Call getTextWindow.writeLine("Traction loads will be defined for each power car
length of " & CStr(tracLenPwr) & " for both leading and trailing power cars")
' Determine if the traction load for the two power cars needs to be scaled
    tracTotLoad = 2.0 * tracUDL * tracLenPwr
    If tracTotLoad > 1000.0 Then
        tracUDL = tracUDL * 1000.0 / tracTotLoad
        Call getTextWindow.writeLine("Traction load UDL has been factored as " &
CStr(tracTotLoad) & " > 1000 kN for default UDL")
    End If
    Call getTextWindow.writeLine("Traction load UDL = " & CStr(tracUDL) & " kN/m")
' Let us now write out the information to the file
    Call fileObj.writeLine("This TAB delimited file defines the HSLM-A" &
CStr(trainID) & " train definitions for a braking train travelling in the positive
(to the right) direction in the RTA model")
    Call fileObj.writeLine("and an accelerating train travelling in the negative
(to the left) direction in the RTA model.")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("The vertical and braking loads for the braking train
are defined first, followed by the vertical and traction loads for the accelerating
train.")
    Call fileObj.writeLine("After importing into Microsoft Excel the appropriate
loads for the analysis being considered can be copied and pasted into the input
spreadsheet.")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("Contact length for point/axle loads = " &
CStr(contLen))
    Call fileObj.writeLine("Origin for loading is the middle of the trainset.")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("BRAKING HSLM-A" & CStr(trainID) & " TRAIN")
    For iaxle = 0 To totNumAxles - 1
        Call fileObj.writeLine("Vertical (" & axleDesc(iaxle) & ")" & Chr(9) &
"TrackID" & Chr(9) & CStr(axleCoord(iaxle) - contLen / 2.0) & Chr(9) &
CStr(axleCoord(iaxle) + contLen / 2.0) & Chr(9) & CStr(equivVertUDL))
    Next
    Call fileObj.writeLine("Braking" & Chr(9) & "TrackID" & Chr(9) &
CStr(axleCoord(0)) & Chr(9) & CStr(axleCoord(totNumAxles - 1)) & Chr(9) &
CStr(brakUDL))
    Call fileObj.writeLine("")
```

```
    If brakTotLoad > 6000.0 Then Call fileObj.writeLine("Braking load UDL has been
factored as total load over the " & CStr(brakLoadLen) & " m trainset is " &
CStr(brakTotLoad) & " kN (> 6000 kN limit for default UDL)")
    Call fileObj.writeLine("Braking load UDL reduced to = " & CStr(brakUDL) & "
kN/m")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("")
    Call fileObj.writeLine("ACCELERATING HSLM-A" & CStr(trainID) & " TRAIN")
    For iaxle = 0 To totNumAxles - 1
        Call fileObj.writeLine("Vertical (" & axleDesc(iaxle) & ")" & Chr(9) &
"TrackID" & Chr(9) & CStr(axleCoord(iaxle) - contLen / 2.0) & Chr(9) &
CStr(axleCoord(iaxle) + contLen / 2.0) & Chr(9) & CStr(equivVertUDL))
    Next
    Call fileObj.writeLine("Traction (Left power car)" & Chr(9) & "TrackID" &
Chr(9) & CStr(-tracFront) & Chr(9) & CStr(-tracBack) & Chr(9) & CStr(tracUDL))
    Call fileObj.writeLine("Traction (Right power car)" & Chr(9) & "TrackID" &
Chr(9) & CStr(tracBack) & Chr(9) & CStr(tracFront) & Chr(9) & CStr(tracUDL))
    Call fileObj.writeLine("")
    If tracTotLoad > 1000.0 Then Call fileObj.writeLine("Traction load UDL has been
factored as total load over the two " & CStr(tracLenPwr) & " m power cars is " &
CStr(tracTotLoad) & " kN (> 1000 kN limit for default UDL)")
    Call fileObj.writeLine("Traction load UDL reduced to = " & CStr(tracUDL) & "
kN/m")
End Sub
```

References

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

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