Rail Track Analysis
User Manual

LUSAS Version 14.5 : Issue 1

LUSAS
Forge House, 66 High Street, Kingston upon Thames,
Surrey, KT1 1HN, United Kingdom

Tel: +44 (0)20 8541 1999
Fax +44 (0)20 8549 9399
Email: info@lusas.com
http://www.lusas.com

Distributors Worldwide

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Rail Track Analysis

Introduction

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

UIC774-3 Code of Practice

According to the Union Internationale des Chemins de fer (International Union of Railways) UIC774-3 Code of Practice, the track-structure interaction effects should be evaluated in terms of the longitudinal reactions at support locations, rail stresses induced by the temperature and train loading effects in addition to the absolute and relative displacements of the rails and deck. To 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**

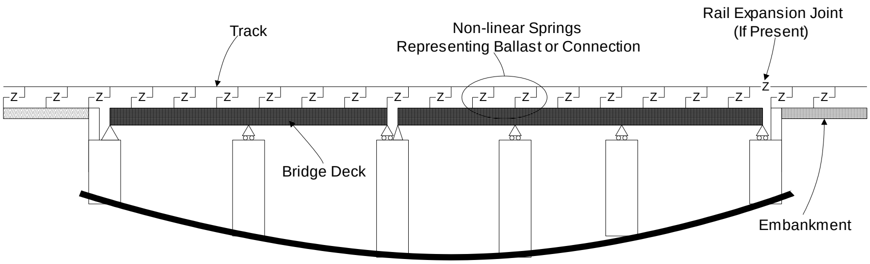


Figure 1: Representation of Structural System for Evaluation of Interaction Effects

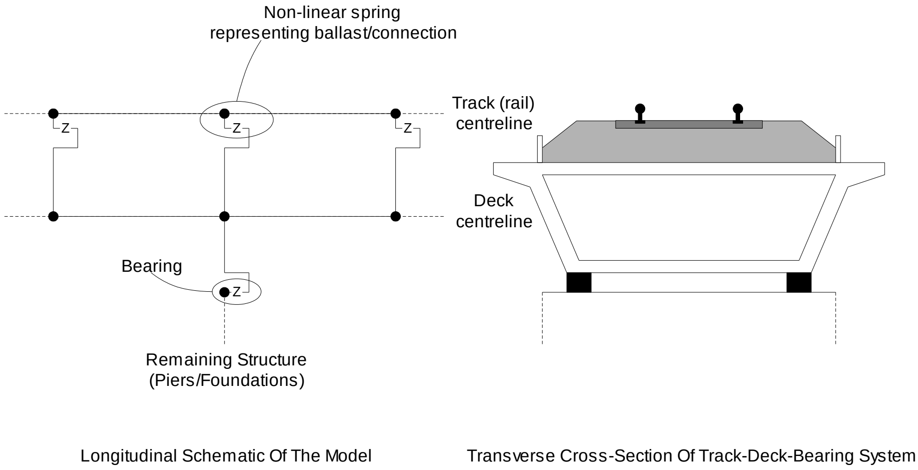


Figure 2: Typical Model of Track-Deck-Bearing System

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.

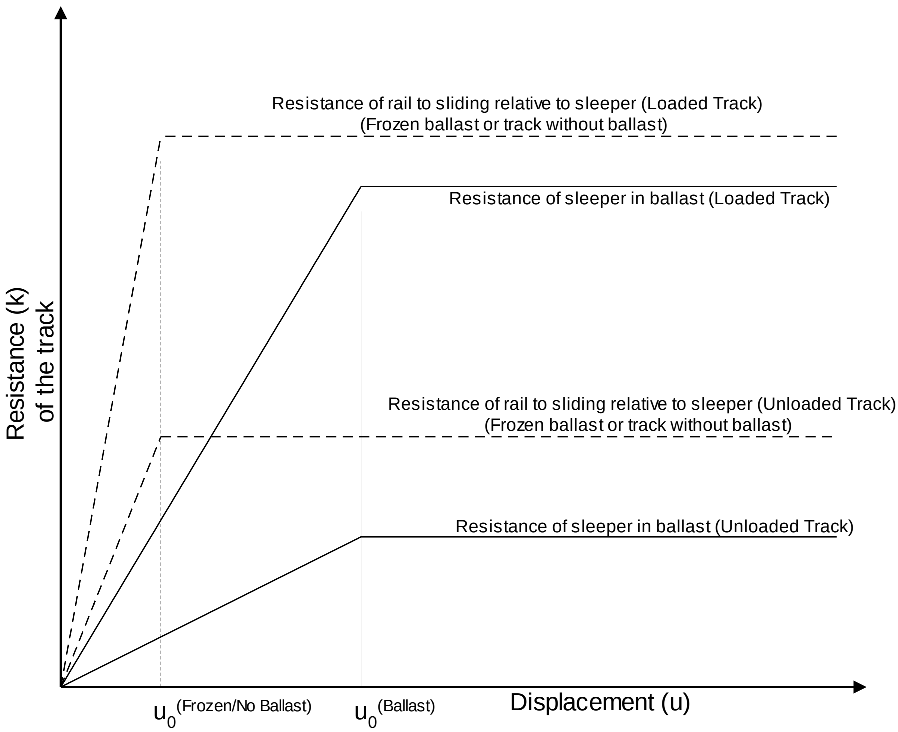


Figure 3: Resistance (k) of the Track per Unit Length versus Longitudinal Relative Displacement of Rails

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.

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

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** directory. Initially this template contains data that reproduces the E1-3 UIC test case model outlined in the code of practice as an illustration and should be edited and saved to the working directory 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

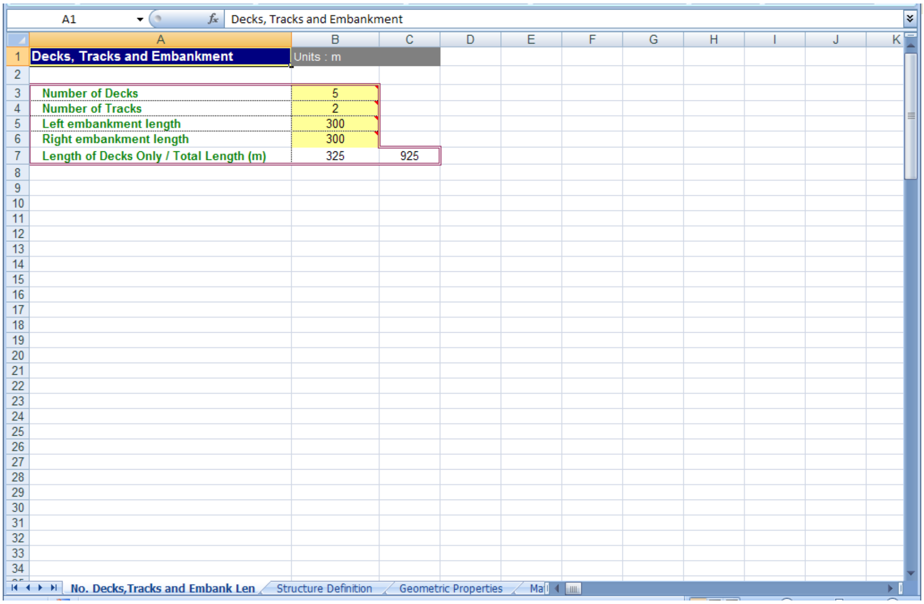


Figure 4: Definition of Number of Decks, Tracks and Embankment Lengths

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).

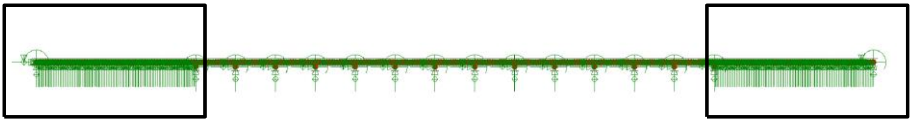


Figure 5: Left and Right Embankments in Model

Worksheet 2: Structure Definition

A1 | Structure Definition

	A	B	C	D	E	F	G	H	K	L
1	Structure Definition		Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m							
2										
3			Spring Support for each abutment/ pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign	Bearing springs on top of each pier	Span Length	Geo. Assign.	Mat. Assign.
4	Deck 1	Left End	R				F			
5		Span 1	R				307	25	1	1
6		Span 2	R				F	25	1	1
7		Span 3								
8		Span 4								
9		Span 5								
10		Span 6								
11		Span 7								
12		Span 8								
13		Span 9								
14		Number of supports for the slab / length	3				3	50		
15	Deck 2	Left End	R				F			
16		Span 1	R				307	25	1	1
17		Span 2	R				F	25	1	1
18		Span 3								
19		Span 4								
20		Span 5								
21		Span 6								
22		Span 7								
23		Span 8								
24		Span 9								
25		Number of supports for the slab / length	3				3	50		
26	k 3	Left End	R				F			
27		Span 1	R				259	25	1	1
28		Span 2	R				F	25	1	1
29		Span 3	R				F	25	1	1
30		Span 4								

No. Decks, Tracks and Embank Len | Structure Definition | Geometric Properties | Ma

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

d_p = displacement at top of support due to elastic deformation

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

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

d_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:

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

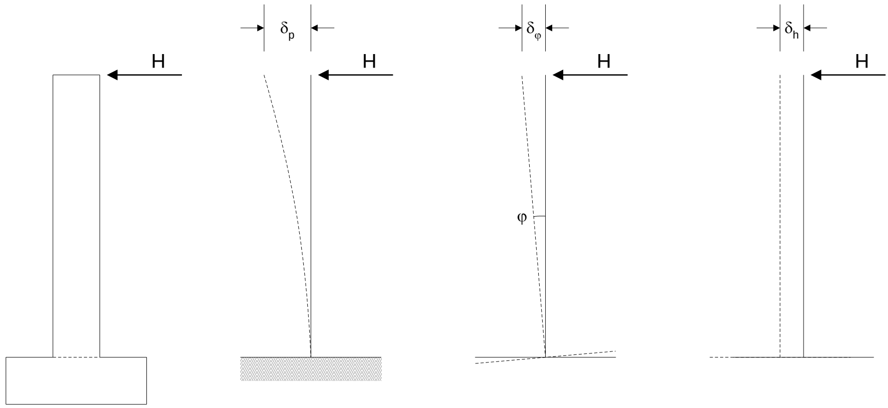


Figure 7: Component Behaviour for Calculating Support Stiffness

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.

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.

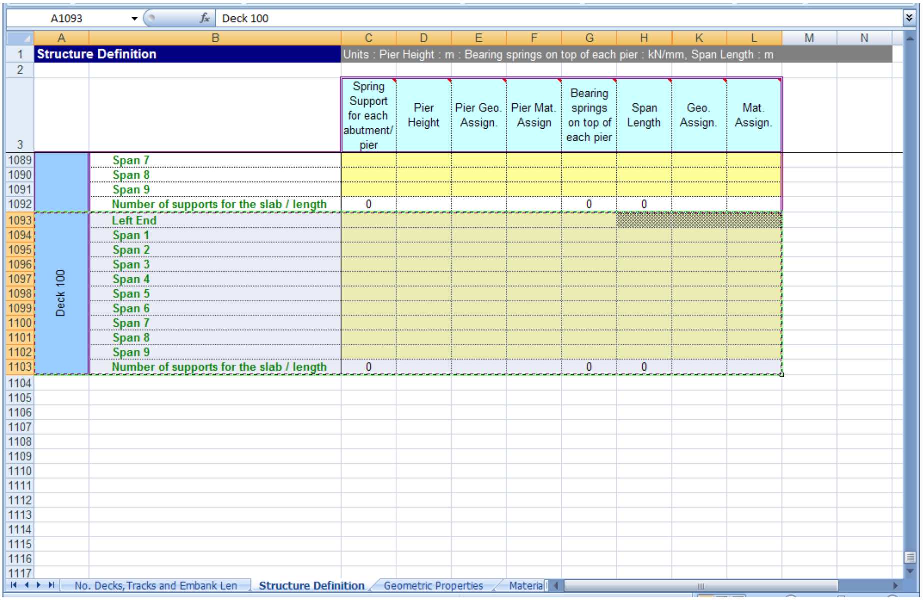


Figure 8: Selection and Copying of Structure Definition Worksheet to Increase Number of Decks

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

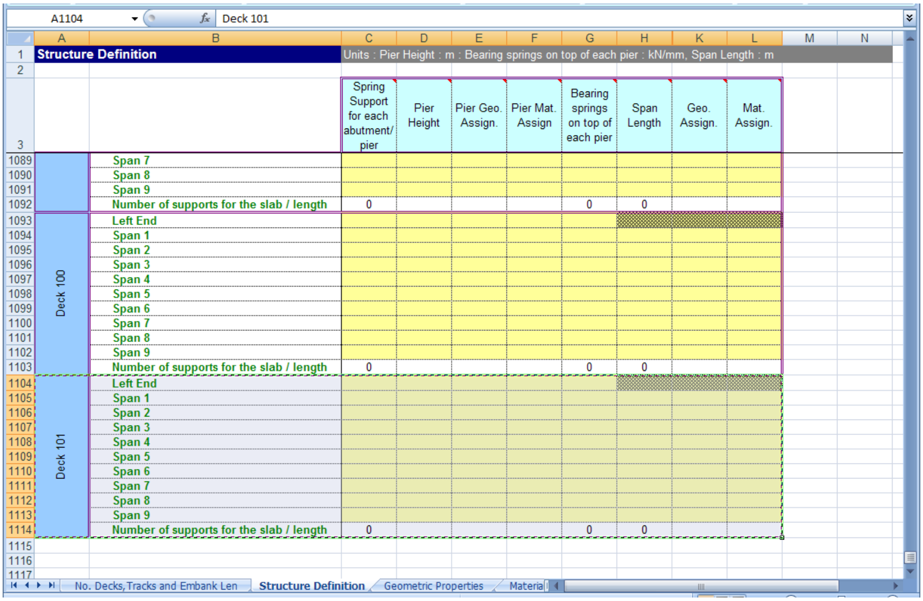


Figure 9: Pasting of Additional Decks to Ensure Formatting Maintained

Worksheet 3: Geometric Properties

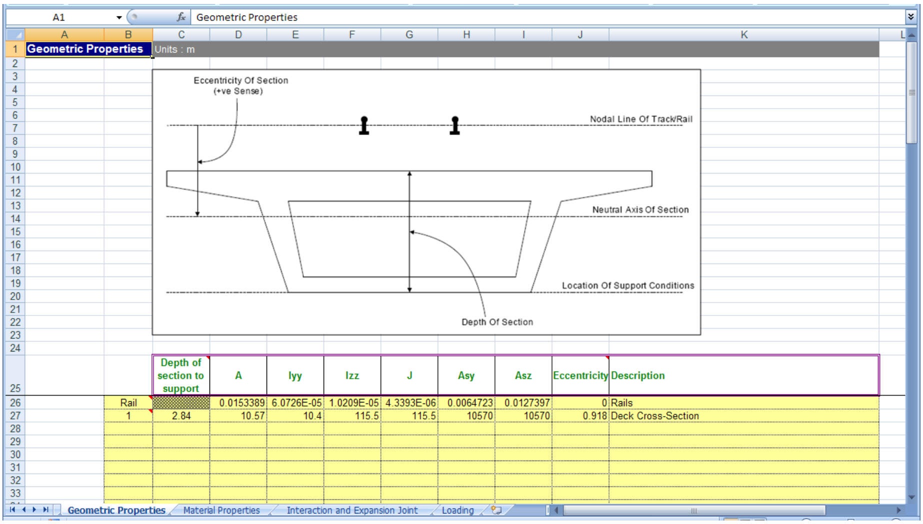


Figure 10: Geometric Properties Table for Structure

The geometric properties worksheet should list all of the section properties required for the modelling of the structure and the unique ID numbers must include all of the geometric properties that have been assigned in the ***Structure Definition*** worksheet.

The properties should be entered in metres and are all standard LUSAS values except the ***Depth of Section to Support*** entry that is needed by the model building to ensure the support conditions occur at the correct elevation.

Element Orientations

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

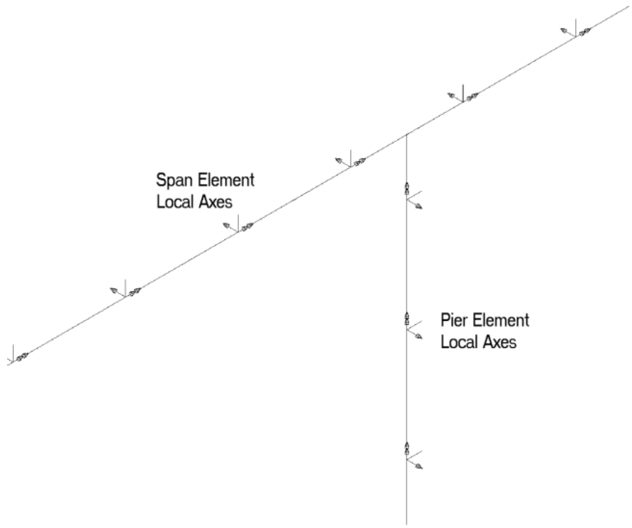


Figure 11: Beam Element Local Axes for Deck and Pier Modelling

For defining the geometric properties of the decks and rails the section axes are illustrated in Figure 12.

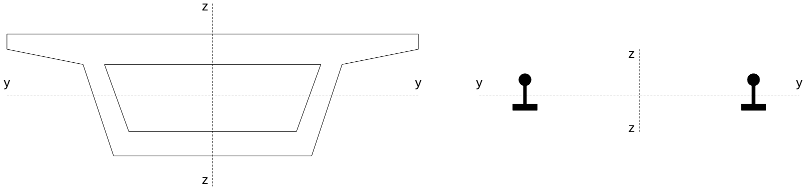


Figure 12: Section Axes for Deck and Rail Definitions

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

Eccentricity

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

Notes

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

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

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

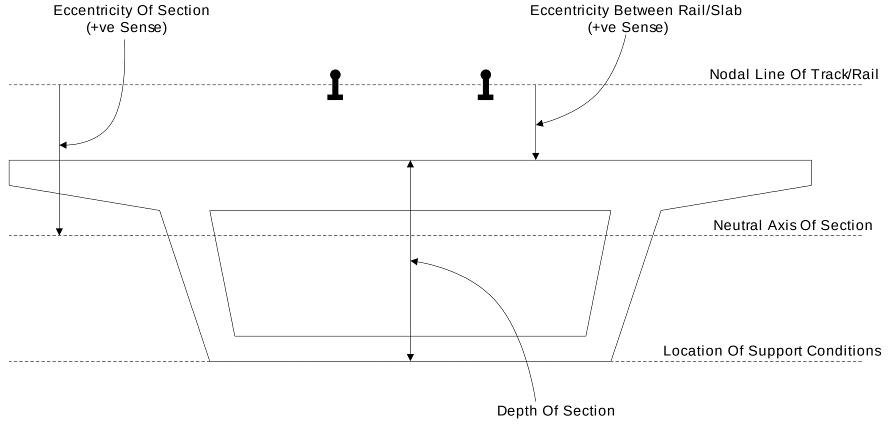


Figure 13: Eccentricity Definition for Geometric Properties and Depth of Section

Varying Section Geometric Properties

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

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

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

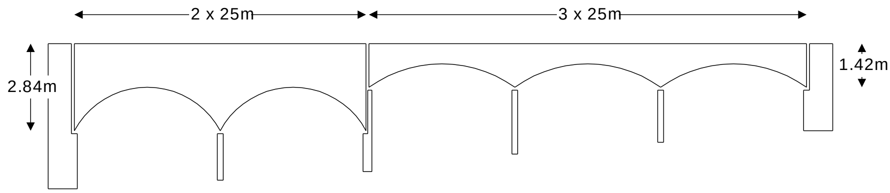


Figure 14: Example Varying Section Structure

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

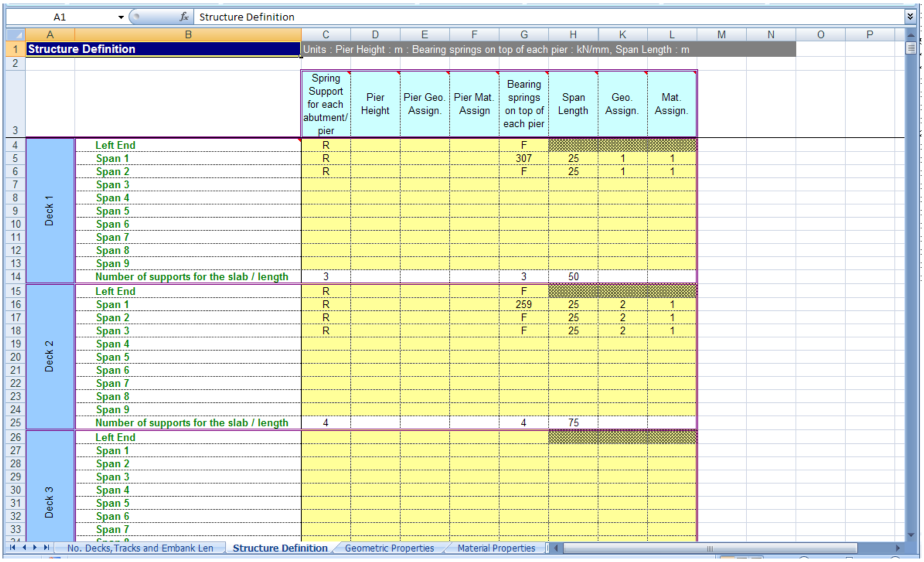


Figure 15: Structure Definition for Sample Varying Section Structure

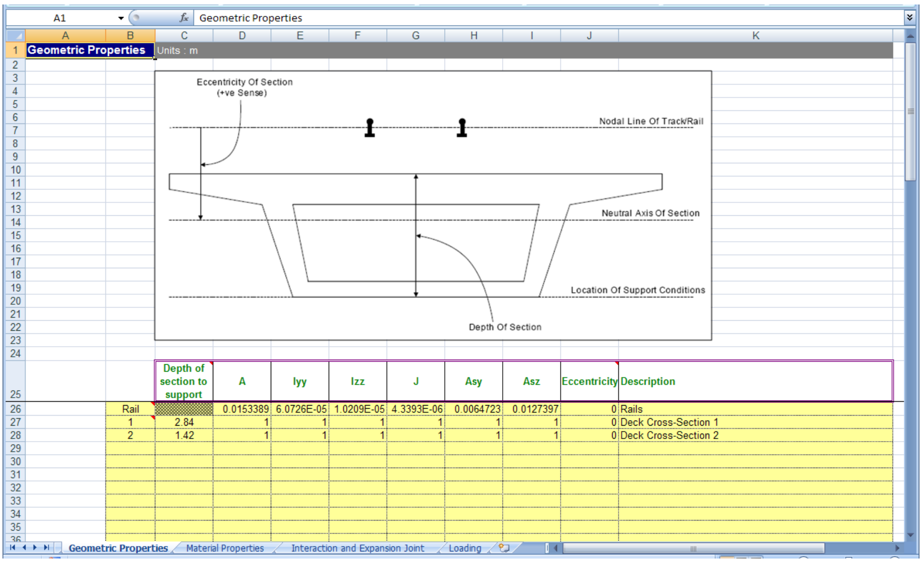


Figure 16: Geometric Properties for Sample Varying Section Structure

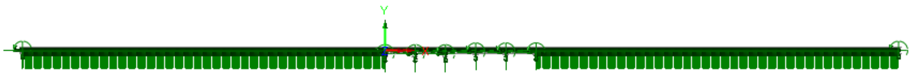


Figure 17: Base Model for Sample Varying Section Structure

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

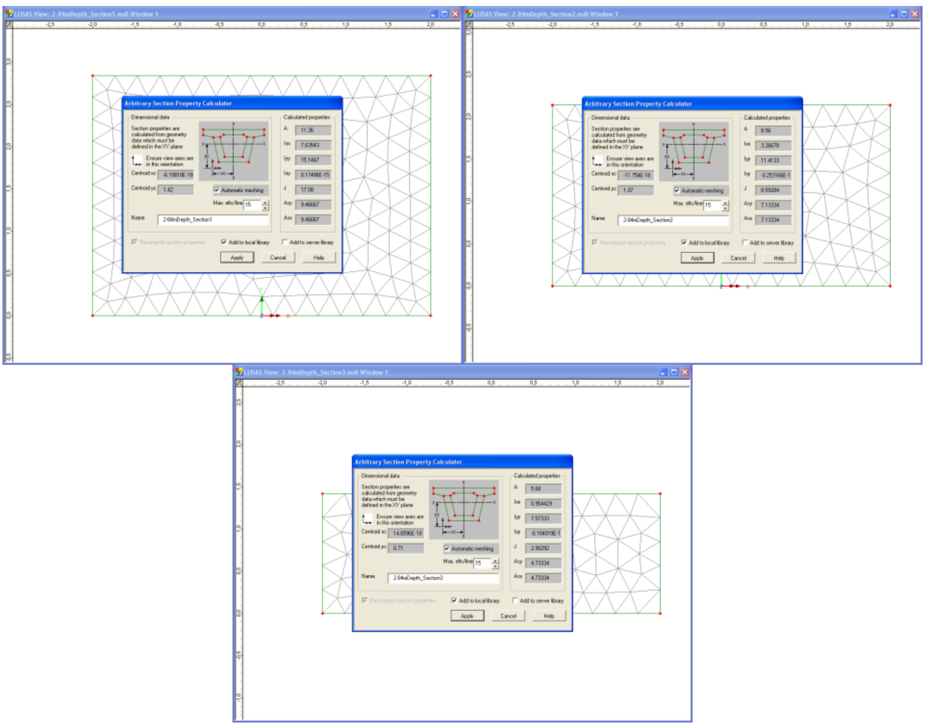


Figure 18: Arbitrary Section Property Calculation for 2.84m Depth of Section Spans

These sections can now be used to define ***Multiple Varying Section*** facility in Modeller. Before defining these multiple varying sections the reference paths along which the variation will take place must be defined. Define a reference path for each of the spans as illustrated in Figure 19 for the first span of the first deck. In this definition the X coordinates match the extent of the span and the Y coordinate has been set to 10 so it can be visualised easily. Four additional reference paths should also be defined, one for each of the other spans. On completion the model will resemble the one in Figure 20 where each reference path has been offset in the Y direction for visualisation purposes.

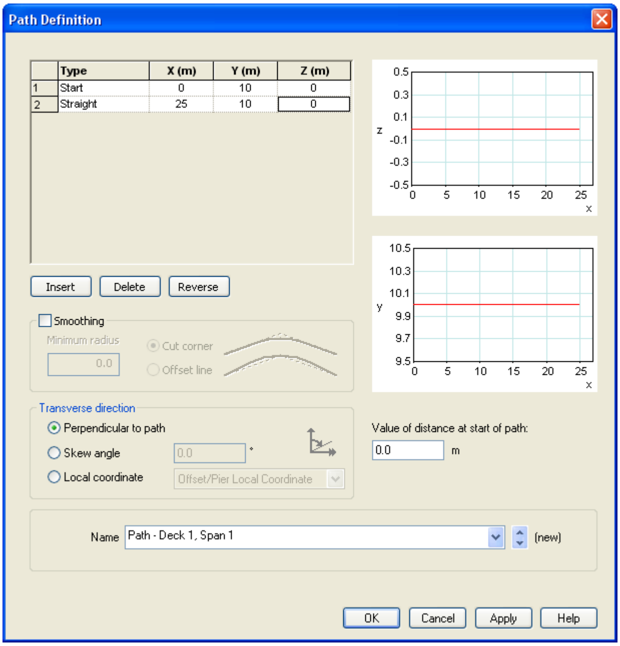


Figure 19: Definition of Reference Path for Deck 1, Span 1

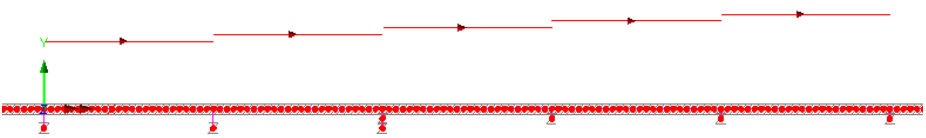


Figure 20: Reference Path for all Decks and Spans (Offset for Visualisation Purposes)

The varying sections can now be defined using the ***Multiple Varying Section*** dialog. For the definition of the varying section for the first span of the first deck the distance interpretation should be set to ***Along reference path*** and the path for the first span of the first deck selected ("Path – Deck 1, Span 1" in this example – see Figure 19). For the start of the varying section the 2.84m deep section should be selected from the user library and the section edited. The Offset Rz would be set to the required value of

1.42m to obtain the required eccentricity of the neutral axis of the section from the nodal line of the track / rail which would have been entered into the ***Geometric Properties*** worksheet. At this stage the Multiple Varying Section dialog will just have the starting section as illustrated in Figure 21.

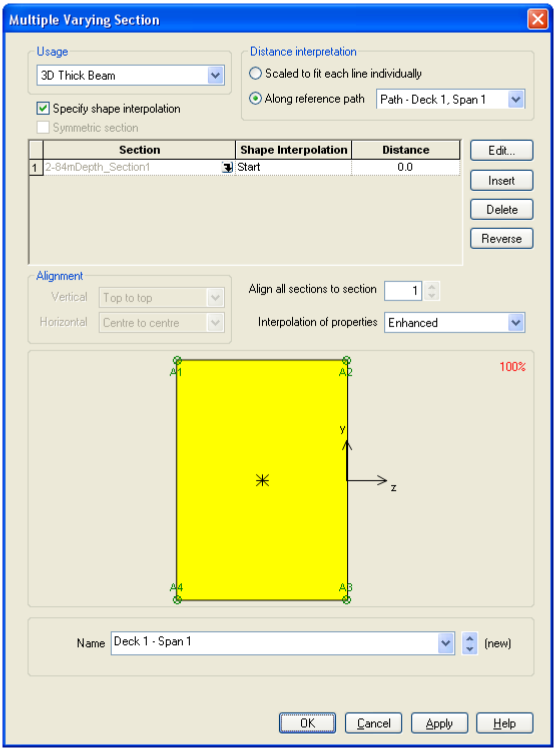


Figure 21: Definition of Multiple Varying Section for Deck 1, Span 1 (1 of 2)

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

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

Table 1: Section Interpolation for Deck 1, Span 1

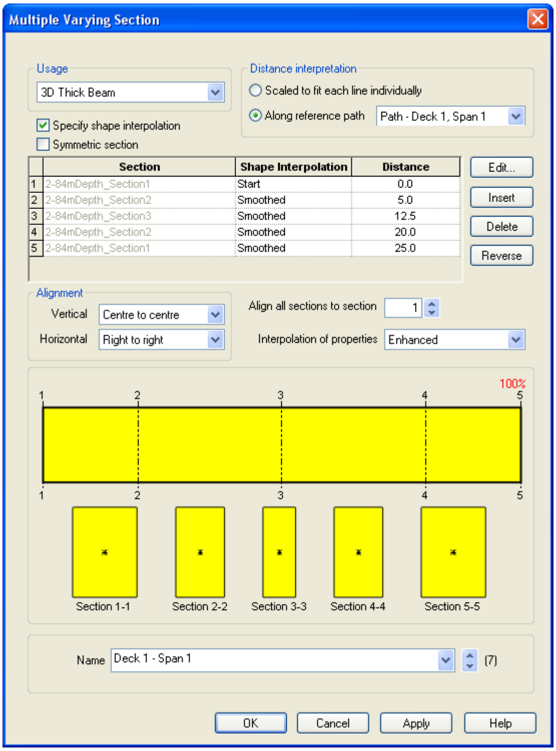


Figure 22: Definition of Multiple Varying Section for Deck 1, Span 1 (2 of 2)

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

The same procedure should also be followed for the 1.42m deep section using associated sections and a starting offset of 0.71m to obtain the required eccentricity of the neutral axis of the section from the nodal line of the track / rail which would have been entered into the ***Geometric Properties*** worksheet. On completion and assignment of the multiple varying section geometric attributes to the appropriate spans of the model the structure would look similar to the model in Figure 23.

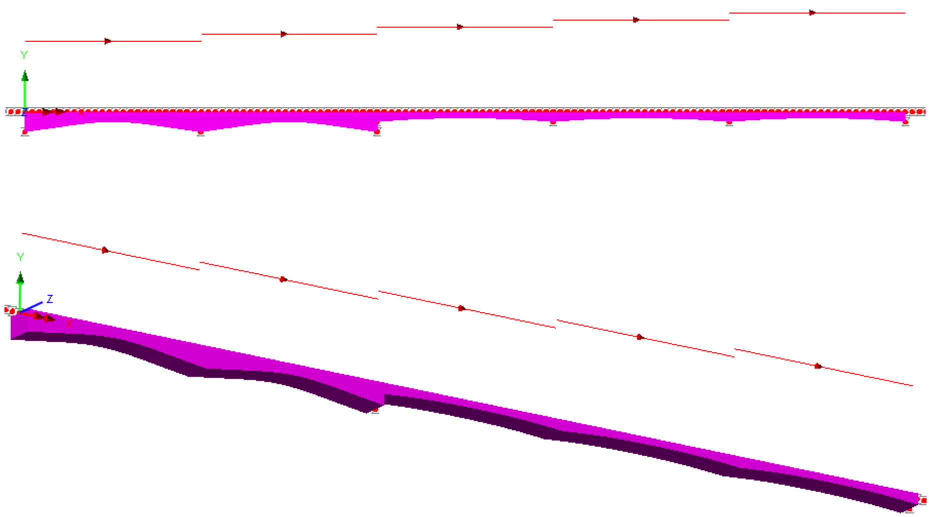


Figure 23: Model after Assignment of Multiple Varying Sections

Note. The multiple varying section could be defined with just two reference paths, one for each of the decks and the geometric attributes defined as indicated in Figure 24. When modelling structures where the sections do not vary smoothly, for example over a pier as indicated in Figure 14, caution should be exercised as using a single reference path per deck could lead to artificial smoothing of the section variation. This is illustrated in Figure 25 and Figure 26 which examine the behaviour at an intermediate pier of a deck when a single path is used for each deck. In Figure 26 the image on the left is from the use of a single reference path for the whole deck and shows the smoothing that has occurred over the pier when compared to the image on the right which is from the use of a single reference path for each span of the deck.

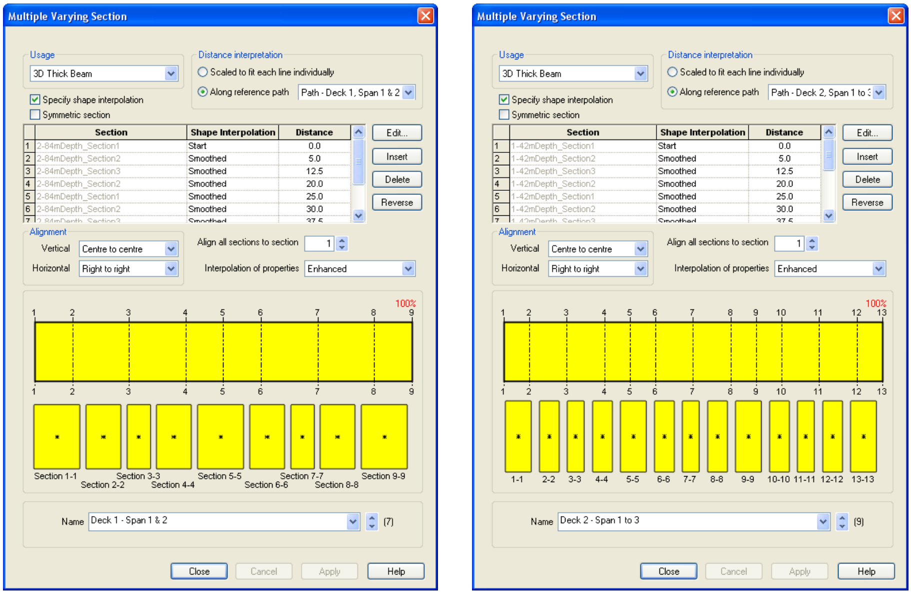


Figure 24: Definition of Multiple Varying Section for Deck 1 and Deck 2 for Two Reference Paths

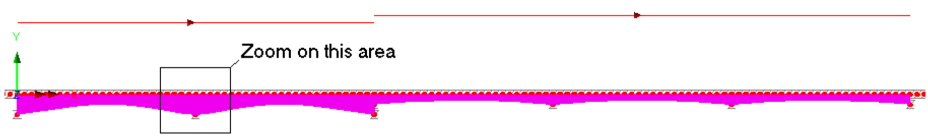
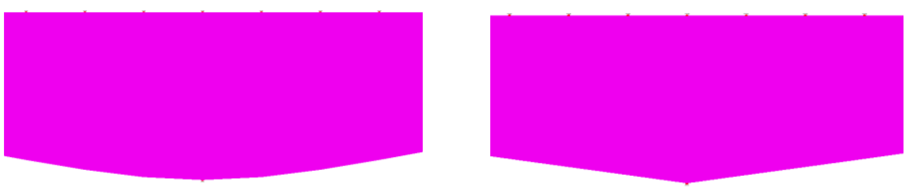


Figure 25: Model after Assignment of Multiple Varying Sections with Two Reference Paths



(a) **(b)**

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

Worksheet 4: Material Properties

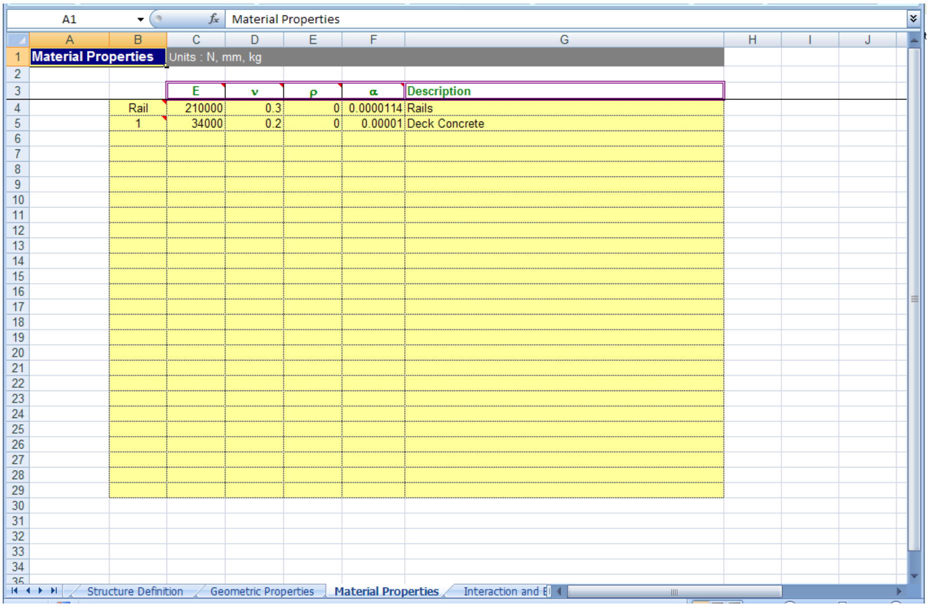


Figure 27: Material Properties Table for Structure

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

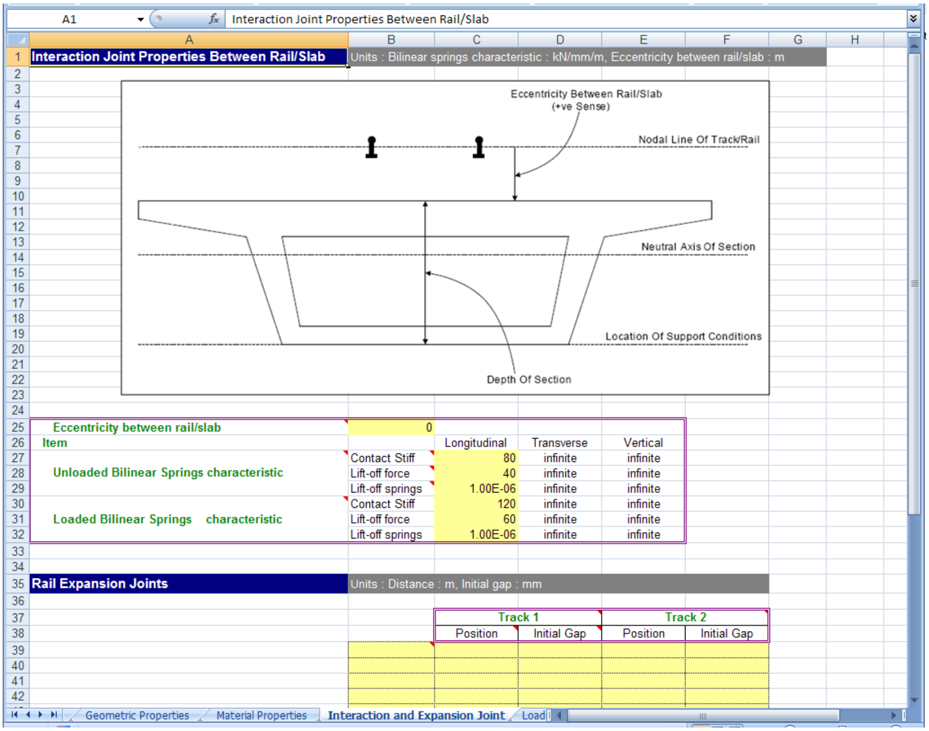
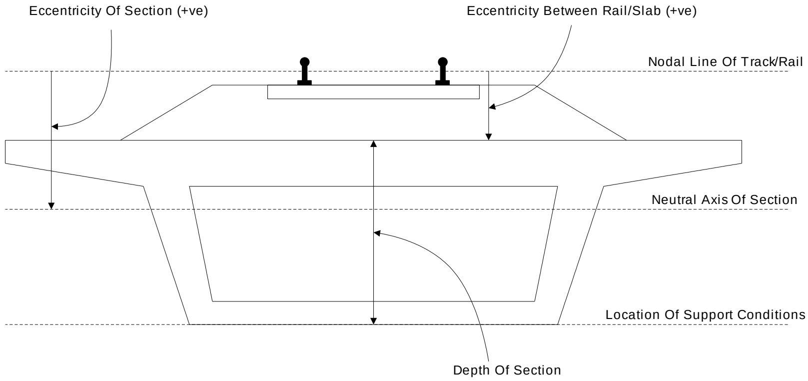


Figure 28: Interaction Properties Between the Track/Bridge and Expansion Joint Definition

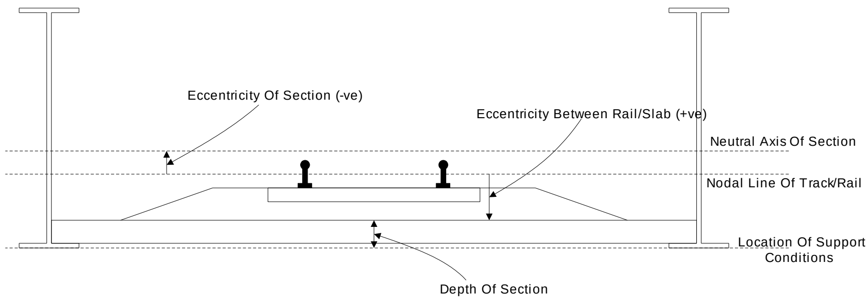
The main bilinear interaction effects for the track/bridge interaction are defined in this worksheet along with additional properties associated with the rail/track. These include the eccentricity between the rail/slab (see Figure 11 and the ***Geometric Properties*** section) and the presence of any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

Eccentricity Between Rail/Slab

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



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



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

Figure 29: Sign Conventions for Eccentricity Definition

Bilinear Interaction Properties

The bilinear interaction properties are derived from the bilinear curves defined in the UIC774-3 Code of Practice. Properties are entered for both the unloaded state where just temperature loads are applied in the model to the track and the loaded state where both temperature and trainset loads are applied to the track. For each state of loading the contact stiffness is defined in kN/mm per metre length of track, the lift-off force (onset of plastic yield) is defined in kN per metre length and the lift-off stiffness defined as a small value so there is no stiffness once plastic yielding has started. The values in Figure 28 are for unballasted track where:

$$u_0 = 0.5\text{mm}$$

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

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

The contact stiffness is calculated directly from:

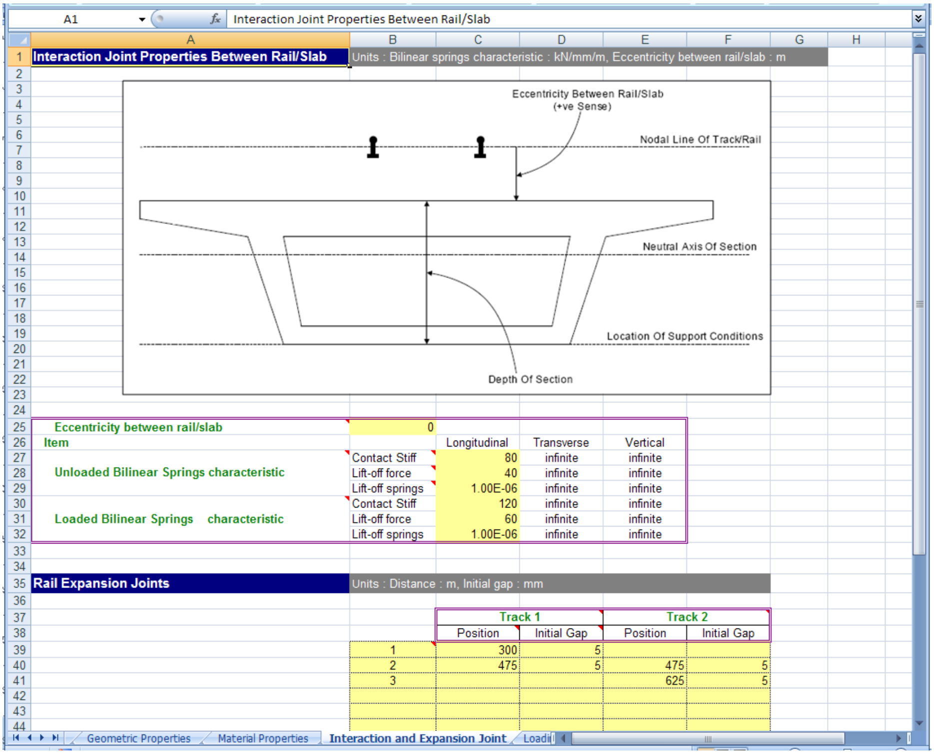
$$\text{Contact Stiffness} = \frac{k}{u_0}$$

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

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



Interaction Joint Properties Between Rail/Slab — Units : Bilinear springs characteristic : kN/mm/m, Eccentricity between rail/slab : m

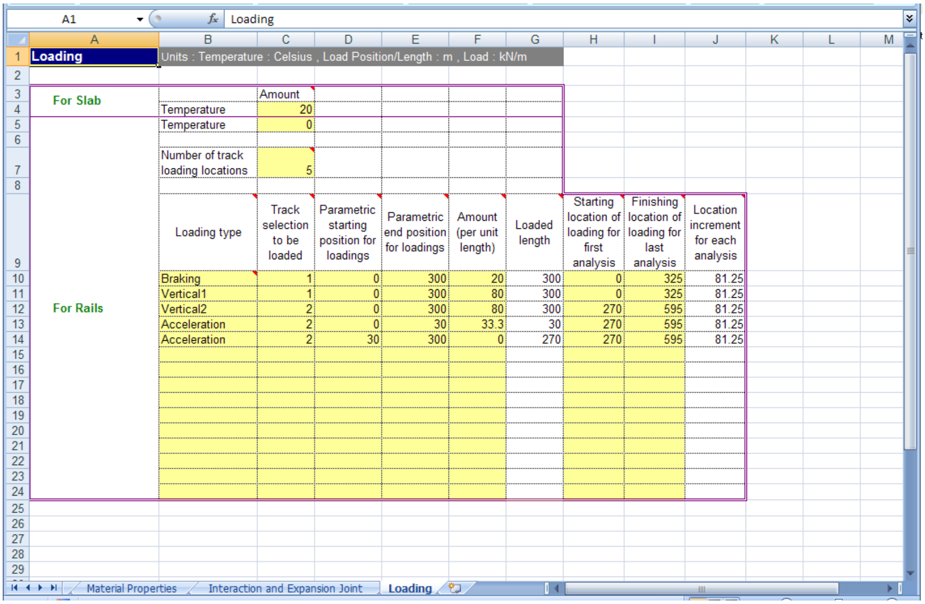
Item		Longitudinal	Transverse	Vertical
Eccentricity between rail/slab		0		
Unloaded Bilinear Springs characteristic	Contact Stiff	80	infinite	infinite
	Lift-off force	40	infinite	infinite
	Lift-off springs	1.00E-06	infinite	infinite
Loaded Bilinear Springs characteristic	Contact Stiff	120	infinite	infinite
	Lift-off force	60	infinite	infinite
	Lift-off springs	1.00E-06	infinite	infinite

Rail Expansion Joints — Units : Distance : m, Initial gap : mm

	Track 1		Track 2	
	Position	Initial Gap	Position	Initial Gap
1	300	5		
2	475	5	475	5
3			625	5

Figure 30: Sample Expansion Joint Definitions

Worksheet 6: Thermal and Train Loading



	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
3	For Slab		Amount							
4		Temperature	20							
5		Temperature	0							
7		Number of track loading locations	5							
9		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
10		Braking	1	0	300	20	300	0	325	81.25
11		Vertical1	1	0	300	80	300	0	325	81.25
12	For Rails	Vertical2	2	0	300	80	300	270	595	81.25
13		Acceleration	2	0	30	33.3	30	270	595	81.25
14		Acceleration	2	30	300	0	270	270	595	81.25

Figure 31: Definition of Thermal and Train Loading for Structure

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

Temperature Loading

The temperature effects in the rails for a continuously welded rail (CWR) track do not cause a displacement of the track and do not need to be considered (UIC774-3 Clause 1.4.2). For all other tracks the change in temperature of the bridge deck and rails relative to the reference temperature of the deck when the rail was fixed needs to be considered in accordance to the code of practice and design specifications. The temperature loads for both the slab/deck and the rail should be entered (zero if not required) in Celsius (degrees centigrade) where temperature rises are entered as positive values and temperature drops are entered as negative values.

Trainset Loading to Rails of Tracks

The trainset loading is defined in terms of the type, track to load, position and magnitude. The loading allows for multiple trainset loading positions to be defined in a single spreadsheet and all of these positions to be analysed on one go by the wizard. All of the trainset loading must fit within the length of the tracks of the model with the left-hand end of the left embankment at a position of 0.0m and the right-hand end of the right embankment at a position equal to the total length of the model reported in the ***Number of Decks, Tracks And Embankment Lengths*** worksheet.

As many rail/train loads as required can be defined in the spreadsheet with data input terminating when blank data is detected in the loading type column. This allows more complex loading patterns to be defined such as the accelerating trainset loading illustrated in Figure 32. To extend the bottom of the table extra rows can be inserted (making sure to copy the formulae in columns G and J) or the last rows copied and pasted as many times as required.

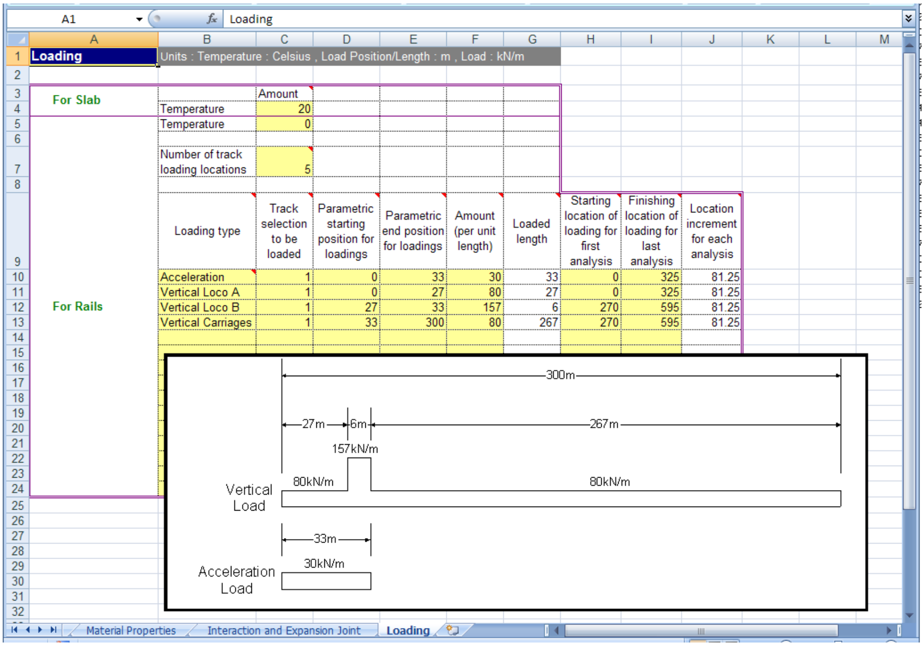


Figure 32: More Complex Train Loading Definition in Spreadsheet

The inputs to the worksheet are:

Number of track loading locations

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

Loading type

Defines the loading type that will be assigned to the selected track. The first character governs the loading type with valid options being **A**cceleration, **B**raking and **V**ertical.

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

Track selection to be loaded

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

Parametric starting position for loadings

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

Parametric end position for loadings

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

Amount (per unit length)

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

Loaded length

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

Figure 33 illustrates some trainset loading configurations and their input into the worksheet. Examples (d) and (e) in this figure are equivalent and both definition methods are equally valid in the worksheet.

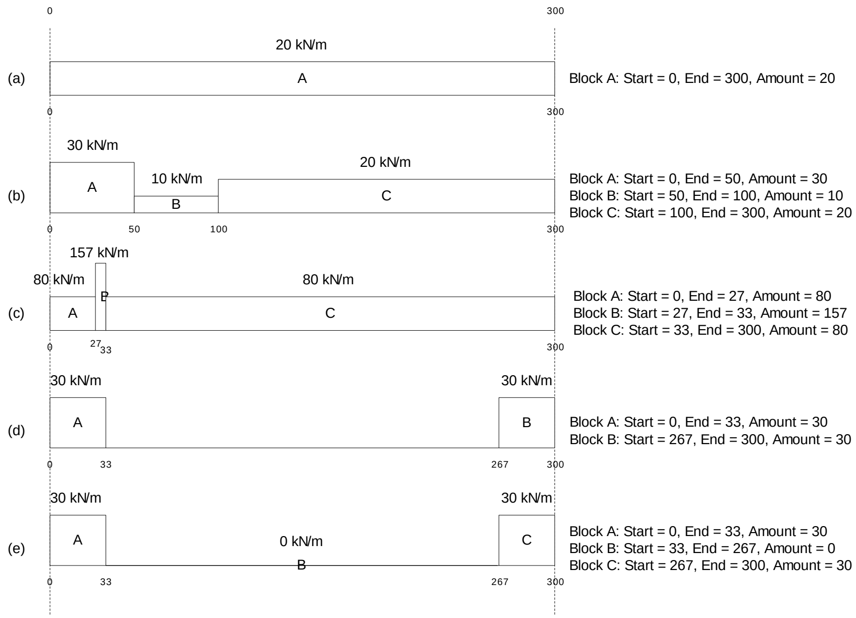


Figure 33: Sample Trainset Loading Position Definitions

Starting location of loading for first analysis

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

Location increment for each analysis

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

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

Rail Track Analysis Menu Options

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

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

Build Model Dialog

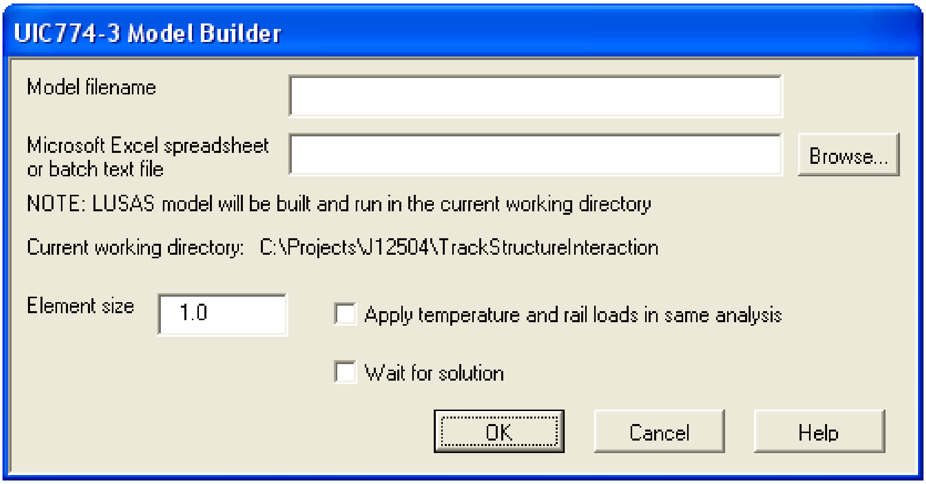


Figure 34: UIC774-3 Model Builder Dialog

- **Model filename** The model filename for the analysis should be entered into the box if batch processing is not being used (see below). The file should not contain any directory specification as all models will be placed in the current working directory 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 directory structure is specified the spreadsheet should be located in the current working directory. 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 list of the Microsoft Excel files to build the models from with one file per line. If no directory structure is defined for the files then the current working directory will be assumed to contain the files, otherwise they may exist at any directory 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 directory. 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.

```
Bridge1.xls
..\SomeDirectory\Bridge2.xls
D:\Project\Spreadsheet\Bridge3.xls
```

Figure 35: Example Batch Text File With Three Bridges To Build

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

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. 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.

Note. If the **Wait for solution** option is not selected then VBScript files with the same base name as the LUSAS model(s) will be created in the working directory to allow easy loading of the results. To post-process a particular model, load the model without the results on top (choose No when Modeller reports that a results file of the same name has been detected) and then load the VBScript file named ?????_Reload.vbs (where ????? is the base name of the model) using the File>Script>Run Script... menu item. These files are also generated if the wait for solution option is selected but will only be required if batch model building is being used or a model and parametric results need to be reloaded at some time in the future.

Caution. You should not attempt to run another rail track analysis in the same directory 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 directory.

Apply Rail Loads Dialog

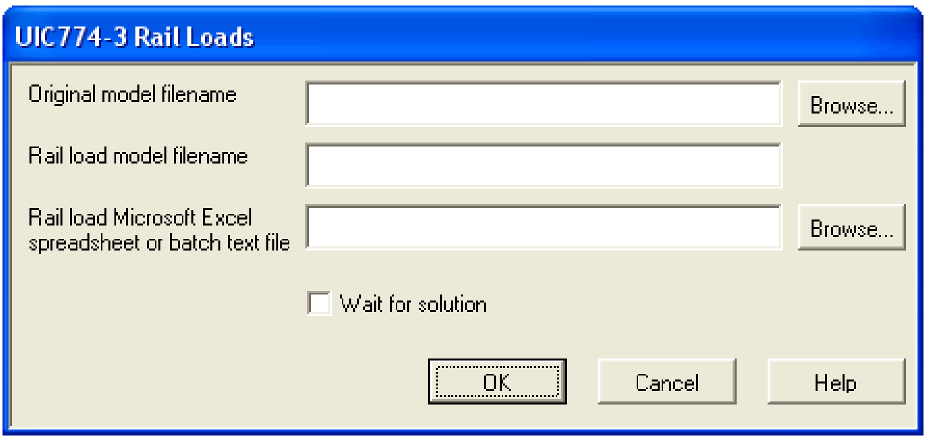


Figure 36: UIC774-3 Apply Rail Loads Dialog

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

- **Original model filename** If a single rail load configuration is to be analysed 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 (directory must exist) but should generally only have the filename defined which will then be saved in the current working directory. This filename can be the same as the original model filename but should generally be different to allow the temperature loading model to be reused for another rail load configuration. For batch processing the new rail load model filename is ignored.
- **Rail load Microsoft Excel spreadsheet or batch text file** If a single rail load configuration is to be analysed for the specified bridge model the filename of the Microsoft Excel spreadsheet containing the required loading should be entered into the box. Alternatively the Browse… button can be used to locate the file. Once the spreadsheet has been specified the OK button can be clicked to carry out the modification of the original bridge model to include the combined effects of the temperature and rail loading.

If multiple models and/or multiple rail load configurations are to be analysed then only the batch text file (which must have a *.txt file extension) listing the information required by the software should be entered into this box. Alternatively, the Browse… button can be used, selecting "Batch text file (*.txt)" as the file type. For each model/rail configuration analysis the batch text file should contain a separate line of data. Each line should specify the original temperature model, the new combined loading model to create and the Microsoft Excel spreadsheet that contains the rail configuration definition. Each item on a line should be TAB delimited to allow spaces to be used in the filenames. An example batch text file is shown below.

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

Figure 37: Sample Rail Loading Batch Text File

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

- **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.

Note. If the **Wait for solution** option is not selected then VBScript files with the same base name as the LUSAS model(s) will be created in the working directory to allow easy loading of the results. To post-process a particular model, load the model without the results on top (choose No when Modeller reports that a results file of the same name has been detected) and then load the VBScript file named ?????_Reload.vbs (where ????? is the base name of the model) using the File>Script>Run Script... menu item. These files are also generated if the wait for solution option is selected but will only be required if batch model building is being used or a model and parametric results need to be reloaded at some time in the future.

Caution. You should not attempt to run another rail track analysis in the same directory 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 directory.

Extract Results To Microsoft Excel Dialog

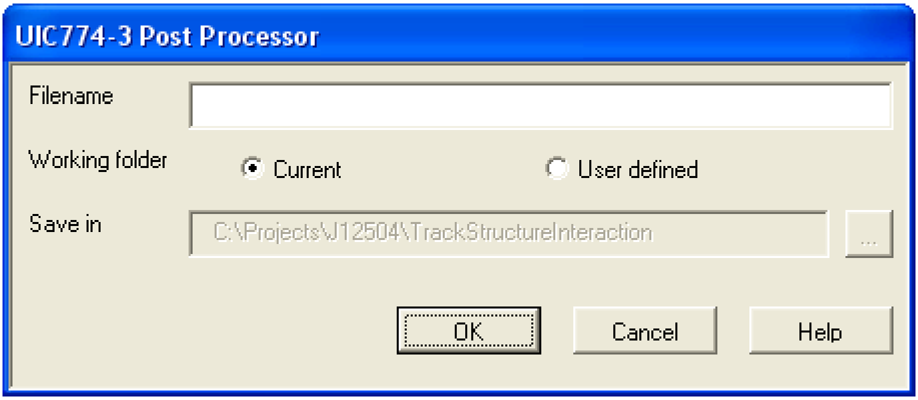


Figure 38: UIC774-3 Post Processor Dialog

A dedicated post-processing dialog is provided that allows the automatic extraction of the results from the track/bridge interaction analysis to a Microsoft Excel spreadsheet. On start-up, if nothing is selected in Modeller, the dialog will inspect the active model to ensure that there are results present and also detect whether the UIC774-3 groups defined during the model building process are present. For this reason any manual editing of the model should be kept to a minimum and the "Track 1", "Track 2" and "Decks" 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 directory structure specified as the file will be placed in the directory selected below.
- **Working folder / Save In** If the spreadsheet is to be saved in a directory other than the current working directory then the User defined option can be selected and the required directory entered into the box or browsed for using the … button.

Three methods of post-processing are available from the dialog. These are:

- **Post-processing of automatically defined groups**
- **Post-processing of selected track / rail nodes**
- **Post-processing of selected lines if groups are missing**

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.

Post-processing of automatically defined groups

If nothing is selected in the Modeller window and all of the UIC774-3 groups are present then separate worksheets are generated for the results in the tracks/rails and decks. If basic combinations or envelopes have been defined in the LUSAS model the results from these will also be output to the worksheets.

Rail Track Results

A separate worksheet is created for each track in the model. In this worksheet the displacement (including railbed relative displacement), forces / moments and axial stresses in the track rails are reported for all of the results files. If only temperature results exist in a results file the post-processing will only generate the output for these (Increment 1 of the nonlinear analysis), Figure 39 to Figure 41. If trainset loading is also present in the analyses then for each results file the results for the temperature only (Increment 1 of the nonlinear analysis) and the combined temperature and trainset loading (Increment 2 of the nonlinear analysis) are output for each results file, Figure 42 to Figure 44. Figure 45 shows a zoomed out version of the worksheet showing the output for multiple results files. In this figure the temperature only and combined results for two results files are illustrated with the analyses incrementing from left to right and for each, the first column of results and graphs are for the temperature only case and the second column are for the combined case for each analysis.

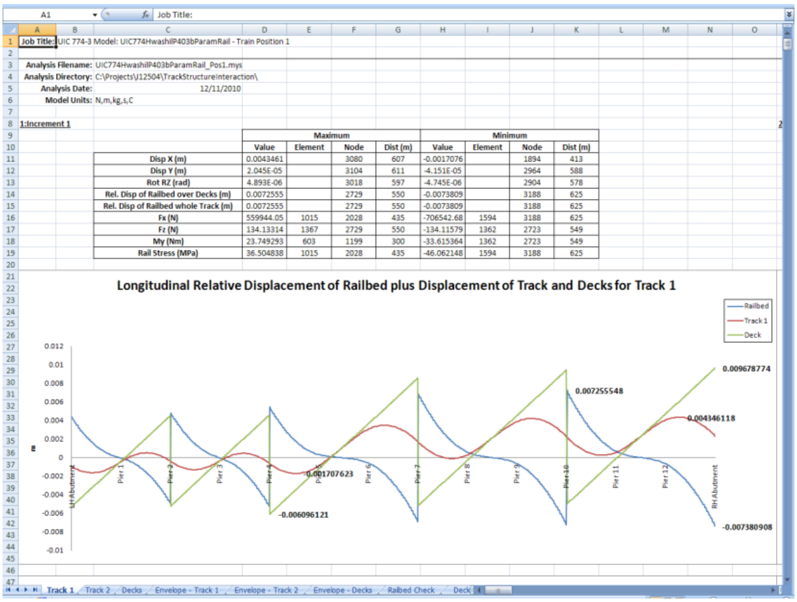


Figure 39: Track Worksheet Summary and Railbed Graph for Temperature Only Results of Analysis, Increment 1 (1 of 3)

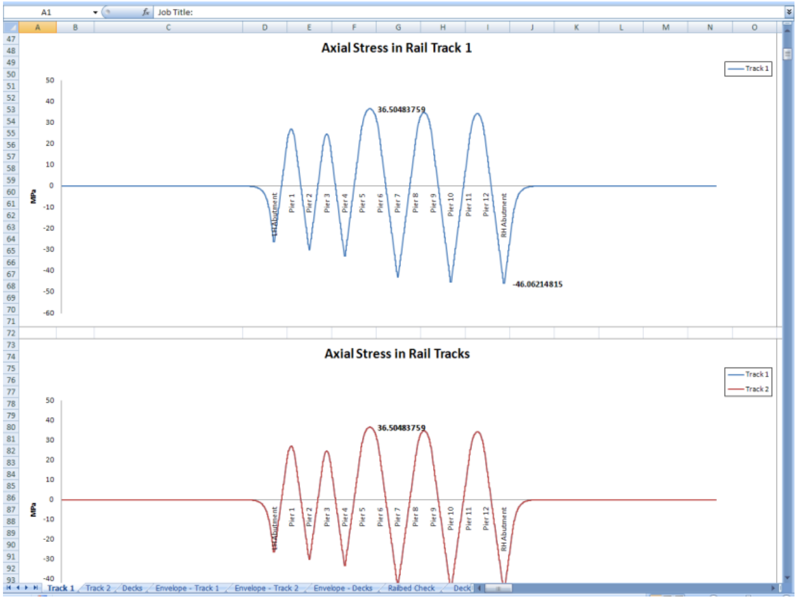
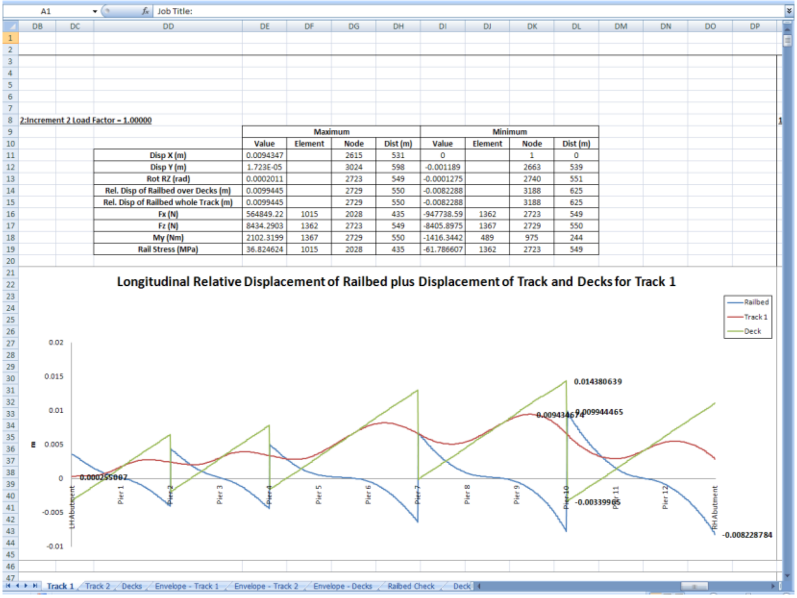


Figure 40: Track Worksheet Rail Stress Graphs for Temperature Only Results of Analysis, Increment 1 (2 of 3)

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)
1	1		0	-300	0	0	0	0	0	0	-3.034E-15	1.555E-64	1.271E-65	-1.978E-19
1	2		1	-299	0	0	-9.42E-25	2.084E-73	1.177E-72	-9.42E-25	-3.034E-15	1.555E-64	1.271E-65	-1.978E-19
3	2		1	-299	0	0	-9.42E-25	2.084E-73	1.177E-72	-9.42E-25	-3.11E-15	-2.246E-64	-2.185E-65	-2.027E-19
3	7		2	-298	0	0	-1.907E-24	-1.497E-73	-2.645E-72	-1.907E-24	-3.11E-15	-2.246E-64	-2.185E-65	-2.027E-19
5	7		2	-298	0	0	-1.907E-24	-1.497E-73	-2.645E-72	-1.907E-24	-3.262E-15	3.059E-64	1.876E-65	-2.127E-19
5	11		3	-297	0	0	-2.92E-24	1.292E-73	4.022E-72	-2.92E-24	-3.262E-15	3.059E-64	1.876E-65	-2.127E-19
7	11		3	-297	0	0	-2.92E-24	1.292E-73	4.022E-72	-2.92E-24	-3.496E-15	-3.871E-64	-2.184E-65	-2.279E-19
7	15		4	-296	0	0	-4.005E-24	-1.445E-73	-5.549E-72	-4.005E-24	-3.496E-15	-3.871E-64	-2.184E-65	-2.279E-19
9	15		4	-296	0	0	-4.005E-24	-1.445E-73	-5.549E-72	-4.005E-24	-3.816E-15	4.873E-64	2.83E-65	-2.488E-19
9	19		5	-295	0	0	-5.19E-24	1.779E-73	7.413E-72	-5.19E-24	-3.816E-15	4.873E-64	2.83E-65	-2.488E-19
11	19		5	-295	0	0	-5.19E-24	1.779E-73	7.413E-72	-5.19E-24	-4.232E-15	-6.183E-64	-3.72E-65	-2.759E-19
11	23		6	-294	0	0	-6.504E-24	-2.255E-73	-9.763E-72	-6.504E-24	-4.232E-15	-6.183E-64	-3.72E-65	-2.759E-19
13	23		6	-294	0	0	-6.504E-24	-2.255E-73	-9.763E-72	-6.504E-24	-4.752E-15	7.902E-64	4.871E-65	-3.098E-19
13	27		7	-293	0	0	-7.979E-24	2.886E-73	1.276E-71	-7.979E-24	-4.752E-15	7.902E-64	4.871E-65	-3.098E-19
15	27		7	-293	0	0	-7.979E-24	2.886E-73	1.276E-71	-7.979E-24	-5.39E-15	-1.015E-63	-6.35E-65	-3.514E-19
15	31		8	-292	0	0	-9.652E-24	-3.712E-73	-1.661E-71	-9.652E-24	-5.39E-15	-1.015E-63	-6.35E-65	-3.514E-19
17	31		8	-292	0	0	-9.652E-24	-3.712E-73	-1.661E-71	-9.652E-24	-6.162E-15	1.307E-63	8.254E-65	-4.018E-19
17	35		9	-291	0	0	-1.157E-23	4.785E-73	2.157E-71	-1.157E-23	-6.162E-15	1.307E-63	8.254E-65	-4.018E-19
19	35		9	-291	0	0	-1.157E-23	4.785E-73	2.157E-71	-1.157E-23	-7.088E-15	-1.686E-63	-1.071E-64	-4.621E-19
19	39		10	-290	0	0	-1.377E-23	-6.177E-73	-2.797E-71	-1.377E-23	-7.088E-15	-1.686E-63	-1.071E-64	-4.621E-19
21	39		10	-290	0	0	-1.377E-23	-6.177E-73	-2.797E-71	-1.377E-23	-8.189E-15	2.178E-63	1.388E-64	-5.339E-19
21	43		11	-289	0	0	-1.631E-23	7.982E-73	3.623E-71	-1.631E-23	-8.189E-15	2.178E-63	1.388E-64	-5.339E-19
23	43		11	-289	0	0	-1.631E-23	7.982E-73	3.623E-71	-1.631E-23	-9.494E-15	-2.815E-63	-1.797E-64	-6.189E-19
23	47		12	-288	0	0	-1.926E-23	-1.032E-72	-4.691E-71	-1.926E-23	-9.494E-15	-2.815E-63	-1.797E-64	-6.189E-19
25	47		12	-288	0	0	-1.926E-23	-1.032E-72	-4.691E-71	-1.926E-23	-1.103E-14	3.639E-63	2.327E-64	-7.193E-19
25	51		13	-287	0	0	-2.268E-23	1.334E-72	6.072E-71	-2.268E-23	-1.103E-14	3.639E-63	2.327E-64	-7.193E-19
27	51		13	-287	0	0	-2.268E-23	1.334E-72	6.072E-71	-2.268E-23	-1.285E-14	-4.707E-63	-3.011E-64	-8.376E-19
27	55		14	-286	0	0	-2.667E-23	-1.726E-72	-7.858E-71	-2.667E-23	-1.285E-14	-4.707E-63	-3.011E-64	-8.376E-19
29	55		14	-286	0	0	-2.667E-23	-1.726E-72	-7.858E-71	-2.667E-23	-1.498E-14	6.088E-63	3.897E-64	-9.767E-19
29	59		15	-285	0	0	-3.132E-23	2.233E-72	1.017E-70	-3.132E-23	-1.498E-14	6.088E-63	3.897E-64	-9.767E-19
31	59		15	-285	0	0	-3.132E-23	2.233E-72	1.017E-70	-3.132E-23	-1.749E-14	-7.876E-63	-5.042E-64	-1.14E-18
31	63		16	-284	0	0	-3.675E-23	-2.889E-72	-1.316E-70	-3.675E-23	-1.749E-14	-7.876E-63	-5.042E-64	-1.14E-18
33	63		16	-284	0	0	-3.675E-23	-2.889E-72	-1.316E-70	-3.675E-23	-2.043E-14	1.019E-62	6.524E-64	-1.332E-18
33	67		17	-283	0	0	-4.309E-23	3.737E-72	1.702E-70	-4.309E-23	-2.043E-14	1.019E-62	6.524E-64	-1.332E-18
35	67		17	-283	0	0	-4.309E-23	3.737E-72	1.702E-70	-4.309E-23	-2.388E-14	-1.318E-62	-8.441E-64	-1.557E-18
35	71		18	-282	0	0	-5.05E-23	-4.835E-72	-2.202E-70	-5.05E-23	-2.388E-14	-1.318E-62	-8.441E-64	-1.557E-18
37	71		18	-282	0	0	-5.05E-23	-4.835E-72	-2.202E-70	-5.05E-23	-2.792E-14	1.705E-62	1.092E-63	-1.82E-18
37	75		19	-281	0	0	-5.917E-23	6.255E-72	2.85E-70	-5.917E-23	-2.792E-14	1.705E-62	1.092E-63	-1.82E-18
39	75		19	-281	0	0	-5.917E-23	6.255E-72	2.85E-70	-5.917E-23	-3.265E-14	-2.206E-62	-1.413E-63	-2.129E-18
39	79		20	-280	0	0	-6.931E-23	-8.092E-72	-3.687E-70	-6.931E-23	-3.265E-14	-2.206E-62	-1.413E-63	-2.129E-18
41	79		20	-280	0	0	-6.931E-23	-8.092E-72	-3.687E-70	-6.931E-23	-3.819E-14	2.855E-62	1.828E-63	-2.49E-18
41	83		21	-279	0	0	-8.116E-23	1.047E-71	4.77E-70	-8.116E-23	-3.819E-14	2.855E-62	1.828E-63	-2.49E-18
43	83		21	-279	0	0	-8.116E-23	1.047E-71	4.77E-70	-8.116E-23	-4.469E-14	-3.693E-62	-2.365E-63	-2.913E-18
43	87		22	-278	0	0	-9.503E-23	-1.355E-71	-6.171E-70	-9.503E-23	-4.469E-14	-3.693E-62	-2.365E-63	-2.913E-18

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



2:Increment 2 Load Factor = 1.00000

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.0094347		2615	531	0		1	0
Disp Y (m)	1.723E-05		3024	598	-0.001189		2663	539
Rot RZ (rad)	0.0002011		2723	549	-0.0001275		2740	551
Rel. Disp of Railbed over Decks (m)	0.0099445		2729	550	-0.0082288		3188	625
Rel. Disp of Railbed whole Track (m)	0.0099445		2729	550	-0.0082288		3188	625
Fx (N)	564849.22	1015	2028	435	-947738.59	1362	2723	549
Fz (N)	8434.2903	1362	2723	549	-8405.8975	1367	2729	550
My (Nm)	2102.3199	1367	2729	550	-1416.3442	489	975	244
Rail Stress (MPa)	36.824624	1015	2028	435	-61.786607	1362	2723	549

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

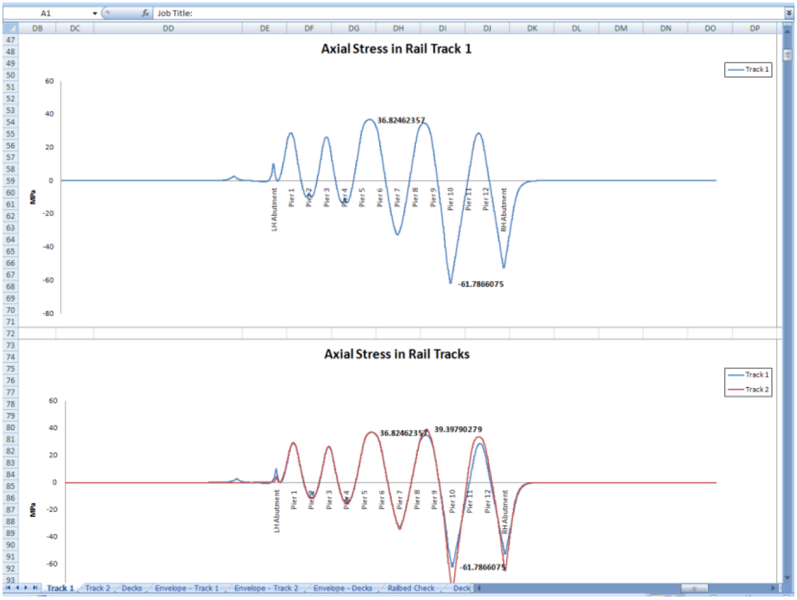
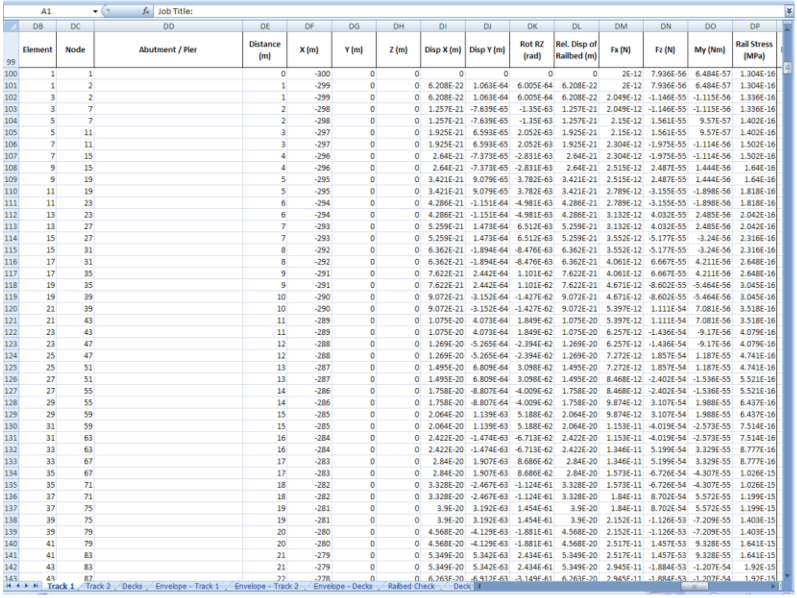


Figure 43: Track Worksheet Rail Stress Graphs for Temperature and Trainset Results of Analysis, Increment 2 (2 of 3)



	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP
99	Element	Node	Abutment / Pier	Distance (m)	X (m)	Y (m)	Z (m)	Disp X (m)	Disp Y (m)	Rot RZ (rad)	Rel. Disp of Railbed (m)	Fx (N)	Fz (N)	My (Nm)	Rail Stress (MPa)
100	1	1		0	-300	0	0	0	0	0	0	2E-12	7.936E-56	6.484E-57	1.304E-16
101	1	2		1	-299	0	0	6.208E-22	1.063E-64	6.005E-64	6.208E-22	2E-12	7.936E-56	6.484E-57	1.304E-16
102	3	2		1	-299	0	0	6.208E-22	1.063E-64	6.005E-64	6.208E-22	2.049E-12	-1.146E-55	-1.115E-56	1.336E-16
103	3	7		2	-298	0	0	1.257E-21	-7.639E-65	-1.35E-63	1.257E-21	2.049E-12	-1.146E-55	-1.115E-56	1.336E-16
104	5	7		2	-298	0	0	1.257E-21	-7.639E-65	-1.35E-63	1.257E-21	2.15E-12	1.561E-55	9.57E-57	1.402E-16
105	5	11		3	-297	0	0	1.925E-21	6.593E-65	2.052E-63	1.925E-21	2.15E-12	1.561E-55	9.57E-57	1.402E-16
106	7	11		3	-297	0	0	1.925E-21	6.593E-65	2.052E-63	1.925E-21	2.304E-12	-1.975E-55	-1.114E-56	1.502E-16
107	7	15		4	-296	0	0	2.64E-21	-7.373E-65	-2.831E-63	2.64E-21	2.304E-12	-1.975E-55	-1.114E-56	1.502E-16
108	9	15		4	-296	0	0	2.64E-21	-7.373E-65	-2.831E-63	2.64E-21	2.515E-12	2.487E-55	1.444E-56	1.64E-16
109	9	19		5	-295	0	0	3.421E-21	9.079E-65	3.782E-63	3.421E-21	2.515E-12	2.487E-55	1.444E-56	1.64E-16
110	11	19		5	-295	0	0	3.421E-21	9.079E-65	3.782E-63	3.421E-21	2.789E-12	-3.155E-55	-1.898E-56	1.818E-16
111	11	23		6	-294	0	0	4.286E-21	-1.151E-64	-4.981E-63	4.286E-21	2.789E-12	-3.155E-55	-1.898E-56	1.818E-16
112	13	23		6	-294	0	0	4.286E-21	-1.151E-64	-4.981E-63	4.286E-21	3.132E-12	4.032E-55	2.485E-56	2.042E-16
113	13	27		7	-293	0	0	5.259E-21	1.473E-64	6.512E-63	5.259E-21	3.132E-12	4.032E-55	2.485E-56	2.042E-16
114	15	27		7	-293	0	0	5.259E-21	1.473E-64	6.512E-63	5.259E-21	3.552E-12	-5.177E-55	-3.24E-56	2.316E-16
115	15	31		8	-292	0	0	6.362E-21	-1.894E-64	-8.476E-63	6.362E-21	3.552E-12	-5.177E-55	-3.24E-56	2.316E-16
116	17	31		8	-292	0	0	6.362E-21	-1.894E-64	-8.476E-63	6.362E-21	4.061E-12	6.667E-55	4.211E-56	2.648E-16
117	17	35		9	-291	0	0	7.622E-21	2.442E-64	1.101E-62	7.622E-21	4.061E-12	6.667E-55	4.211E-56	2.648E-16
118	19	35		9	-291	0	0	7.622E-21	2.442E-64	1.101E-62	7.622E-21	4.671E-12	-8.602E-55	-5.464E-56	3.045E-16
119	19	39		10	-290	0	0	9.072E-21	-3.152E-64	-1.427E-62	9.072E-21	4.671E-12	-8.602E-55	-5.464E-56	3.045E-16
120	21	39		10	-290	0	0	9.072E-21	-3.152E-64	-1.427E-62	9.072E-21	5.397E-12	1.111E-54	7.081E-56	3.518E-16
121	21	43		11	-289	0	0	1.075E-20	4.073E-64	1.849E-62	1.075E-20	5.397E-12	1.111E-54	7.081E-56	3.518E-16
122	23	43		11	-289	0	0	1.075E-20	4.073E-64	1.849E-62	1.075E-20	6.257E-12	-1.436E-54	-9.17E-56	4.079E-16
123	23	47		12	-288	0	0	1.269E-20	-5.265E-64	-2.394E-62	1.269E-20	6.257E-12	-1.436E-54	-9.17E-56	4.079E-16
124	25	47		12	-288	0	0	1.269E-20	-5.265E-64	-2.394E-62	1.269E-20	7.272E-12	1.857E-54	1.187E-55	4.741E-16
125	25	51		13	-287	0	0	1.495E-20	6.809E-64	3.098E-62	1.495E-20	7.272E-12	1.857E-54	1.187E-55	4.741E-16
126	27	51		13	-287	0	0	1.495E-20	6.809E-64	3.098E-62	1.495E-20	8.468E-12	-2.402E-54	-1.536E-55	5.521E-16
127	27	55		14	-286	0	0	1.758E-20	-8.807E-64	-4.009E-62	1.758E-20	8.468E-12	-2.402E-54	-1.536E-55	5.521E-16
128	29	55		14	-286	0	0	1.758E-20	-8.807E-64	-4.009E-62	1.758E-20	9.874E-12	3.107E-54	1.988E-55	6.437E-16
129	29	59		15	-285	0	0	2.064E-20	1.139E-63	5.188E-62	2.064E-20	9.874E-12	3.107E-54	1.988E-55	6.437E-16
130	31	59		15	-285	0	0	2.064E-20	1.139E-63	5.188E-62	2.064E-20	1.153E-11	-4.019E-54	-2.573E-55	7.514E-16
131	31	63		16	-284	0	0	2.422E-20	-1.474E-63	-6.713E-62	2.422E-20	1.153E-11	-4.019E-54	-2.573E-55	7.514E-16
132	33	63		16	-284	0	0	2.422E-20	-1.474E-63	-6.713E-62	2.422E-20	1.346E-11	5.199E-54	3.329E-55	8.777E-16
133	33	67		17	-283	0	0	2.84E-20	1.907E-63	8.686E-62	2.84E-20	1.346E-11	5.199E-54	3.329E-55	8.777E-16
134	35	67		17	-283	0	0	2.84E-20	1.907E-63	8.686E-62	2.84E-20	1.573E-11	-6.726E-54	-4.307E-55	1.026E-15
135	35	71		18	-282	0	0	3.328E-20	-2.467E-63	-1.124E-61	3.328E-20	1.573E-11	-6.726E-54	-4.307E-55	1.026E-15
136	37	71		18	-282	0	0	3.328E-20	-2.467E-63	-1.124E-61	3.328E-20	1.84E-11	8.702E-54	5.572E-55	1.199E-15
137	37	75		19	-281	0	0	3.9E-20	3.192E-63	1.454E-61	3.9E-20	1.84E-11	8.702E-54	5.572E-55	1.199E-15
138	39	75		19	-281	0	0	3.9E-20	3.192E-63	1.454E-61	3.9E-20	2.152E-11	-1.126E-53	-7.209E-55	1.403E-15
139	39	79		20	-280	0	0	4.568E-20	-4.129E-63	-1.881E-61	4.568E-20	2.152E-11	-1.126E-53	-7.209E-55	1.403E-15
140	41	79		20	-280	0	0	4.568E-20	-4.129E-63	-1.881E-61	4.568E-20	2.517E-11	1.457E-53	9.328E-55	1.641E-15
141	41	83		21	-279	0	0	5.349E-20	5.342E-63	2.434E-61	5.349E-20	2.517E-11	1.457E-53	9.328E-55	1.641E-15
142	43	83		21	-279	0	0	5.349E-20	5.342E-63	2.434E-61	5.349E-20	2.945E-11	-1.884E-53	-1.207E-54	1.92E-15
143	43	87		22	-278	0	0	6.263E-20	-6.912E-63	-3.149E-61	6.263E-20	2.945E-11	-1.884E-53	-1.207E-54	1.92E-15

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

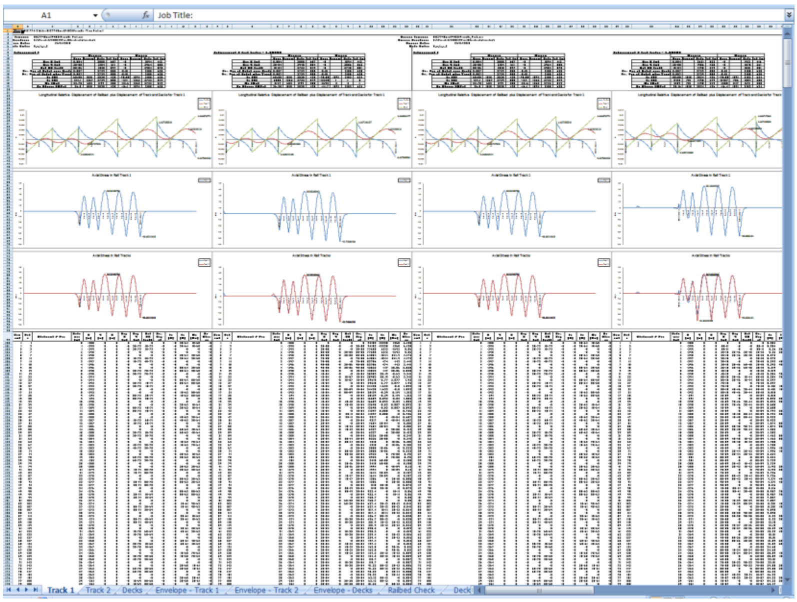


Figure 45: Track Worksheet for Multiple Results Files

Deck Results

A separate worksheet is created for the deck in the model. In this worksheet the displacement and forces / moments in the deck are reported for all of the results files. If only temperature results exist in a results file the post-processing will only generate the output for these (Increment 1 of the nonlinear analysis). If trainset loading is also present in the analyses then for each results file the results for the temperature only (Increment 1 of the nonlinear analysis) and the combined temperature and trainset loading (Increment 2 of the nonlinear analysis) are output for each results file. Figure 46 to Figure 49 show the tabulated and graph output generated for the deck for all of the loading conditions included in the analyses. Figure 50 shows a zoomed out version of the worksheet showing the output for multiple results files. In this figure the temperature only and combined results for more than two results files are illustrated with the analyses incrementing from left to right and for each, the first column of results and graphs are for the temperature only case and the second column are for the combined case for each analysis.

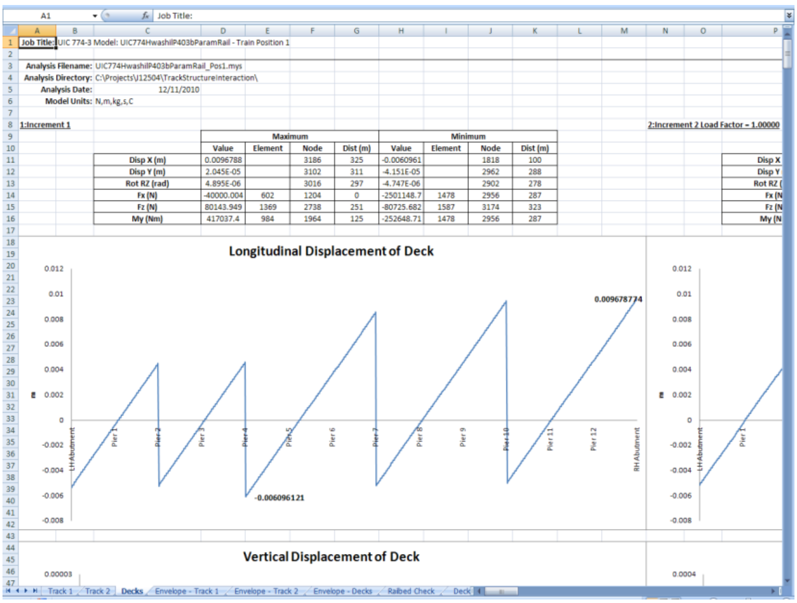


Figure 46: Deck Worksheet Summary and Longitudinal Displacement Graph for Results of Analysis (1 of 4)

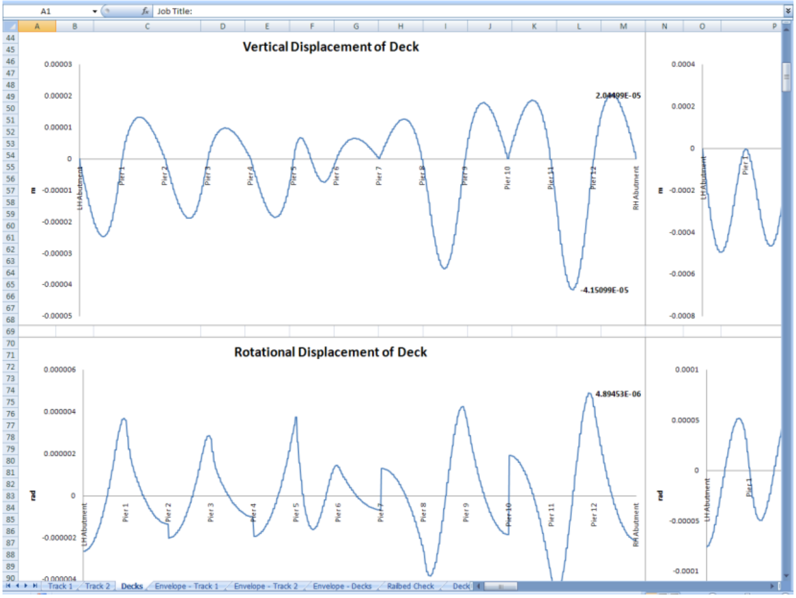


Figure 47: Deck Worksheet Verical and Rotational Displacement Graphs for Results of Analysis (2 of 4)

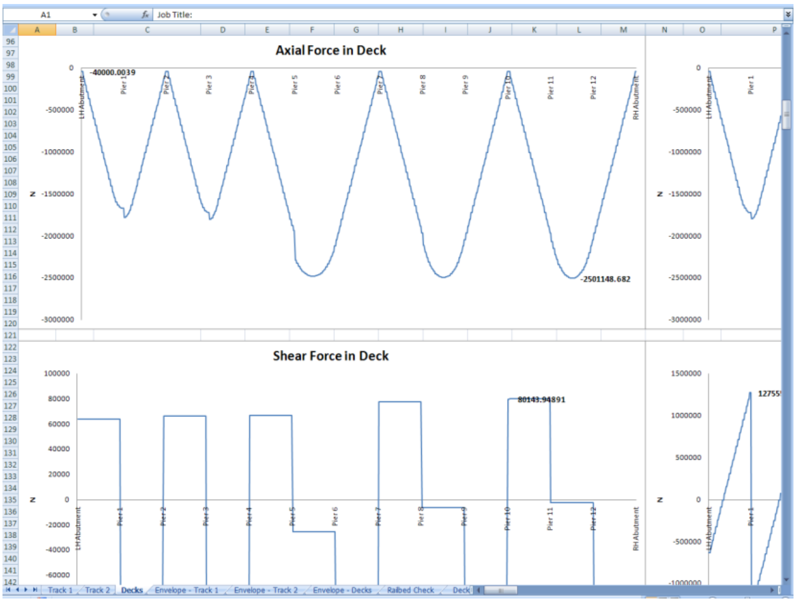


Figure 48: Deck Worksheet Axial and Shear Force Graphs for Results of Analysis (3 of 4)

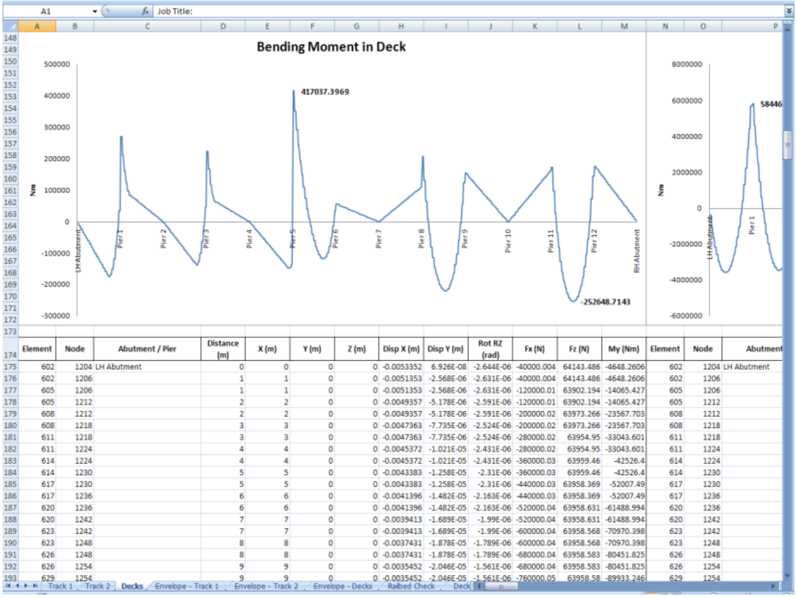


Figure 49: Deck Worksheet Bending Moment Graph and Tabulated Output for Results of Analysis (4 of 4)

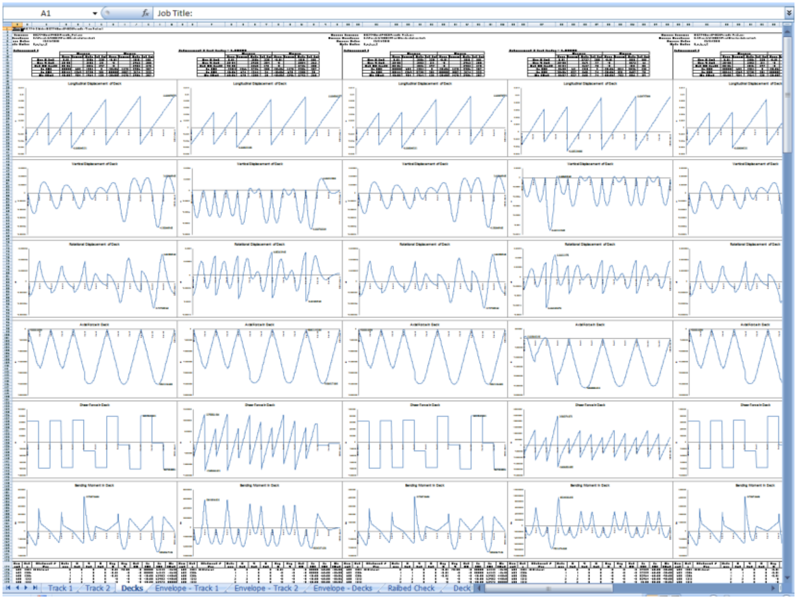


Figure 50: Deck Worksheet for Multiple Results Files

Additional Results from Enveloping

If more than one results file is loaded, no combinations or envelopes are defined in the model 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 need to be checked in UIC774-3. 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 loading (an envelope of the above two)

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 (Horizontal Loading)
- ❑ Longitudinal Relative Displacement between Ends of Decks (Vertical Loading)
- ❑ Vertical Relative Displacement between Ends of Decks
- ❑ Longitudinal Reactions
- ❑ Axial Rail Stress

Sample tables are shown in the following figures and these allow the quick determination of which analysis is causing the worst effects for each of the checks that need to be performed.

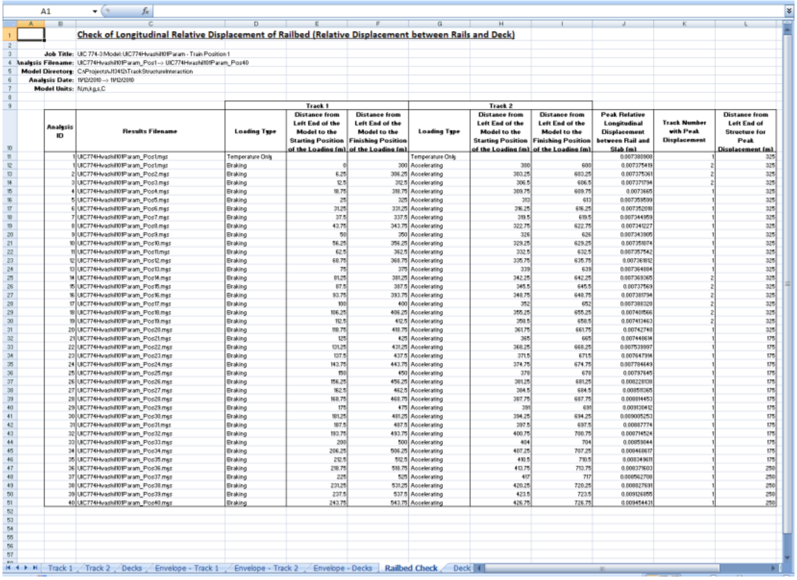


Figure 51: Railbed Check Worksheet for Multiple Results Files

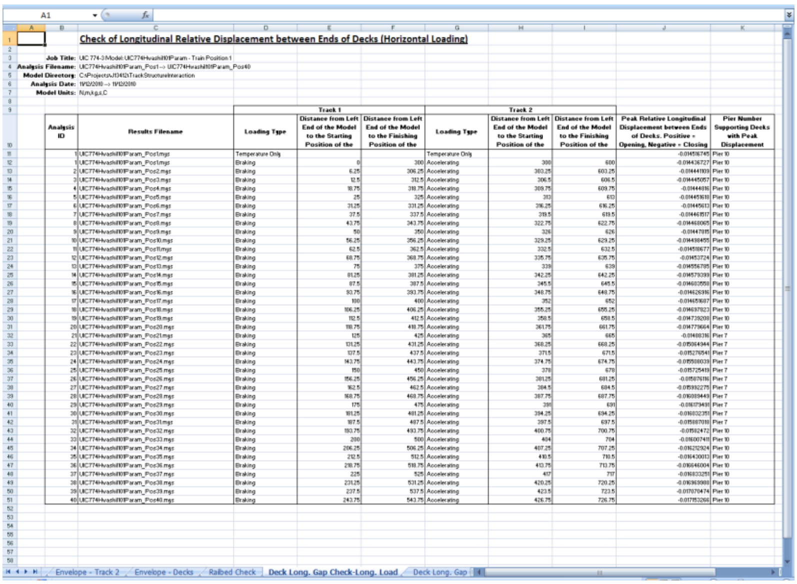
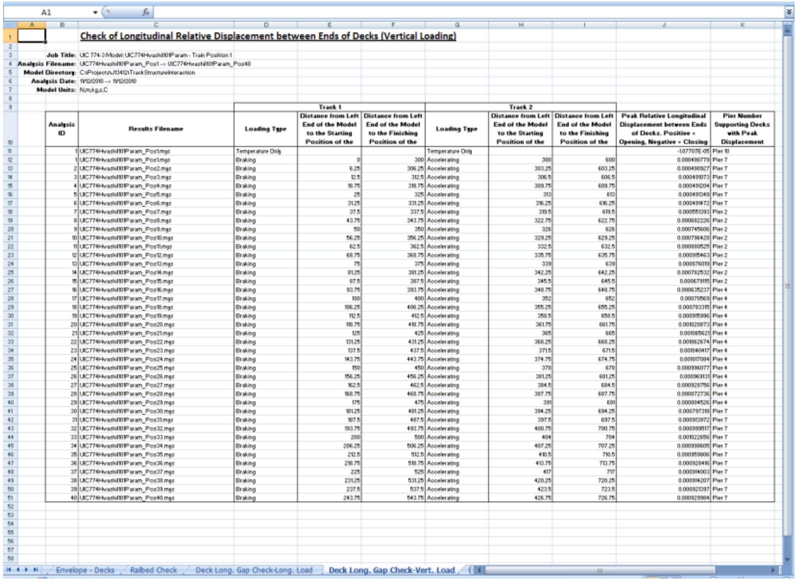


Figure 52: Longitudinal Deck End Displacement due to Horizontal Loading Check Worksheet for Multiple Results Files

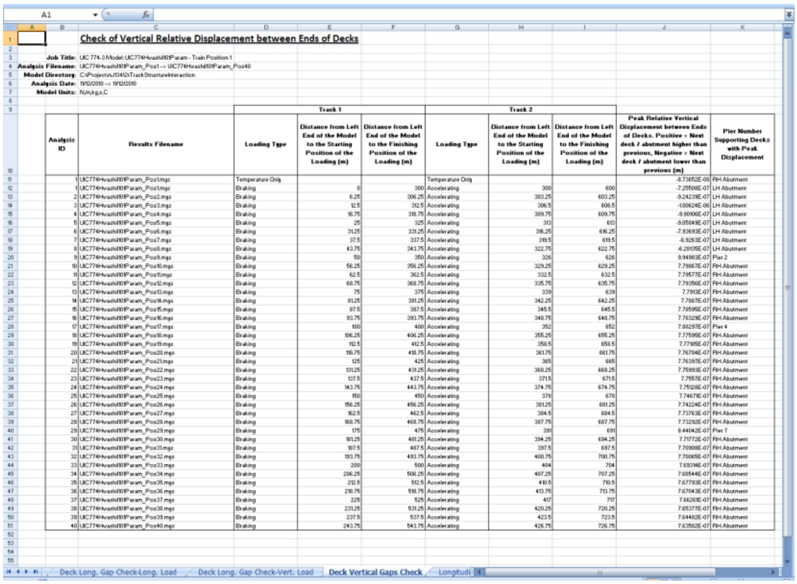


Check of Longitudinal Relative Displacement between Ends of Decks (Vertical Loading)

Job Title: UIC 774-3 Model: UIC774Hvashil10fParam - Train Position 1
Analysis Filename: UIC774Hvashil10fParam_Pos1 --> UIC774Hvashil10fParam_Pos40
Model Directory: C:\Projects\J13412\TrackStructureInteraction
Analysis Date: 11/12/2010 --> 11/12/2010
Model Units: N,m,kg,s,C

		Track 1			Track 2				
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Peak Relative Longitudinal Displacement between Ends of Decks. Positive = Opening, Negative = Closing	Pier Number Supporting Decks with Peak Displacement
1	UIC774Hvashil10fParam_Pos1.mys	Temperature Only			Temperature Only			-1.07707E-05	Pier 10
1	UIC774Hvashil10fParam_Pos1.mys	Braking	0	300	Accelerating	300	600	0.000490779	Pier 7
2	UIC774Hvashil10fParam_Pos2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	0.000490927	Pier 7
3	UIC774Hvashil10fParam_Pos3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	0.000491073	Pier 7
4	UIC774Hvashil10fParam_Pos4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	0.000491204	Pier 7
5	UIC774Hvashil10fParam_Pos5.mys	Braking	25	325	Accelerating	313	613	0.000491349	Pier 7
6	UIC774Hvashil10fParam_Pos6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	0.000491472	Pier 7
7	UIC774Hvashil10fParam_Pos7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	0.000551393	Pier 2
8	UIC774Hvashil10fParam_Pos8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	0.000682226	Pier 2
9	UIC774Hvashil10fParam_Pos9.mys	Braking	50	350	Accelerating	326	626	0.000745606	Pier 2
10	UIC774Hvashil10fParam_Pos10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	0.000796428	Pier 2
11	UIC774Hvashil10fParam_Pos11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	0.000880525	Pier 2
12	UIC774Hvashil10fParam_Pos12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	0.000915463	Pier 2
13	UIC774Hvashil10fParam_Pos13.mys	Braking	75	375	Accelerating	339	639	0.000876019	Pier 2
14	UIC774Hvashil10fParam_Pos14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	0.000782532	Pier 2
15	UIC774Hvashil10fParam_Pos15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	0.000679115	Pier 2
16	UIC774Hvashil10fParam_Pos16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	0.000635237	Pier 4
17	UIC774Hvashil10fParam_Pos17.mys	Braking	100	400	Accelerating	352	652	0.00070569	Pier 4
18	UIC774Hvashil10fParam_Pos18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	0.000783315	Pier 4
19	UIC774Hvashil10fParam_Pos19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	0.000915936	Pier 4
20	UIC774Hvashil10fParam_Pos20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	0.001020873	Pier 4
21	UIC774Hvashil10fParam_Pos21.mys	Braking	125	425	Accelerating	365	665	0.001065621	Pier 4
22	UIC774Hvashil10fParam_Pos22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	0.001062674	Pier 4
23	UIC774Hvashil10fParam_Pos23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	0.001040417	Pier 4
24	UIC774Hvashil10fParam_Pos24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	0.001017084	Pier 4
25	UIC774Hvashil10fParam_Pos25.mys	Braking	150	450	Accelerating	378	678	0.000996077	Pier 4
26	UIC774Hvashil10fParam_Pos26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	0.000969131	Pier 4
27	UIC774Hvashil10fParam_Pos27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	0.000928756	Pier 4
28	UIC774Hvashil10fParam_Pos28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	0.000872736	Pier 4
29	UIC774Hvashil10fParam_Pos29.mys	Braking	175	475	Accelerating	391	691	0.000804526	Pier 4
30	UIC774Hvashil10fParam_Pos30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	0.000797318	Pier 7
31	UIC774Hvashil10fParam_Pos31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	0.000913972	Pier 7
32	UIC774Hvashil10fParam_Pos32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	0.000999517	Pier 7
33	UIC774Hvashil10fParam_Pos33.mys	Braking	200	500	Accelerating	404	704	0.001022656	Pier 7
34	UIC774Hvashil10fParam_Pos34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	0.000998605	Pier 7
35	UIC774Hvashil10fParam_Pos35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	0.000959806	Pier 7
36	UIC774Hvashil10fParam_Pos36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	0.000928416	Pier 7
37	UIC774Hvashil10fParam_Pos37.mys	Braking	225	525	Accelerating	417	717	0.000914003	Pier 7
38	UIC774Hvashil10fParam_Pos38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	0.000914207	Pier 7
39	UIC774Hvashil10fParam_Pos39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	0.000921397	Pier 7
40	UIC774Hvashil10fParam_Pos40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	0.000929984	Pier 7

Figure 53: Longitudinal Deck End Displacement due to Vertical Loading Check Worksheet for Multiple Results Files

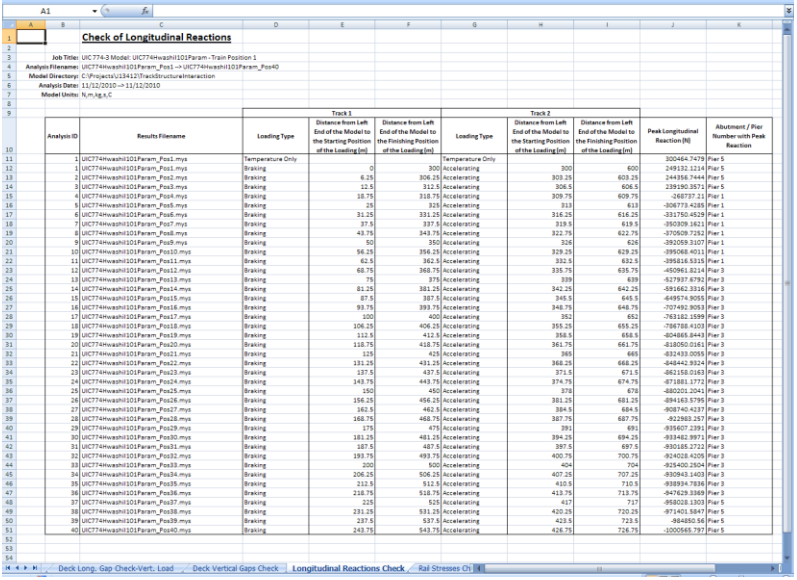


Check of Vertical Relative Displacement between Ends of Decks

Job Title: UIC 774-3 Model: UIC774Hvashil10fParam - Train Position 1
Analysis Filename: UIC774Hvashil10fParam_Pos1 --> UIC774Hvashil10fParam_Pos40
Model Directory: C:\Projects\J13412\TrackStructureInteraction
Analysis Date: 11/12/2010 --> 11/12/2010
Model Units: N,m,kg,s,C

		Track 1			Track 2				
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Peak Relative Vertical Displacement between Ends of Decks. Positive = Next deck / abutment higher than previous, Negative = Next deck / abutment lower than previous (m)	Pier Number Supporting Decks with Peak Displacement
1	UIC774Hvashil10fParam_Pos1.mys	Temperature Only			Temperature Only			-8.73652E-08	RH Abutment
1	UIC774Hvashil10fParam_Pos1.mys	Braking	0	300	Accelerating	300	600	-7.25508E-07	LH Abutment
2	UIC774Hvashil10fParam_Pos2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	-9.24239E-07	LH Abutment
3	UIC774Hvashil10fParam_Pos3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	-1.00624E-06	LH Abutment
4	UIC774Hvashil10fParam_Pos4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-9.90106E-07	LH Abutment
5	UIC774Hvashil10fParam_Pos5.mys	Braking	25	325	Accelerating	313	613	-9.05849E-07	LH Abutment
6	UIC774Hvashil10fParam_Pos6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-7.93693E-07	LH Abutment
7	UIC774Hvashil10fParam_Pos7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-6.9263E-07	LH Abutment
8	UIC774Hvashil10fParam_Pos8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-6.28135E-07	LH Abutment
9	UIC774Hvashil10fParam_Pos9.mys	Braking	50	350	Accelerating	326	626	9.94983E-07	Pier 2
10	UIC774Hvashil10fParam_Pos10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	7.79867E-07	RH Abutment
11	UIC774Hvashil10fParam_Pos11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	7.79577E-07	RH Abutment
12	UIC774Hvashil10fParam_Pos12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	7.79356E-07	RH Abutment
13	UIC774Hvashil10fParam_Pos13.mys	Braking	75	375	Accelerating	339	639	7.7913E-07	RH Abutment
14	UIC774Hvashil10fParam_Pos14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	7.7887E-07	RH Abutment
15	UIC774Hvashil10fParam_Pos15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	7.78595E-07	RH Abutment
16	UIC774Hvashil10fParam_Pos16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	7.78329E-07	RH Abutment
17	UIC774Hvashil10fParam_Pos17.mys	Braking	100	400	Accelerating	352	652	7.88297E-07	Pier 4
18	UIC774Hvashil10fParam_Pos18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	7.77595E-07	RH Abutment
19	UIC774Hvashil10fParam_Pos19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	7.77185E-07	RH Abutment
20	UIC774Hvashil10fParam_Pos20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	7.76784E-07	RH Abutment
21	UIC774Hvashil10fParam_Pos21.mys	Braking	125	425	Accelerating	365	665	7.76397E-07	RH Abutment
22	UIC774Hvashil10fParam_Pos22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	7.75993E-07	RH Abutment
23	UIC774Hvashil10fParam_Pos23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	7.7557E-07	RH Abutment
24	UIC774Hvashil10fParam_Pos24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	7.75128E-07	RH Abutment
25	UIC774Hvashil10fParam_Pos25.mys	Braking	150	450	Accelerating	378	678	7.74671E-07	RH Abutment
26	UIC774Hvashil10fParam_Pos26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	7.74224E-07	RH Abutment
27	UIC774Hvashil10fParam_Pos27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	7.73763E-07	RH Abutment
28	UIC774Hvashil10fParam_Pos28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	7.73292E-07	RH Abutment
29	UIC774Hvashil10fParam_Pos29.mys	Braking	175	475	Accelerating	391	691	8.44042E-07	Pier 7
30	UIC774Hvashil10fParam_Pos30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	7.71772E-07	RH Abutment
31	UIC774Hvashil10fParam_Pos31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	7.70908E-07	RH Abutment
32	UIC774Hvashil10fParam_Pos32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	7.70065E-07	RH Abutment
33	UIC774Hvashil10fParam_Pos33.mys	Braking	200	500	Accelerating	404	704	7.69314E-07	RH Abutment
34	UIC774Hvashil10fParam_Pos34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	7.68544E-07	RH Abutment
35	UIC774Hvashil10fParam_Pos35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	7.67793E-07	RH Abutment
36	UIC774Hvashil10fParam_Pos36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	7.67043E-07	RH Abutment
37	UIC774Hvashil10fParam_Pos37.mys	Braking	225	525	Accelerating	417	717	7.66261E-07	RH Abutment
38	UIC774Hvashil10fParam_Pos38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	7.65377E-07	RH Abutment
39	UIC774Hvashil10fParam_Pos39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	7.64402E-07	RH Abutment
40	UIC774Hvashil10fParam_Pos40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	7.63582E-07	RH Abutment

Figure 54: Vertical Deck End Displacement Check Worksheet for Multiple Results Files



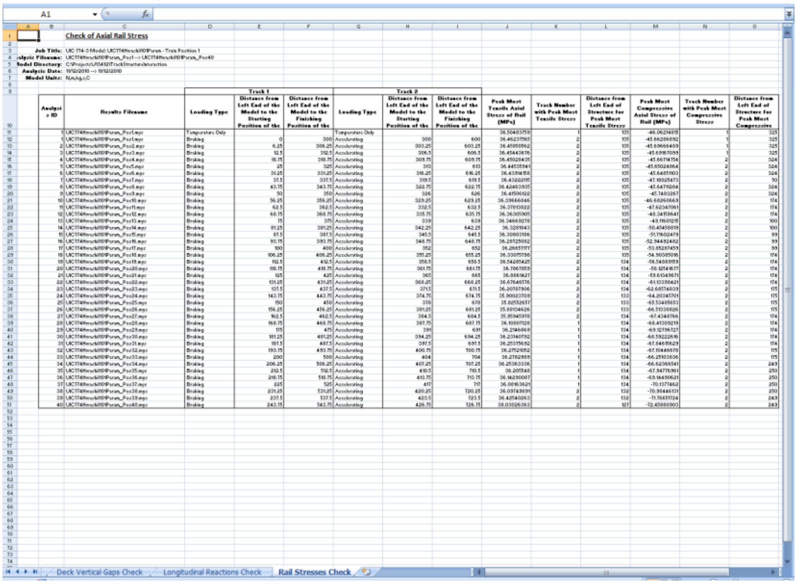
Check of Longitudinal Reactions

Job Title: UIC 774-3 Model: UIC774Hwashil101Param - Train Position 1
Analysis Filename: UIC774Hwashil101Param_Pos1 --> UIC774Hwashil101Param_Pos40
Model Directory: C:\Projects\J13412\TrackStructureInteraction
Analysis Date: 11/12/2010 --> 11/12/2010
Model Units: N,m,kg,s,C

		Track 1			Track 2				
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction
1	UIC774Hwashil101Param_Pos1.mys	Temperature Only			Temperature Only			300464.7479	Pier 5
1	UIC774Hwashil101Param_Pos1.mys	Braking	0	300	Accelerating	300	600	249132.1214	Pier 5
2	UIC774Hwashil101Param_Pos2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	244356.7444	Pier 5
3	UIC774Hwashil101Param_Pos3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	239190.3571	Pier 5
4	UIC774Hwashil101Param_Pos4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	-268737.21	Pier 1
5	UIC774Hwashil101Param_Pos5.mys	Braking	25	325	Accelerating	313	613	-306773.4285	Pier 1
6	UIC774Hwashil101Param_Pos6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	-331750.4529	Pier 1
7	UIC774Hwashil101Param_Pos7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	-350309.1621	Pier 1
8	UIC774Hwashil101Param_Pos8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	-370509.7252	Pier 1
9	UIC774Hwashil101Param_Pos9.mys	Braking	50	350	Accelerating	326	626	-392059.3107	Pier 1
10	UIC774Hwashil101Param_Pos10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	-395068.4011	Pier 1
11	UIC774Hwashil101Param_Pos11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	-395816.5315	Pier 1
12	UIC774Hwashil101Param_Pos12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	-450961.8214	Pier 3
13	UIC774Hwashil101Param_Pos13.mys	Braking	75	375	Accelerating	339	639	-527937.6792	Pier 3
14	UIC774Hwashil101Param_Pos14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	-591662.3316	Pier 3
15	UIC774Hwashil101Param_Pos15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	-649574.9055	Pier 3
16	UIC774Hwashil101Param_Pos16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	-707492.9053	Pier 3
17	UIC774Hwashil101Param_Pos17.mys	Braking	100	400	Accelerating	352	652	-763182.1599	Pier 3
18	UIC774Hwashil101Param_Pos18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	-786788.4103	Pier 3
19	UIC774Hwashil101Param_Pos19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	-804865.8443	Pier 3
20	UIC774Hwashil101Param_Pos20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	-818050.0161	Pier 3
21	UIC774Hwashil101Param_Pos21.mys	Braking	125	425	Accelerating	365	665	-832433.0055	Pier 3
22	UIC774Hwashil101Param_Pos22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	-848442.9324	Pier 3
23	UIC774Hwashil101Param_Pos23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	-862158.0163	Pier 3
24	UIC774Hwashil101Param_Pos24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	-871881.1772	Pier 3
25	UIC774Hwashil101Param_Pos25.mys	Braking	150	450	Accelerating	378	678	-880201.2041	Pier 3
26	UIC774Hwashil101Param_Pos26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	-894163.5795	Pier 3
27	UIC774Hwashil101Param_Pos27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	-908740.4237	Pier 3
28	UIC774Hwashil101Param_Pos28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	-922983.257	Pier 3
29	UIC774Hwashil101Param_Pos29.mys	Braking	175	475	Accelerating	391	691	-935607.2391	Pier 3
30	UIC774Hwashil101Param_Pos30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	-933482.9971	Pier 3
31	UIC774Hwashil101Param_Pos31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	-930185.2722	Pier 3
32	UIC774Hwashil101Param_Pos32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	-924028.4205	Pier 3
33	UIC774Hwashil101Param_Pos33.mys	Braking	200	500	Accelerating	404	704	-925400.2504	Pier 3
34	UIC774Hwashil101Param_Pos34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	-930943.1403	Pier 3
35	UIC774Hwashil101Param_Pos35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	-938934.7836	Pier 3
36	UIC774Hwashil101Param_Pos36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	-947629.3369	Pier 3
37	UIC774Hwashil101Param_Pos37.mys	Braking	225	525	Accelerating	417	717	-958028.1303	Pier 5
38	UIC774Hwashil101Param_Pos38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	-971401.5847	Pier 5
39	UIC774Hwashil101Param_Pos39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	-984850.56	Pier 5
40	UIC774Hwashil101Param_Pos40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	-1000565.797	Pier 5

Deck Long. Gap Check-Vert. Load | Deck Vertical Gaps Check | Longitudinal Reactions Check | Rail Stresses Ch

Figure 55: Longitudinal Reaction Check Worksheet for Multiple Results Files



Check of Axial Rail Stress

Job Title: UIC 774-3 Model: UIC774Hwashil101Param - Train Position 1
Analysis Filename: UIC774Hwashil101Param_Pos1 --> UIC774Hwashil101Param_Pos40
Model Directory: C:\Projects\J13412\TrackStructureInteraction
Analysis Date: 11/12/2010 --> 11/12/2010
Model Units: N,m,kg,s,C

		Track 1			Track 2								
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Peak Most Tensile Axial Stress of Rail (MPa)	Track Number with Peak Most Tensile Stress	Distance from Left End of Structure for Peak Most Tensile Stress	Peak Most Compressive Axial Stress of Rail (MPa)	Track Number with Peak Most Compressive Stress	Distance from Left End of Structure for Peak Most Compressive
1	UIC774Hwashil101Param_Pos1.mys	Temperature Only			Temperature Only			36.50483759	1	135	-46.06214815	1	325
1	UIC774Hwashil101Param_Pos1.mys	Braking	0	300	Accelerating	300	600	36.46237565	2	135	-45.66286832	1	325
2	UIC774Hwashil101Param_Pos2.mys	Braking	6.25	306.25	Accelerating	303.25	603.25	36.45850562	2	135	-45.63666489	1	325
3	UIC774Hwashil101Param_Pos3.mys	Braking	12.5	312.5	Accelerating	306.5	606.5	36.45443676	2	135	-45.63167099	1	325
4	UIC774Hwashil101Param_Pos4.mys	Braking	18.75	318.75	Accelerating	309.75	609.75	36.45028435	2	135	-45.66714754	2	324
5	UIC774Hwashil101Param_Pos5.mys	Braking	25	325	Accelerating	313	613	36.44535941	2	135	-45.65024864	2	324
6	UIC774Hwashil101Param_Pos6.mys	Braking	31.25	331.25	Accelerating	316.25	616.25	36.43914158	2	135	-45.64851103	2	324
7	UIC774Hwashil101Param_Pos7.mys	Braking	37.5	337.5	Accelerating	319.5	619.5	36.43222115	2	135	-47.10025473	2	50
8	UIC774Hwashil101Param_Pos8.mys	Braking	43.75	343.75	Accelerating	322.75	622.75	36.42463035	2	135	-45.64711204	2	324
9	UIC774Hwashil101Param_Pos9.mys	Braking	50	350	Accelerating	326	626	36.41506122	2	135	-45.7403267	2	324
10	UIC774Hwashil101Param_Pos10.mys	Braking	56.25	356.25	Accelerating	329.25	629.25	36.39666846	2	135	-46.60260663	2	174
11	UIC774Hwashil101Param_Pos11.mys	Braking	62.5	362.5	Accelerating	332.5	632.5	36.37813822	2	135	-47.62347061	2	174
12	UIC774Hwashil101Param_Pos12.mys	Braking	68.75	368.75	Accelerating	335.75	635.75	36.36305905	2	135	-48.34158641	2	174
13	UIC774Hwashil101Param_Pos13.mys	Braking	75	375	Accelerating	339	639	36.34669278	2	135	-49.1168125	2	100
14	UIC774Hwashil101Param_Pos14.mys	Braking	81.25	381.25	Accelerating	342.25	642.25	36.3281843	2	135	-50.45458819	2	100
15	UIC774Hwashil101Param_Pos15.mys	Braking	87.5	387.5	Accelerating	345.5	645.5	36.30803186	2	135	-51.71602479	2	99
16	UIC774Hwashil101Param_Pos16.mys	Braking	93.75	393.75	Accelerating	348.75	648.75	36.28725082	2	135	-52.94492482	2	99
17	UIC774Hwashil101Param_Pos17.mys	Braking	100	400	Accelerating	352	652	36.2665117	2	135	-53.85287459	2	99
18	UIC774Hwashil101Param_Pos18.mys	Braking	106.25	406.25	Accelerating	355.25	655.25	36.33075798	2	135	-54.90385016	2	174
19	UIC774Hwashil101Param_Pos19.mys	Braking	112.5	412.5	Accelerating	358.5	658.5	36.54285425	2	134	-56.54869159	2	174
20	UIC774Hwashil101Param_Pos20.mys	Braking	118.75	418.75	Accelerating	361.75	661.75	36.7867859	2	134	-58.12541677	2	174
21	UIC774Hwashil101Param_Pos21.mys	Braking	125	425	Accelerating	365	665	36.8864827	2	134	-59.61349671	2	174
22	UIC774Hwashil101Param_Pos22.mys	Braking	131.25	431.25	Accelerating	368.25	668.25	36.67646576	2	134	-61.10390421	2	174
23	UIC774Hwashil101Param_Pos23.mys	Braking	137.5	437.5	Accelerating	371.5	671.5	36.20787906	2	134	-62.60574039	2	175
24	UIC774Hwashil101Param_Pos24.mys	Braking	143.75	443.75	Accelerating	374.75	674.75	35.90023709	2	133	-64.20345701	2	175
25	UIC774Hwashil101Param_Pos25.mys	Braking	150	450	Accelerating	378	678	35.82552657	2	133	-65.53485653	2	175
26	UIC774Hwashil101Param_Pos26.mys	Braking	156.25	456.25	Accelerating	381.25	681.25	35.88134626	2	133	-66.51338826	2	175
27	UIC774Hwashil101Param_Pos27.mys	Braking	162.5	462.5	Accelerating	384.5	684.5	35.95945978	2	134	-67.4348766	2	174
28	UIC774Hwashil101Param_Pos28.mys	Braking	168.75	468.75	Accelerating	387.75	687.75	36.10807128	1	134	-68.41309219	2	174
29	UIC774Hwashil101Param_Pos29.mys	Braking	175	475	Accelerating	391	691	36.2146869	1	134	-69.12796127	2	174
30	UIC774Hwashil101Param_Pos30.mys	Braking	181.25	481.25	Accelerating	394.25	694.25	36.23140792	1	134	-68.59222616	2	174
31	UIC774Hwashil101Param_Pos31.mys	Braking	187.5	487.5	Accelerating	397.5	697.5	36.25375692	1	134	-67.84615629	2	174
32	UIC774Hwashil101Param_Pos32.mys	Braking	193.75	493.75	Accelerating	400.75	700.75	36.27521052	1	134	-67.10446678	2	175
33	UIC774Hwashil101Param_Pos33.mys	Braking	200	500	Accelerating	404	704	36.2782989	1	134	-66.25103836	2	175
34	UIC774Hwashil101Param_Pos34.mys	Braking	206.25	506.25	Accelerating	407.25	707.25	36.25363336	1	134	-66.62366541	2	249
35	UIC774Hwashil101Param_Pos35.mys	Braking	212.5	512.5	Accelerating	410.5	710.5	36.205548	1	134	-67.94776961	2	250
36	UIC774Hwashil101Param_Pos36.mys	Braking	218.75	518.75	Accelerating	413.75	713.75	36.16290087	1	134	-69.16490621	2	250
37	UIC774Hwashil101Param_Pos37.mys	Braking	225	525	Accelerating	417	717	36.08163621	1	134	-70.1377462	2	250
38	UIC774Hwashil101Param_Pos38.mys	Braking	231.25	531.25	Accelerating	420.25	720.25	36.03743891	2	132	-70.90446131	2	250
39	UIC774Hwashil101Param_Pos39.mys	Braking	237.5	537.5	Accelerating	423.5	723.5	36.42540263	2	132	-71.76651724	2	249
40	UIC774Hwashil101Param_Pos40.mys	Braking	243.75	543.75	Accelerating	426.75	726.75	38.03026363	2	127	-72.45880903	2	249

Deck Vertical Gaps Check | Longitudinal Reactions Check | Rail Stresses Check

Figure 56: Axial Rail Stress Check Worksheet for Multiple Results Files

Microsoft Excel Fails with Insufficient Resources when Enveloping

If Microsoft Excel fails to complete the post-processing successfully with a complaint of insufficient resources 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.

Note. After the failure of a post-processing the Microsoft Excel application will still be dormant on the computer and must be terminated by ending the process in Windows Task Manager.

Two automatic post-processing options are available if there are insufficient resources for Microsoft Excel to carry out the enveloping of the analyses. 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 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.

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 57 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 57: 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 58 and Figure 59 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 59 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 60 and Figure 61 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.

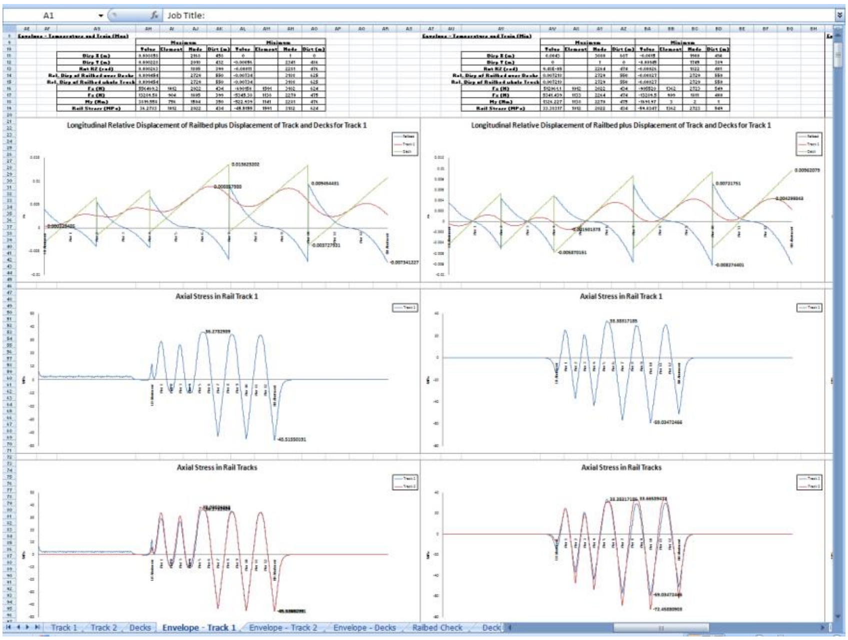


Figure 58: Track Envelopes Performed in Microsoft Excel

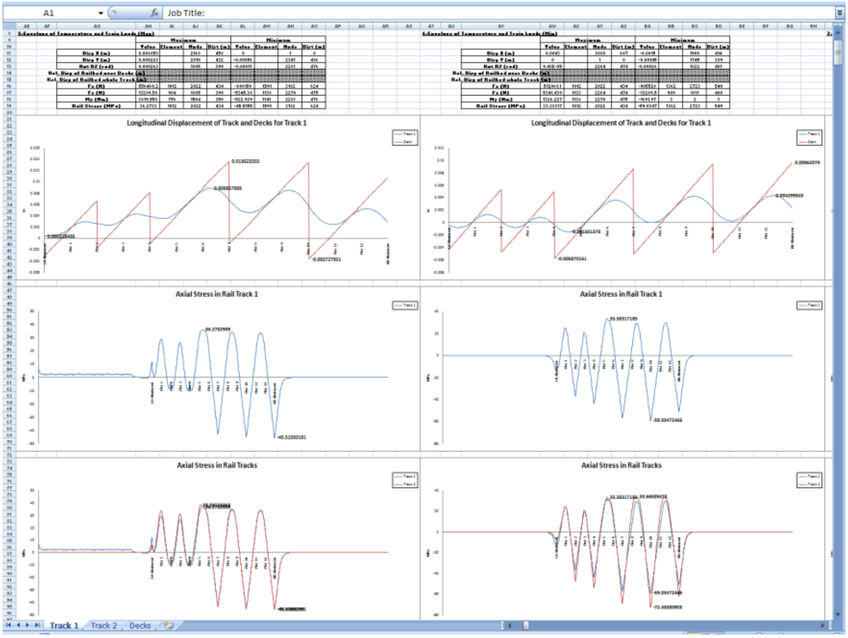


Figure 59: Track Envelopes Performed in Modeller

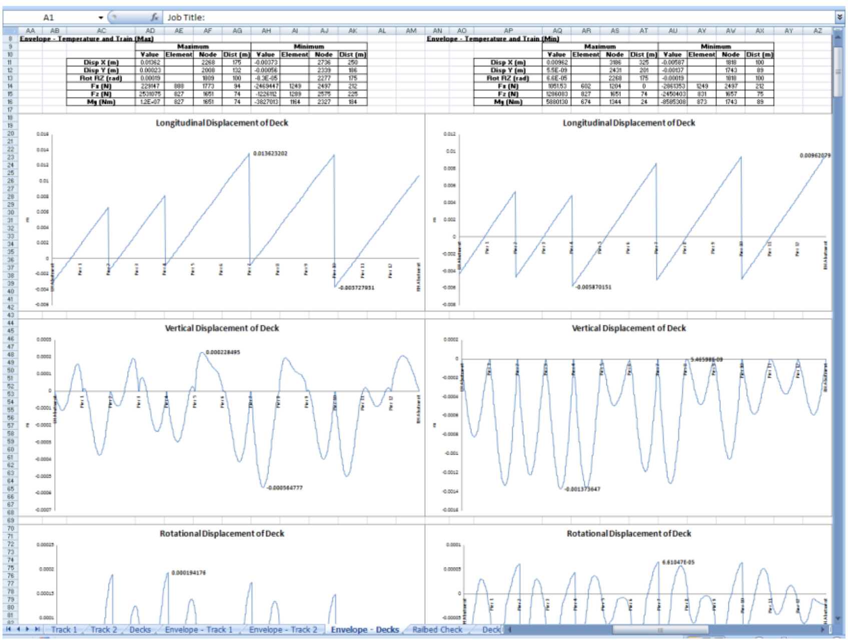


Figure 60: Deck Envelopes Performed in Microsoft Excel

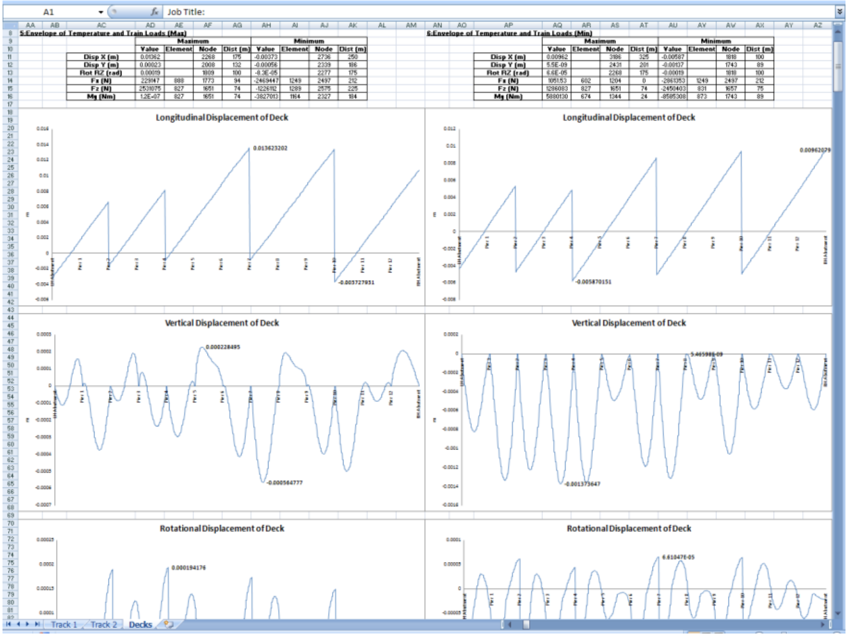
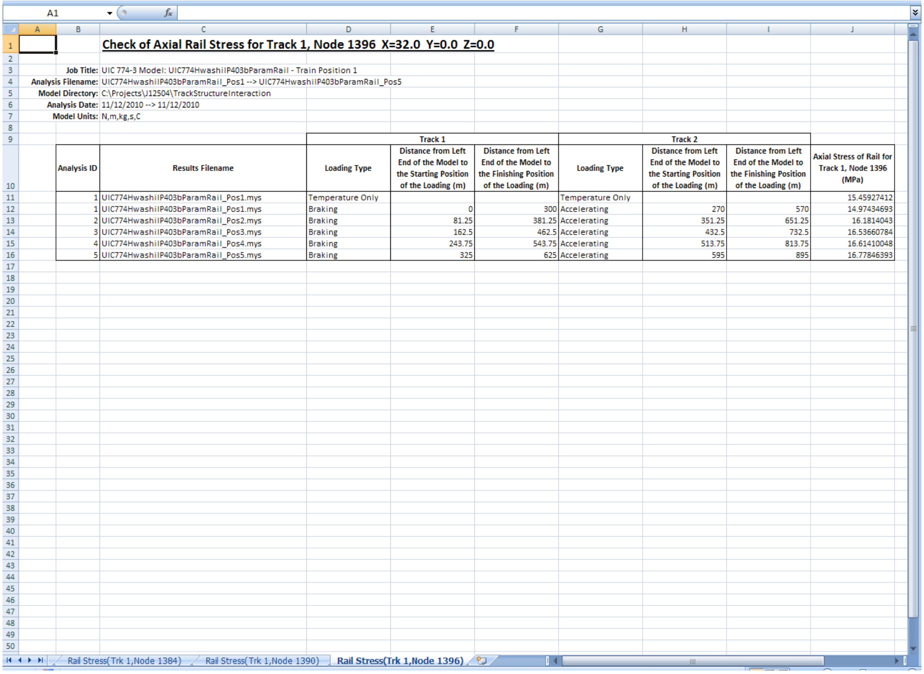


Figure 61: Deck Envelopes Performed in Modeller

Post-processing of selected track / rail nodes

If spot checks need to be performed on specific locations of the tracks then the nodes of the track/rail can be post-processed individually. To perform the post-processing the selection must contains nodes that are part of either 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 62 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 1396 X=32.0 Y=0.0 Z=0.0

Job Title: UIC 774-3 Model: UIC774HwashiIP403bParamRail - Train Position 1
Analysis Filename: UIC774HwashiIP403bParamRail_Pos1 --> UIC774HwashiIP403bParamRail_Pos5
Model Directory: C:\Projects\J12504\TrackStructureInteraction
Analysis Date: 11/12/2010 --> 11/12/2010
Model Units: N,m,kg,s,C

		Track 1			Track 2			
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Axial Stress of Rail for Track 1, Node 1396 (MPa)
1	UIC774HwashiIP403bParamRail_Pos1.mys	Temperature Only			Temperature Only			15.45927412
1	UIC774HwashiIP403bParamRail_Pos1.mys	Braking	0	300	Accelerating	270	570	14.97434693
2	UIC774HwashiIP403bParamRail_Pos2.mys	Braking	81.25	381.25	Accelerating	351.25	651.25	16.1814043
3	UIC774HwashiIP403bParamRail_Pos3.mys	Braking	162.5	462.5	Accelerating	432.5	732.5	16.53660784
4	UIC774HwashiIP403bParamRail_Pos4.mys	Braking	243.75	543.75	Accelerating	513.75	813.75	16.61410048
5	UIC774HwashiIP403bParamRail_Pos5.mys	Braking	325	625	Accelerating	595	895	16.77846393

Figure 62: 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 63 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.

A1 | Job Title:

Job Title: UIC 774-3 Model: UIC774HwashilP403bParamRail - Train Position 1

Analysis Filename: UIC774HwashilP403bParamRail_Pos1.mys
Analysis Directory: C:\Projects\J12504\TrackStructureInteraction\
Analysis Date: 12/11/2010
Model Units: N,m,kg,s,C

1:Increment 1 | **2:Increment 2 Load Factor = 1.00000**

	Maximum				Minimum			
	Value	**Element**	**Node**	**Dist (m)**	**Value**	**Element**	**Node**	**Dist (m)**
Disp X (m)	0.00967877		3186	325	-0.0053352		1204	0
Disp Y (m)	2.045E-05		3102	311	-4.151E-05		2962	288
Rot RZ (rad)	4.25E-06		2563	223	-3.616E-06		2926	282
Fx (N)	-40000.004	602	1204	0	-2501148.7	1478	2956	287
Fz (N)	80060.1119	1381	2762	255	-80725.682	1587	3174	323
My (Nm)	225001.593	831	1657	75	-252648.71	1478	2956	287

(Increment 2 block, column O: **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
602	1204	0	0	0	0	-0.0053352	6.9261E-08	-2.644E-06	-40000.004	64143.4859	-4648.2606	602	1204	
602	1206	1	1	0	0	-0.0051353	-2.568E-06	-2.631E-06	-40000.004	64143.4859	-4648.2606	602	1206	
605	1206	1	1	0	0	-0.0051353	-2.568E-06	-2.631E-06	-120000.01	63902.194	-14065.427	605	1206	
605	1212	2	2	0	0	-0.0049357	-5.178E-06	-2.591E-06	-120000.01	63902.194	-14065.427	605	1212	
608	1212	2	2	0	0	-0.0049357	-5.178E-06	-2.591E-06	-200000.02	63973.2656	-23567.703	608	1212	
608	1218	3	3	0	0	-0.0047363	-7.735E-06	-2.524E-06	-200000.02	63973.2656	-23567.703	608	1218	
611	1218	3	3	0	0	-0.0047363	-7.735E-06	-2.524E-06	-280000.02	63954.9505	-33043.601	611	1218	
611	1224	4	4	0	0	-0.0045372	-1.021E-05	-2.431E-06	-280000.02	63954.9505	-33043.601	611	1224	
614	1224	4	4	0	0	-0.0045372	-1.021E-05	-2.431E-06	-360000.03	63959.4601	-42526.4	614	1224	
614	1230	5	5	0	0	-0.0043383	-1.258E-05	-2.31E-06	-360000.03	63959.4601	-42526.4	614	1230	
617	1230	5	5	0	0	-0.0043383	-1.258E-05	-2.31E-06	-440000.03	63958.369	-52007.49	617	1230	
617	1236	6	6	0	0	-0.0041396	-1.482E-05	-2.163E-06	-440000.03	63958.369	-52007.49	617	1236	
620	1236	6	6	0	0	-0.0041396	-1.482E-05	-2.163E-06	-520000.04	63958.6311	-61488.994	620	1236	
620	1242	7	7	0	0	-0.0039413	-1.689E-05	-1.99E-06	-520000.04	63958.6311	-61488.994	620	1242	
623	1242	7	7	0	0	-0.0039413	-1.689E-05	-1.99E-06	-600000.04	63958.5683	-70970.398	623	1242	
623	1248	8	8	0	0	-0.0037431	-1.878E-05	-1.789E-06	-600000.04	63958.5683	-70970.398	623	1248	
626	1248	8	8	0	0	-0.0037431	-1.878E-05	-1.789E-06	-680000.04	63958.5834	-80451.825	626	1248	
626	1254	9	9	0	0	-0.0035452	-2.046E-05	-1.561E-06	-680000.04	63958.5834	-80451.825	626	1254	
629	1254	9	9	0	0	-0.0035452	-2.046E-05	-1.561E-06	-760000.05	63958.5798	-89933.246	629	1254	
629	1260	10	10	0	0	-0.0033476	-2.189E-05	-1.307E-06	-760000.05	63958.5798	-89933.246	629	1260	
699	1394	32	32	0	0	0.00096211	1.2263E-05	6.6804E-07	-1400000.1	-77841.185	77056.2004	699	1394	
699	1400	33	33	0	0	0.00115841	1.2822E-05	4.5012E-07	-1400000.1	-77841.185	77056.2004	699	1400	
702	1400	33	33	0	0	0.00115841	1.2822E-05	4.5012E-07	-1320000.1	-77841.212	72655.002	702	1400	
702	1406	34	34	0	0	0.00135493	1.3168E-05	2.4465E-07	-1320000.1	-77841.212	72655.002	702	1406	

Selection | Envelope - Selection

Figure 63: Sample Output from Post-Processing of Selected Lines when the Groups are Missing or Invalid

If more than one results file is loaded, no combinations or envelopes are defined in the model and Microsoft Excel enveloping is 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 loading (an envelope of the above two)

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 centrelines are coincident with the centreline of the deck.
- Curved bridges cannot be modelled.
- Only up to two tracks can be considered.
- 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.

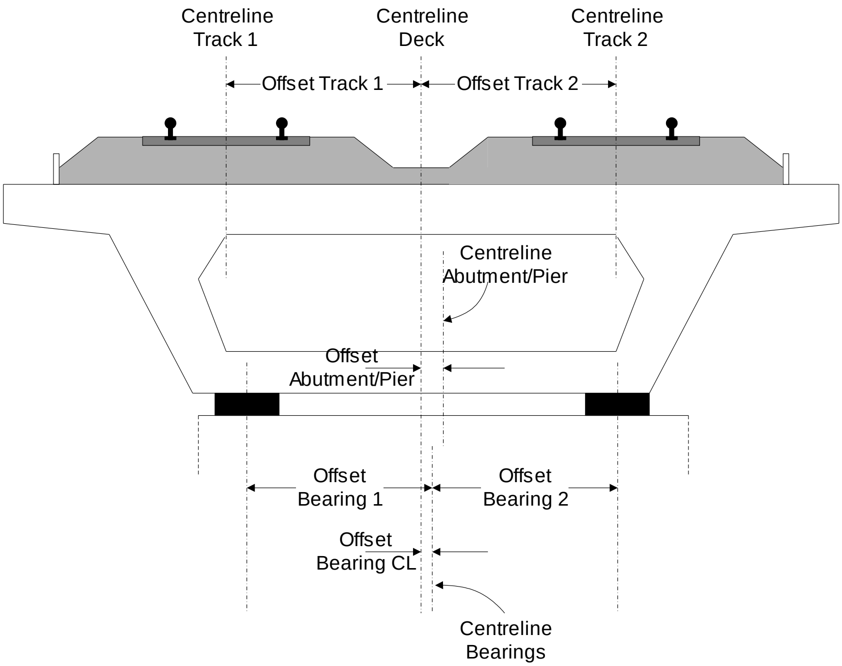


Figure 64: Offsets of Tracks/Bearings/Piers from Centreline Of Deck

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 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. 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.

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.

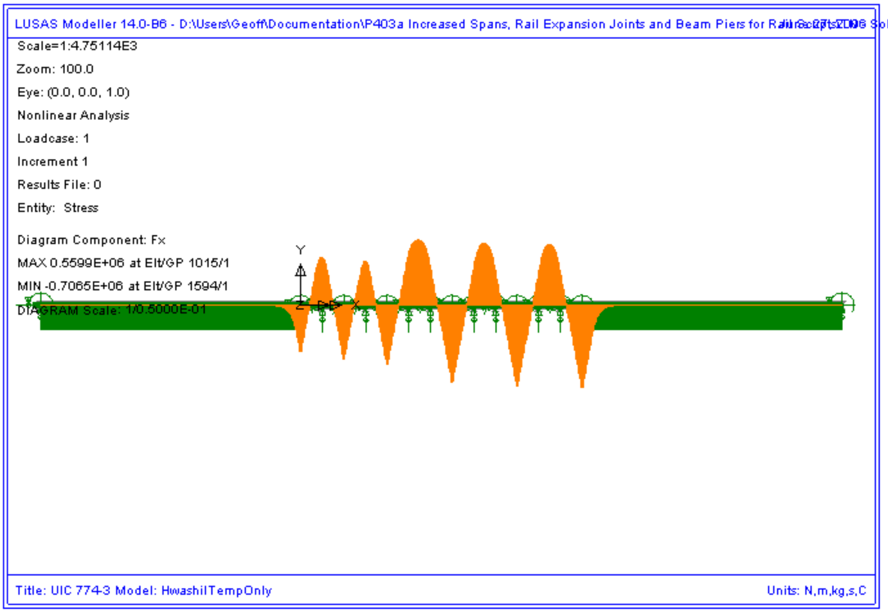


Figure 65: Axial Force In Rails Due To Thermal Effects Only

These thermal effects give a peak compressive rail stress of 46.06 N/mm^2 (F/A = 0.7065E+06/0.0153389). 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.

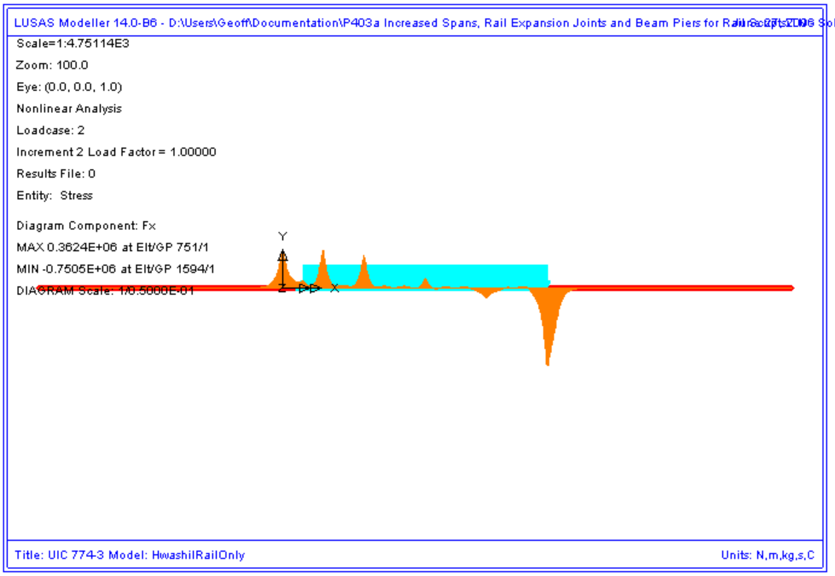


Figure 66: Axial Force In Rails Due To Braking Train Loads On Track 1

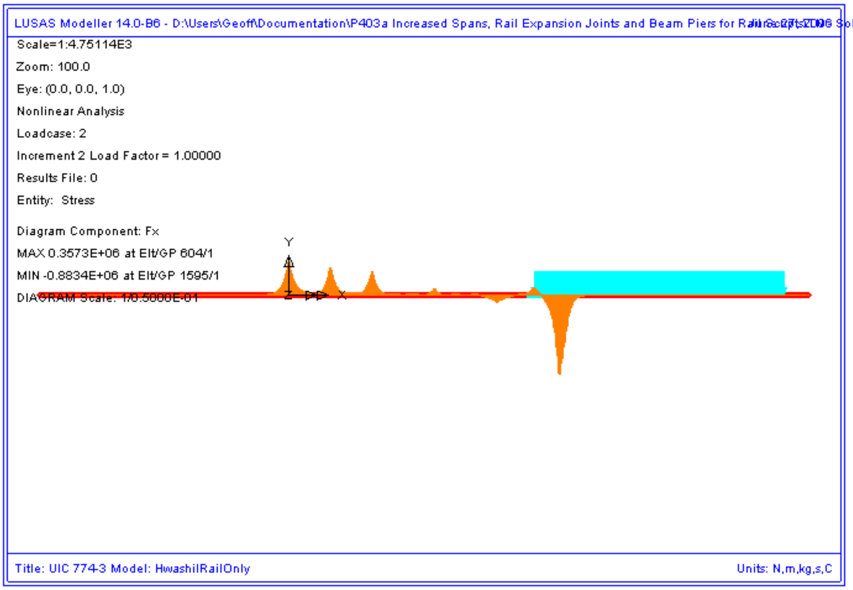


Figure 67: Axial Force In Rails Due To AcceleratingTrain Loads On Track 2

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

Track 1:	**48.93 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**

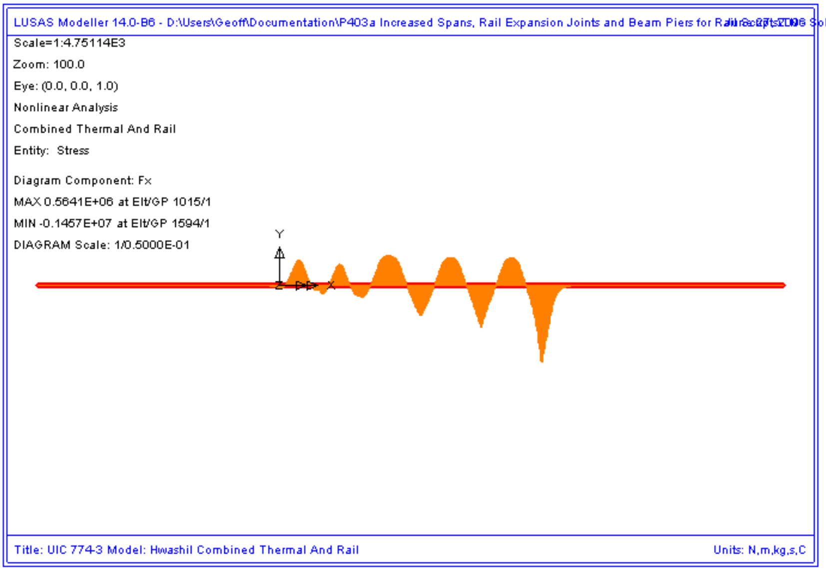


Figure 68: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 1

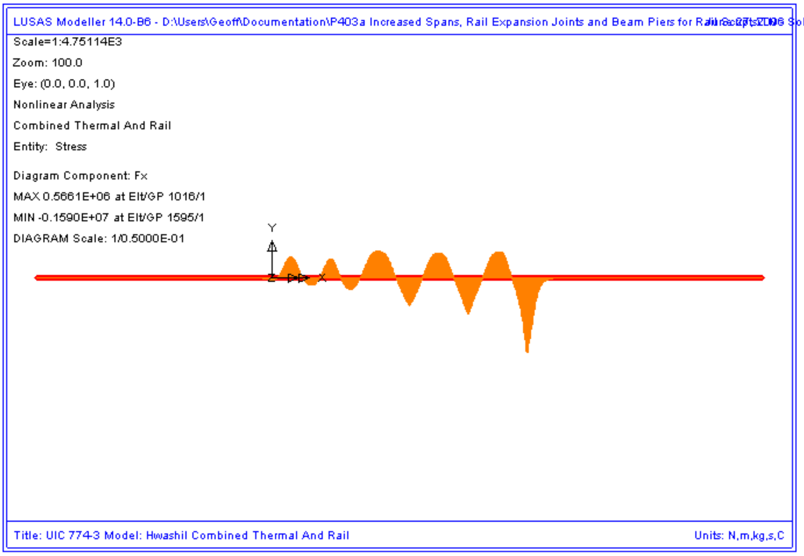


Figure 69: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 2

Inspection of the two plots shows that there is a reduction in the axial force / rail stresses over the first two span 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 force for this location with the thermal diagram showing identical values either side of these piers for all of the spans in the model. The reason for the reduction in the axial force becomes clear from the axial force diagram for the train braking load alone, Figure 71, where the axial force has a positive peak over the span transition piers which is not symmetrical. Looking at the transition from the first span to the second (2^{nd} pier from left abutment) the axial force in the rail over the end of the first span is equal to a tension force of 362.4 kN while the axial force over the start of the second span is equal to a tension force of 344.7 kN. Like for like comparison of the elements a certain distance from the pier for each span shows that the second span is consistently lower and this difference has caused the non-symmetric nature of the combined axial force / rail stress diagram over the span transition piers.

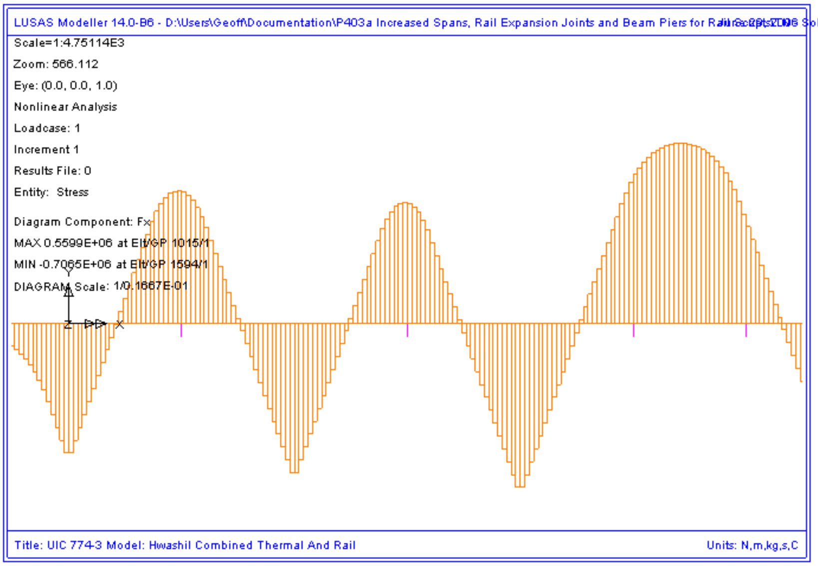


Figure 70: Zoomed Axial Force In Rails Due To Thermal Effects Only

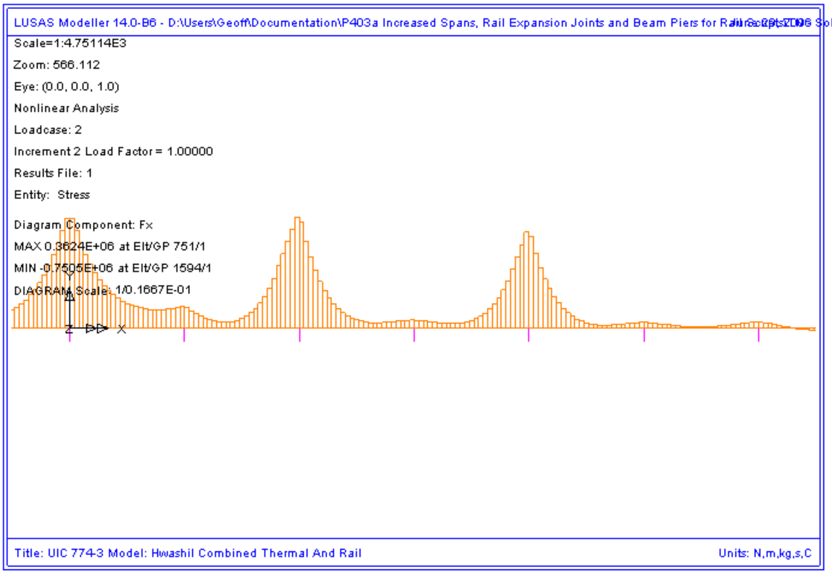


Figure 71: Zoomed Axial Force In Rails Due To Braking Train Loads On Track 1

NOTE: When viewing this axial force diagram it should be recognised that while the first two spans (2*25m each) have identical geometry and pier/bearing properties, the first span segment of the first span 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 72, the reason for the differences in axial force either side of the pier becomes clear as yielding has occurred to the left but not to the right of the span transition pier for these first two spans.

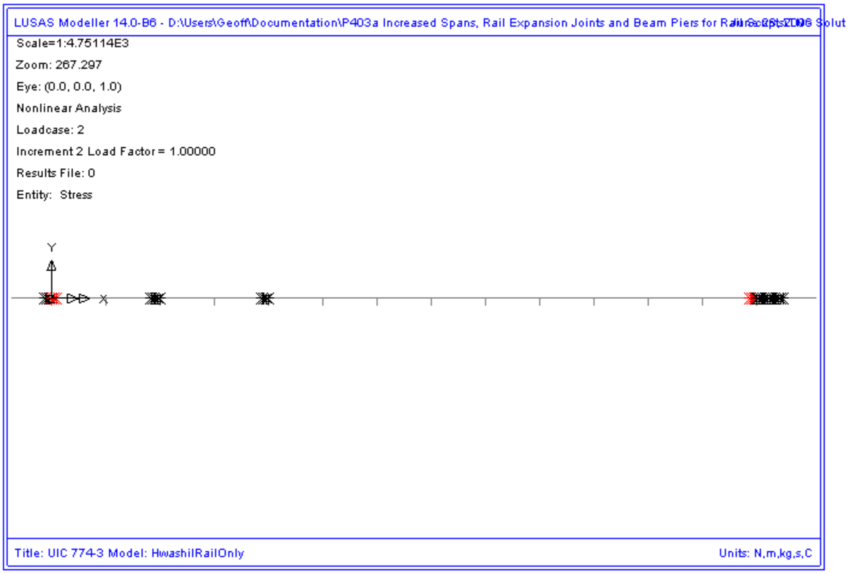


Figure 72: Yield In Track/Bridge Interaction Due To Train Braking Load On Track 1

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 force / stress observed it 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 force 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.

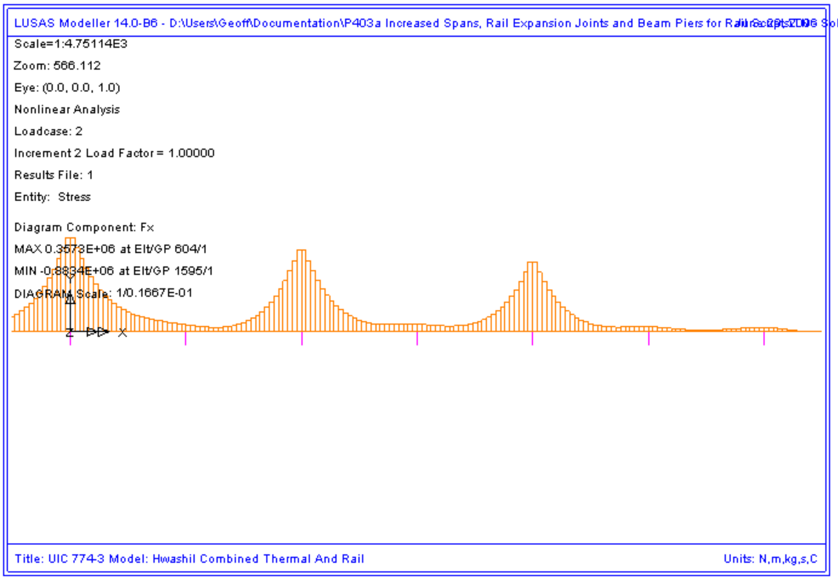


Figure 73: Zoomed Axial Force In Rails Due To Accelerating Train Loads On Track 2

Looking again at the yielding, Figure 74, the difference between this track and the one with the braking train becomes obvious as, without the action of any train load over the span transition for this track, the yield is roughly symmetrical and occurring across the transition between spans – colour change indicates changing yield direction. This yield over the whole region of the span transition is the whole reason why a smooth behaviour is observed in the rail force / stress in the second track as opposed to the first track that has the braking train load.

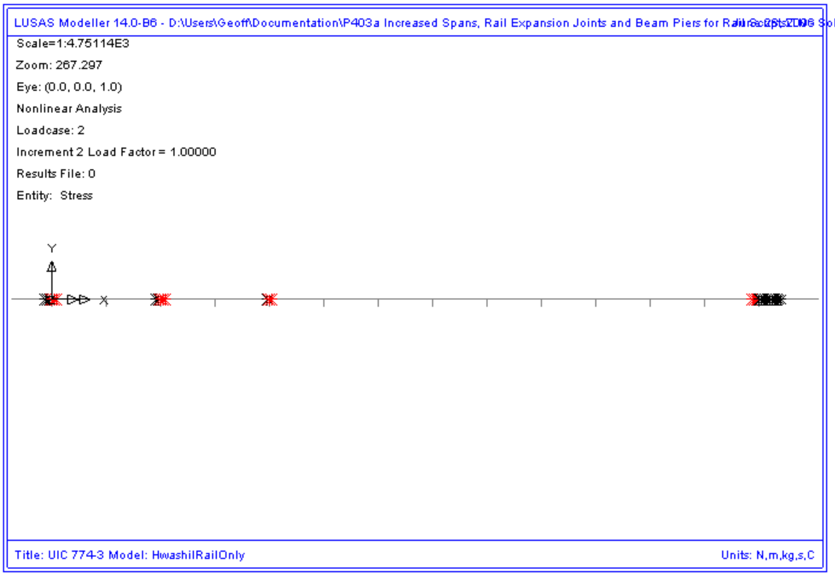


Figure 74: Yield In Track/Bridge Interaction Due To Train Acceleration Load On Track 2

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:	**85.6 N/mm^2**
Track 2:	**100.6 N/mm^2**

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

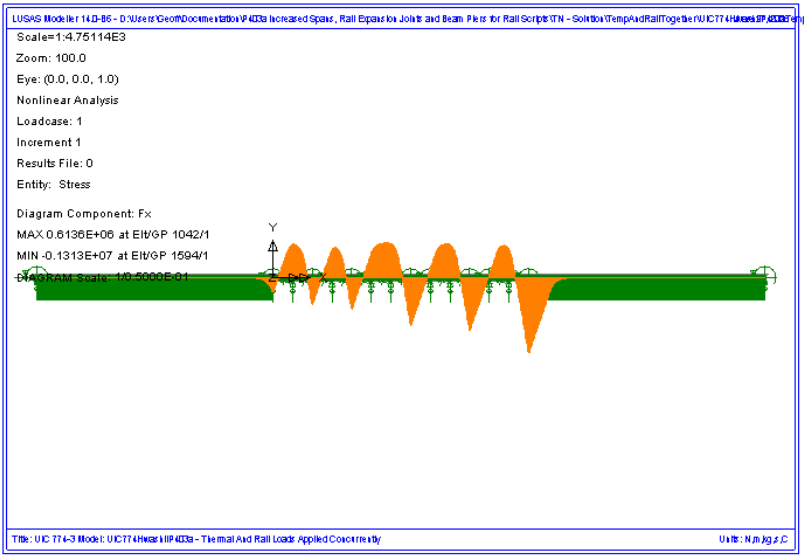


Figure 75: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 1 (One Step)

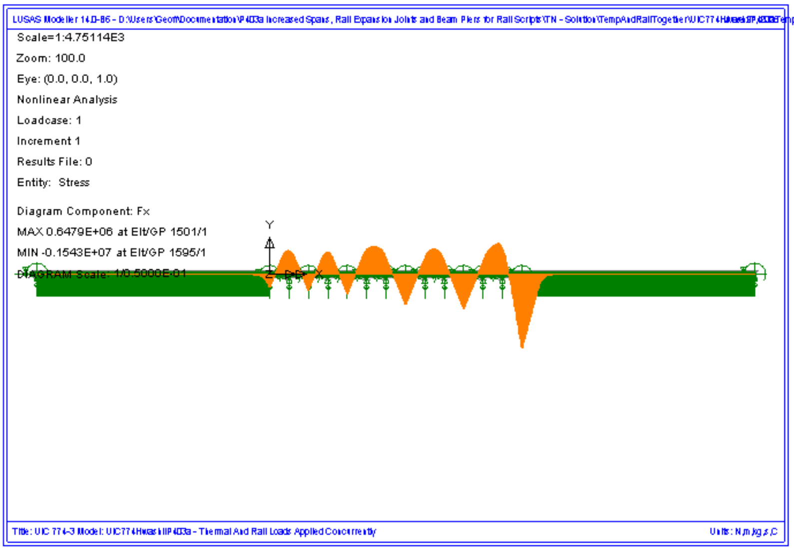


Figure 76: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 2 (One Step)

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

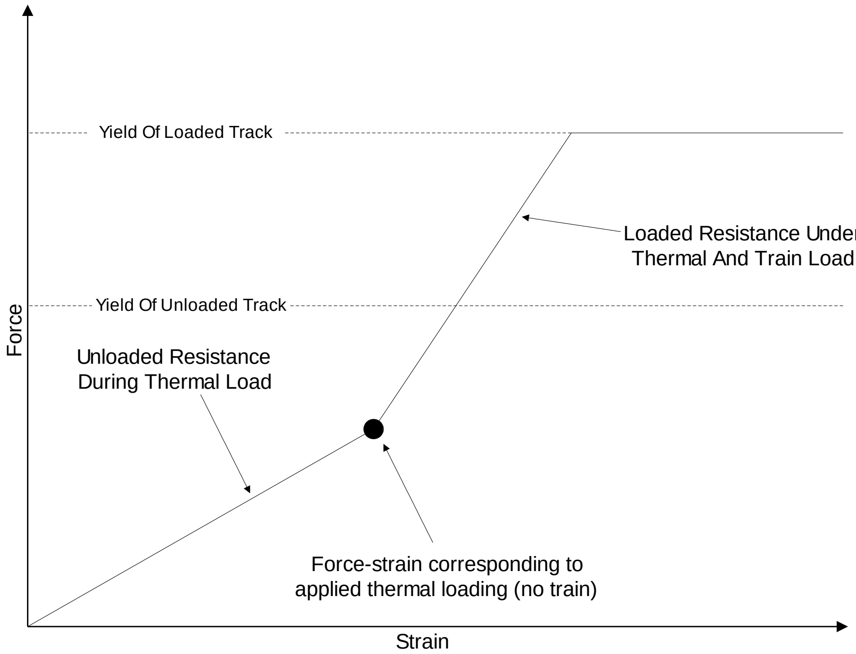


Figure 77: Representation of Transition From Unloaded To Loaded In LUSAS

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):	**79.08 N/mm^2**
Track 2 (Thermal and Train):	**92.58 N/mm^2**

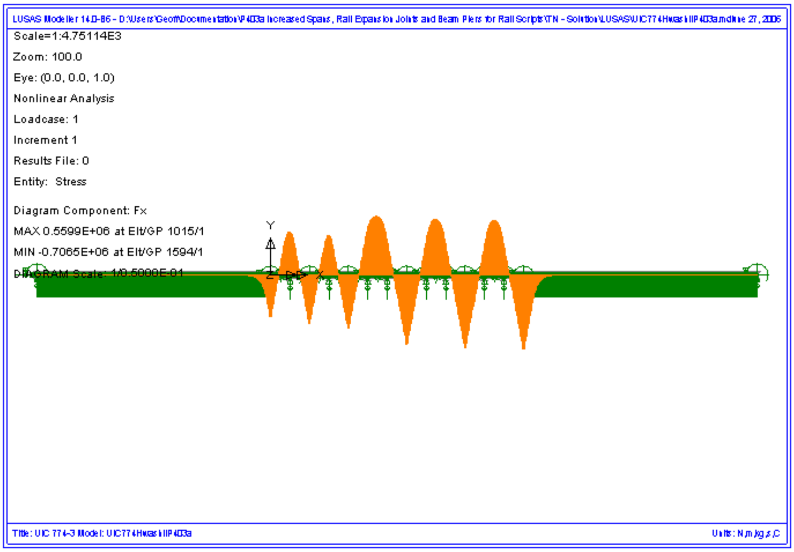


Figure 78: Axial Force In Rails Due To Thermal Only

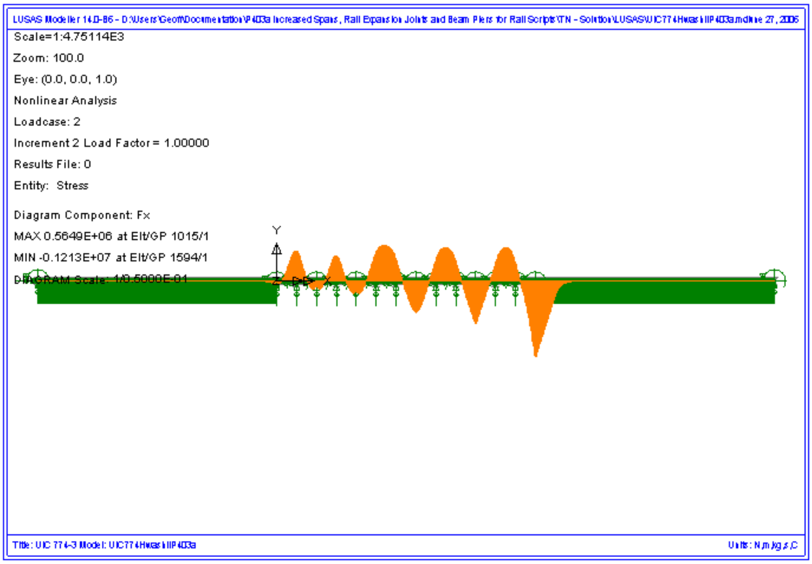


Figure 79: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 1

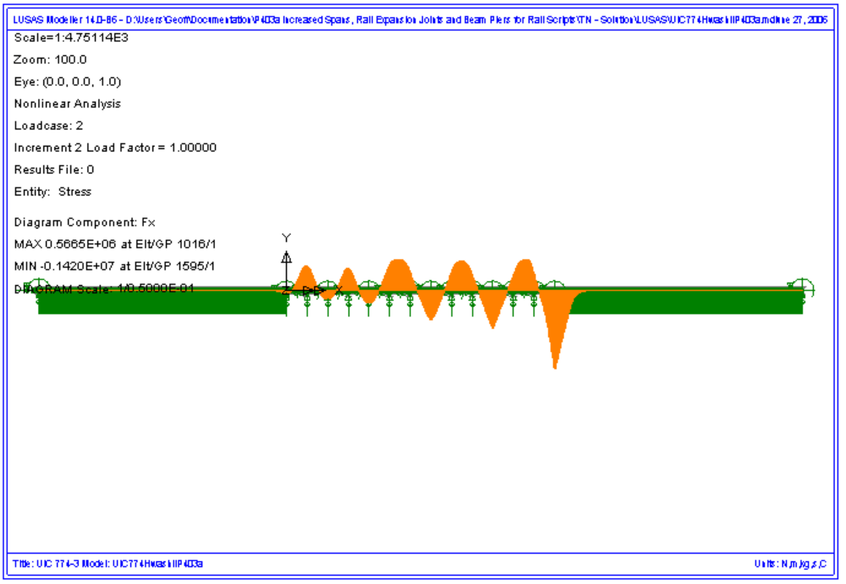


Figure 80: Axial Force In Rails Due To Combined Thermal And Train Loads In Track 2

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 in Section 0 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 84) and the concurrent thermal/train loading analysis (Figure 83) shows that the overall yield behaviour is almost identical, hence the similarity in the peak compressive rail stresses obtained albeit with the LUSAS value slightly lower. Looking now at the separate analysis, the yield layout for both the LUSAS and concurrent thermal/train loading analyses are comparable with the yield layout for thermal effects alone (Figure 81) with very little yield associated with the accelerating rail load analysis (Figure 82). This is primarily 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.

Figure 81: Track/Rail 2 Yield Due To Thermal Load On Track Alone

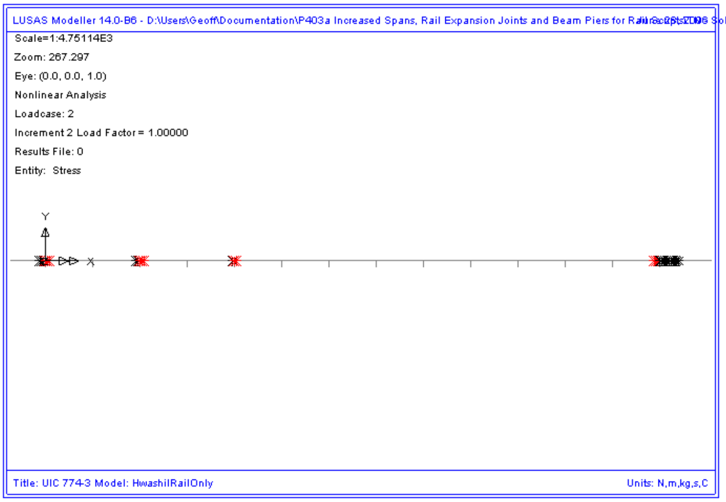


Figure 82: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 – Separate Analysis

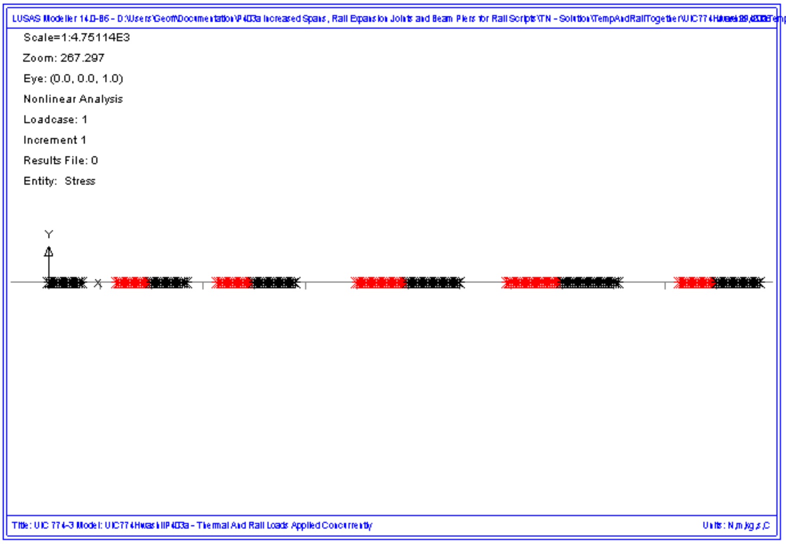


Figure 83: Track/Rail 2 Yield Due To Accelerating Train Loads On Track 2 - Thermal And Rail Applied Concurrently

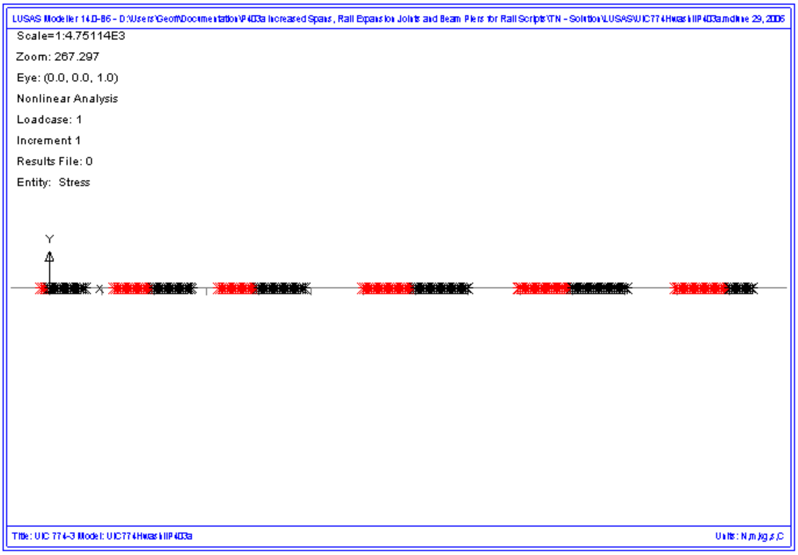


Figure 84: Track/Rail 2 Yield Due To Accelerating Train Load On Track 2 - LUSAS Combined Analysis

Looking at what is effectively happening in these analyses, Figure 85, 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.

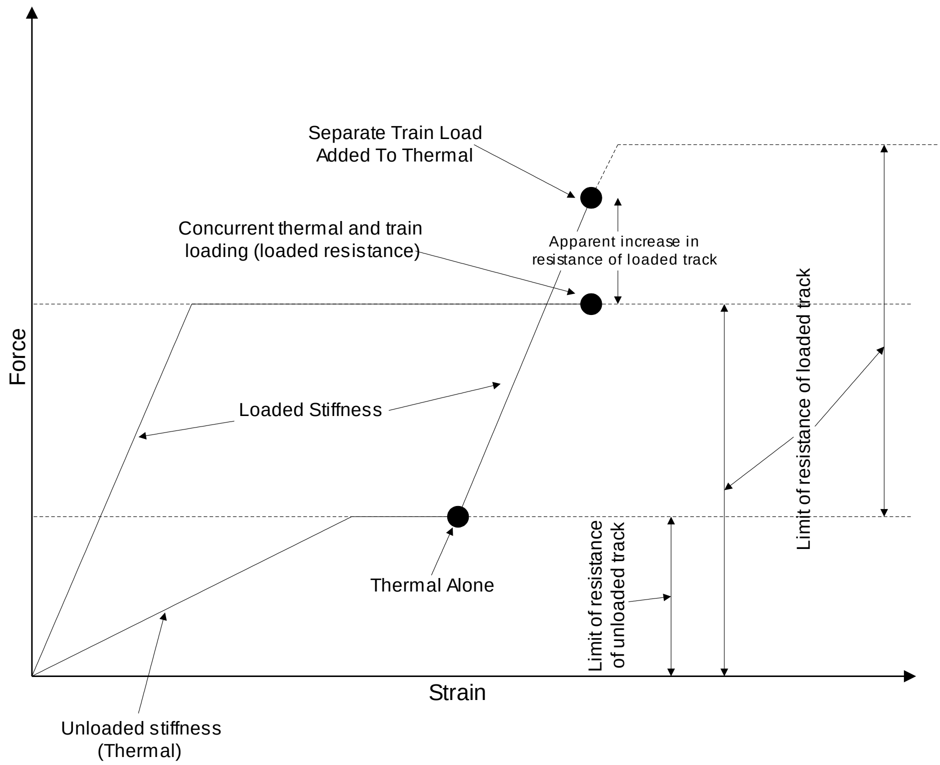


Figure 85: Illustration Of Behaviour Of Separate Analysis Vs. Concurrent Thermal And Rail Loading

Similar comparisons can be made between the separate analysis and the LUSAS analysis - Figure 86. 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 93 to 103 N/mm^2.

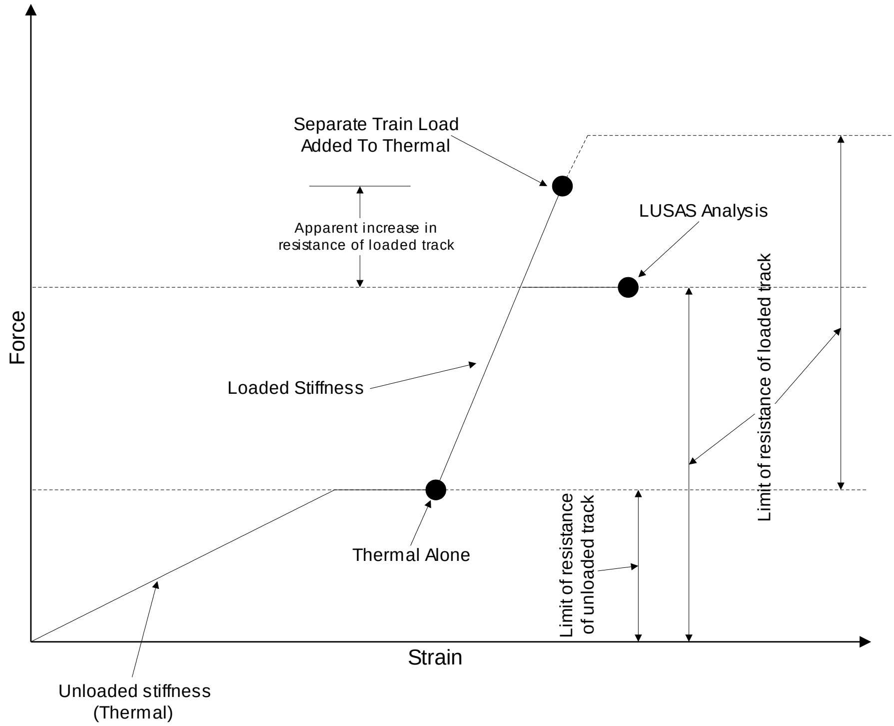


Figure 86: Illustration Of Behaviour Of Separate Analysis Vs. LUSAS Analysis

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 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 87) shows close similarity to the yielding observed when the thermal and train loading are applied concurrently (Figure 89) – minimal yielding is observed under the action of the train load alone in the separate analysis (Figure 88).

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 88 and Figure 90 where the yielding underneath the braking train is greater for the LUSAS analysis than in the separate rail load analysis.

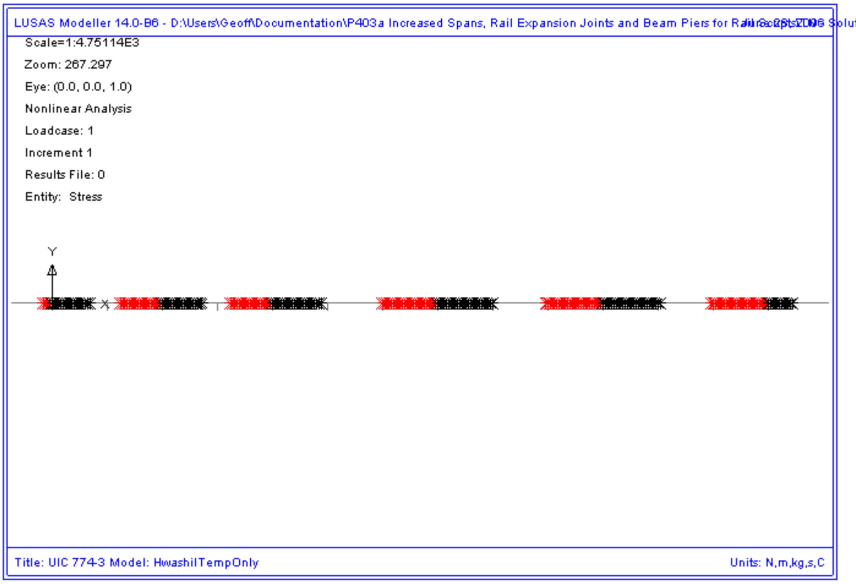


Figure 87: Track/Rail 1 Yield Due To Thermal Load On Track Alone

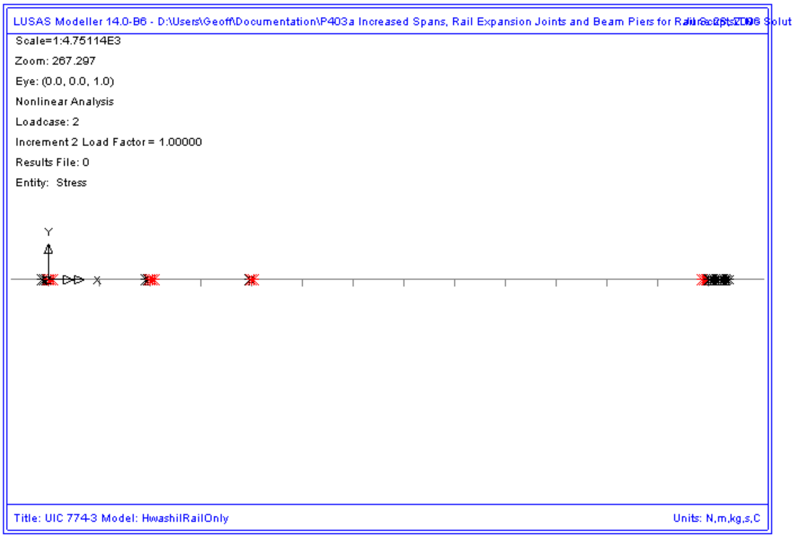


Figure 88: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 – Separate Analysis

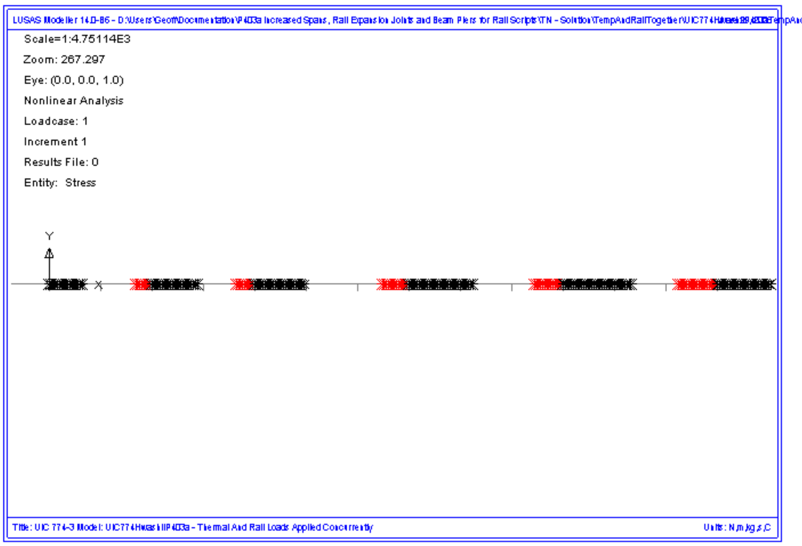


Figure 89: Track/Rail 1 Yield Due To Braking Train Loads On Track 1 - Thermal And Rail Applied Concurrently

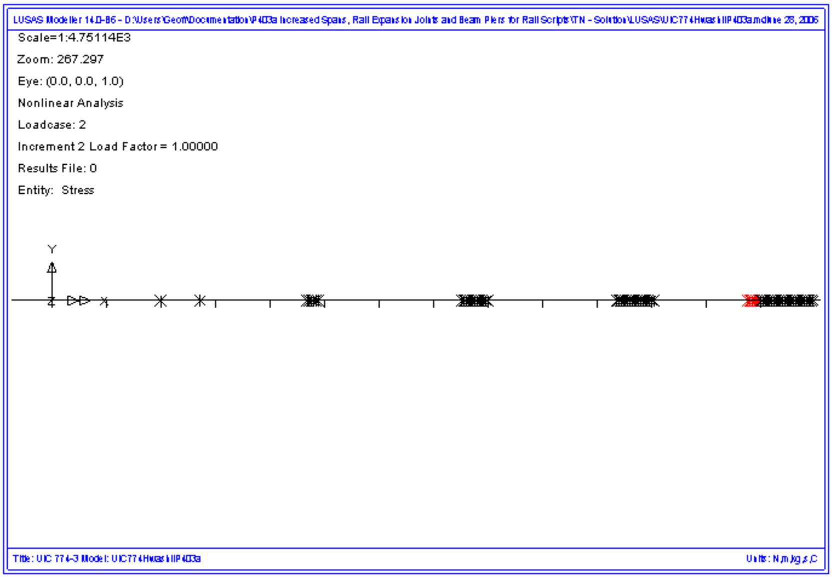


Figure 90: Track/Rail 1 Yield Due To Braking Train Load On Track 1 - LUSAS Combined Analysis

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 91 and Figure 92 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 93.

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.

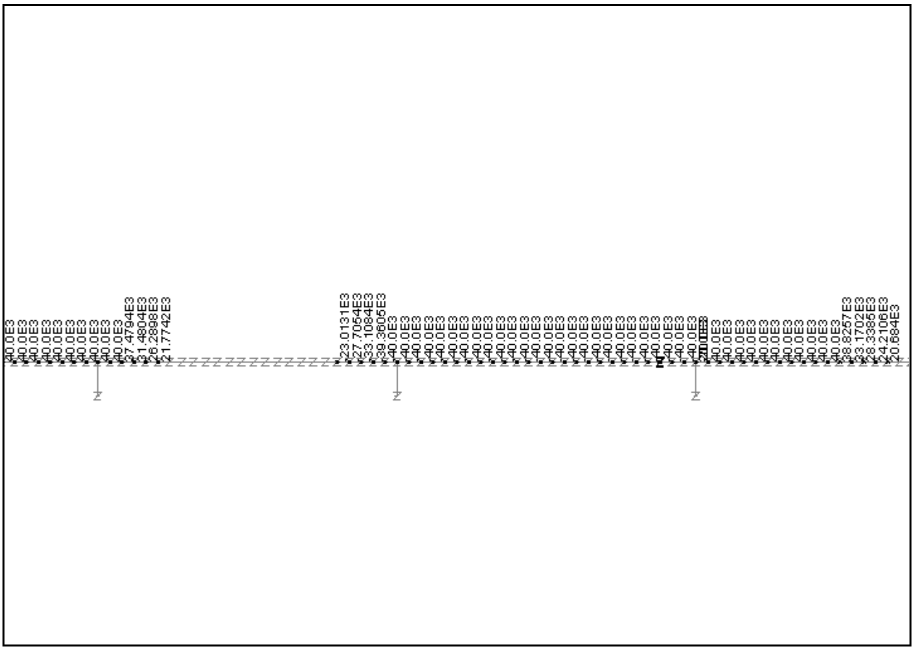


Figure 91: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 – Separate Thermal Loading (N/m length)

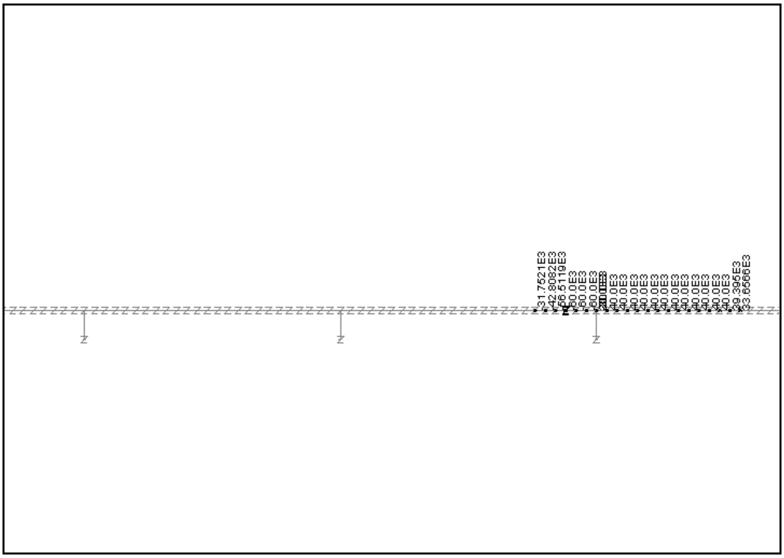


Figure 92: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In The Rail - Track 1 - Separate Train Loading (N/m length)

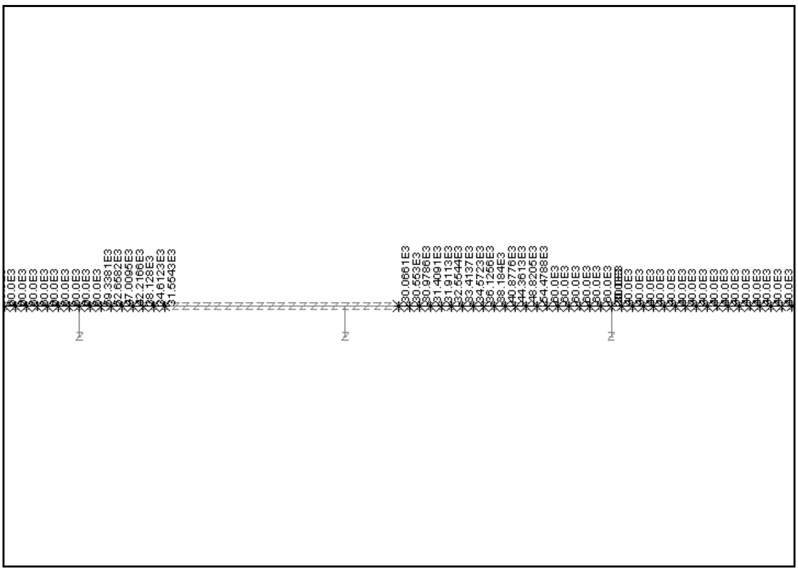


Figure 93: Force In Interaction At Right-Hand End Of Structure Where Peak Compressive Stresses Occur In THe Rail - Track 1 – LUSAS Nonlinear (N/m length)

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 150.21 N/mm^2 which compares well with the code of practice value of 156.67 N/mm^2 (allowing for slight differences in material properties which have been estimated).

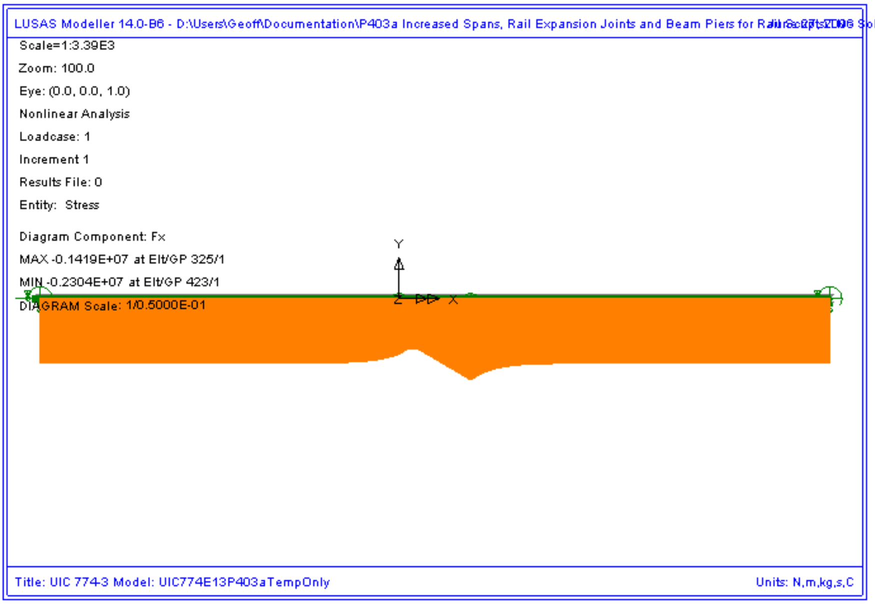


Figure 94: Axial Force In Rails Due To Temperature In Bridge And Rail

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.

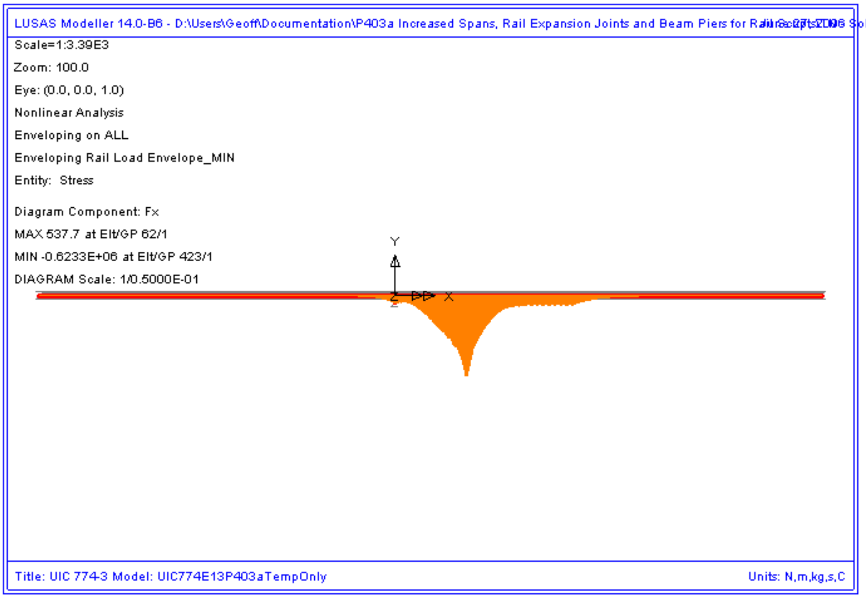


Figure 95: Envelope Of Axial Force In Rails Due To Rail Loading

Manual combination of the peaks would give a peak compressive rail stress of 190.85 N/mm^2 (ignoring locations of the peaks) and combination of the results in LUSAS gives 190.82 N/mm^2.

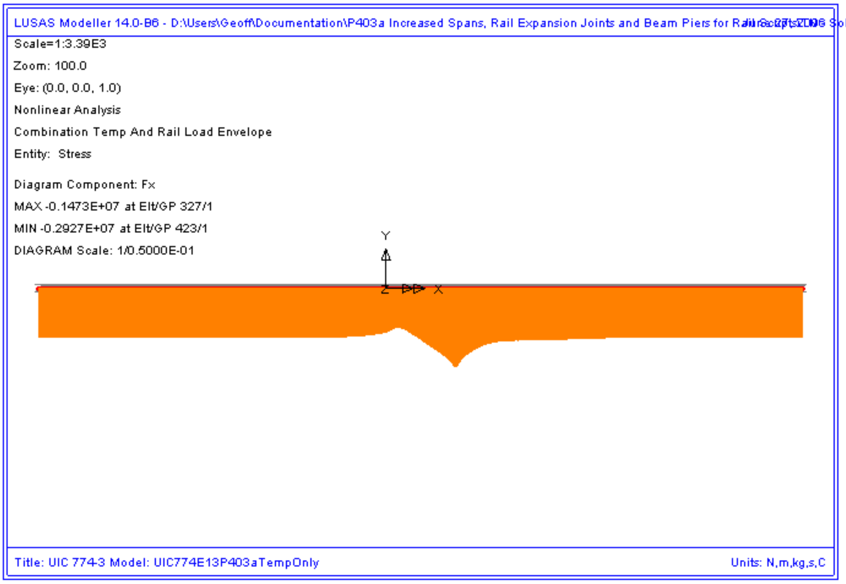


Figure 96: Axial Force In Rails Due To Combined Temperature And Rail Loading

Comparison of these results with the UIC774-3 code of practice test results shows that the result compares directly 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) and are close to the rigorous answer of 182.4 N/mm^2.

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:	**150.21 N/mm^2**
Thermal & Rail:	**187.56 N/mm^2**

Comparison of the results shows that the rail stresses are in excellent agreement for both parts of the analysis with the compressive rail stress having a percentage error of 2.83% when compared against the target rigorous solution of 182.4 N/mm^2.

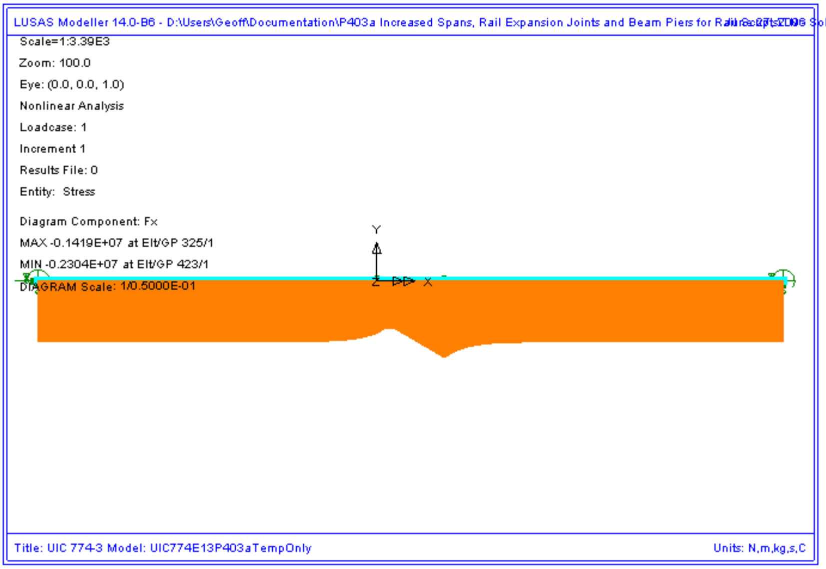


Figure 97: Axial Force In Rails Due To Temperature In Bridge And Rail

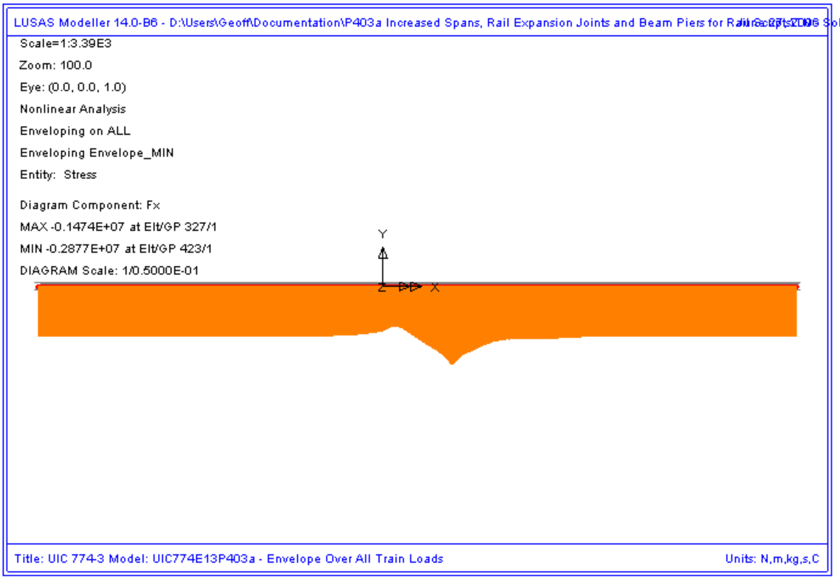


Figure 98: Axial Force In Rails Due To Combined Temperature And Enveloped Rail Loading

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 99. 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 100 and Figure 101. 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.

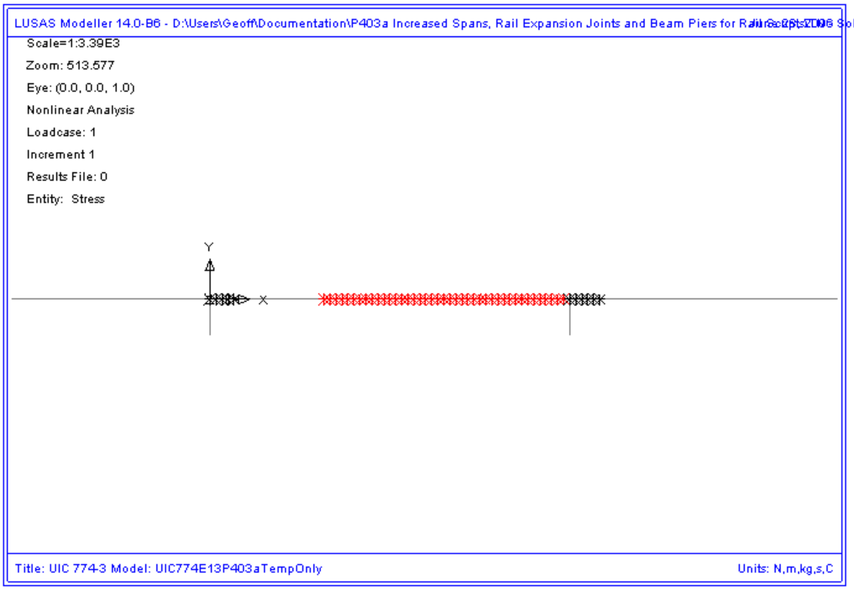


Figure 99: Yield Layout For Thermal Loading Only

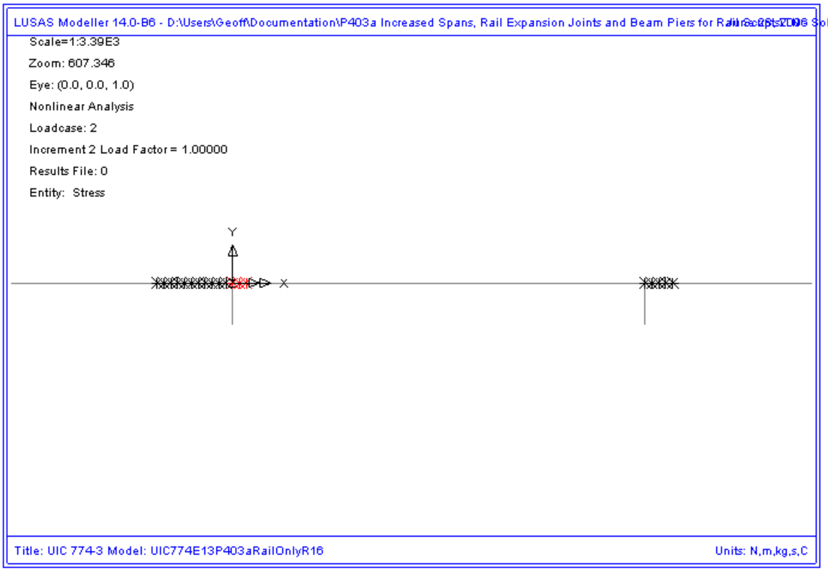


Figure 100: Yield Layout For Train Loading Only From Separate Analysis

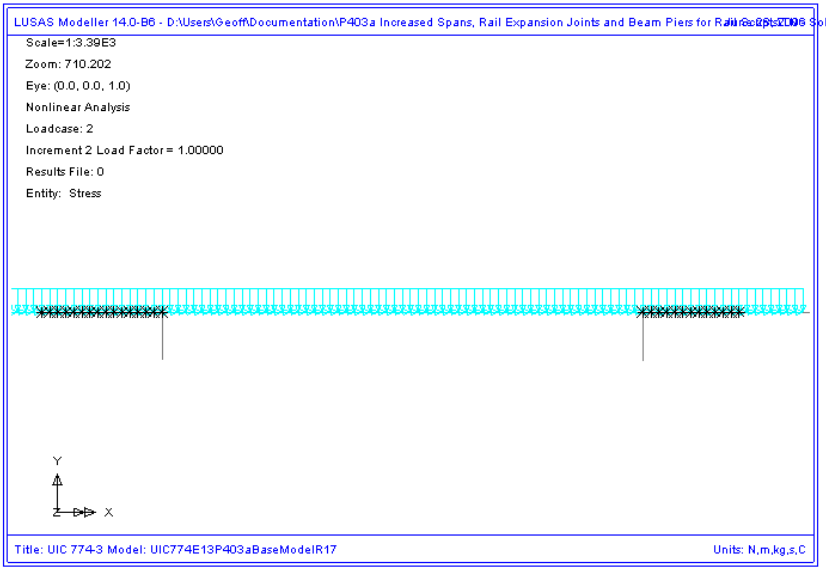


Figure 101: Yield Layout For Combined Thermal And Train Loading From LUSAS Nonlinear Analysis

The following two plots show the forces in the interaction joints for the thermal and train loads from the separate analysis. 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 25.7 kN/m over the structure. Combining these two results means that the total force per unit length for the separate analysis is 45.7 kN/m which is comparable to the LUSAS nonlinear solution of 40.4 kN/m – see Figure 104. 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 105.

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 25.7 kN/m then significant differences could be observed in the two analysis methods as the separate method would still allow a further 20 kN/m track resistance to be mobilised before the onset of plastic yielding and the separate analysis would potentially over predict the rail stresses occurring. This potentially means that…

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

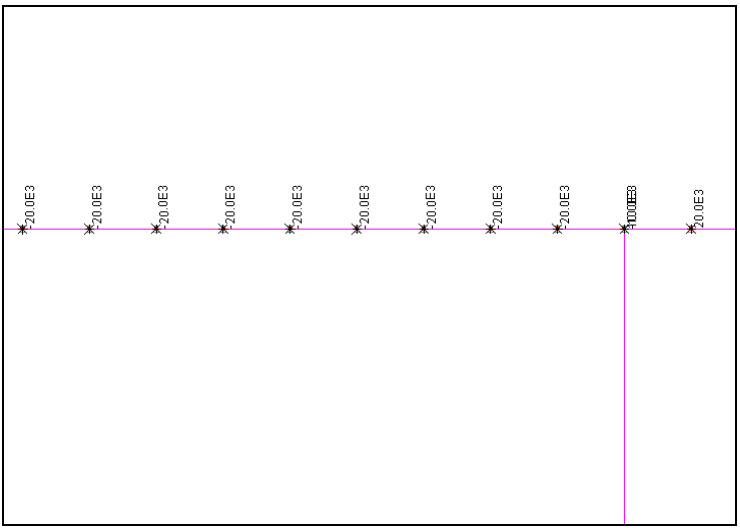


Figure 102: Force Per Metre Length In Interaction From Thermal Loading - Separate Analysis

Figure 103: Force Per Metre Length In Interaction From Train Loading - Separate Analysis

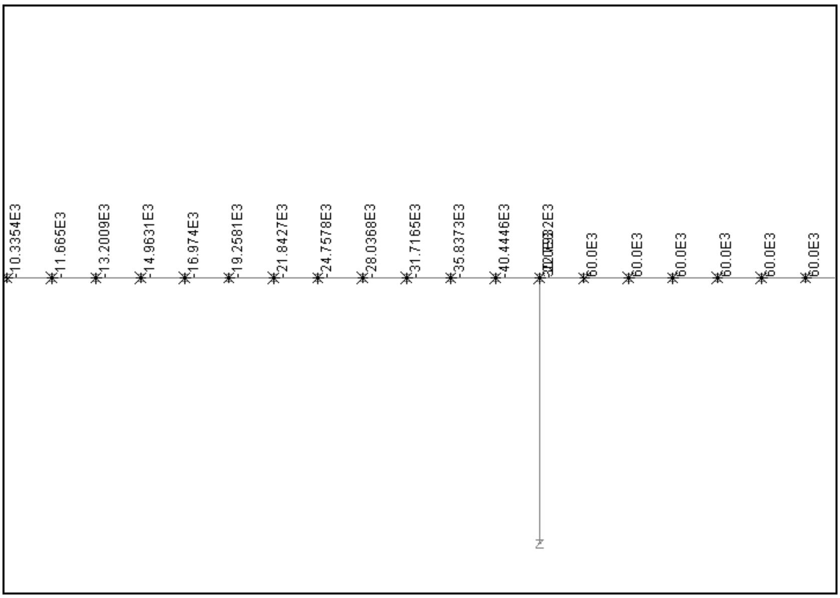


Figure 104: Force Per Metre Length In Interaction From Combined Loading - LUSAS Analysis

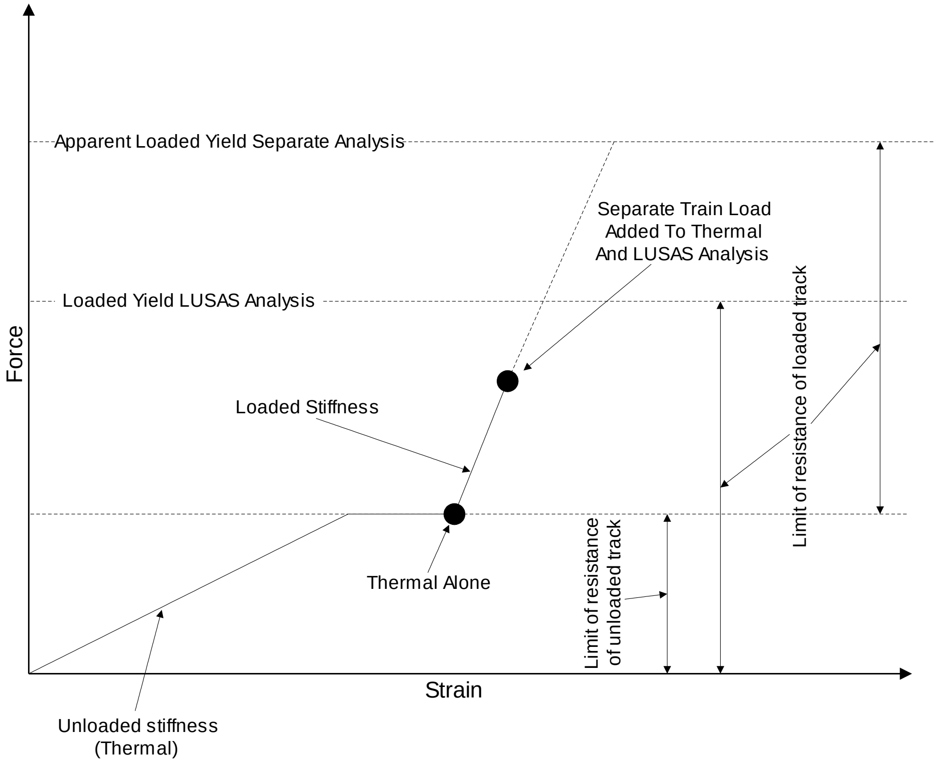


Figure 105: Illustration Of Behvaiour For UIC774-3 Standard Test E1-3 For Separate And LUSAS Analyses

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 161.48 N/mm^2 which compares well with the code of practice value of 169.14 N/mm^2 (allowing for slight differences in material properties which have been estimated).

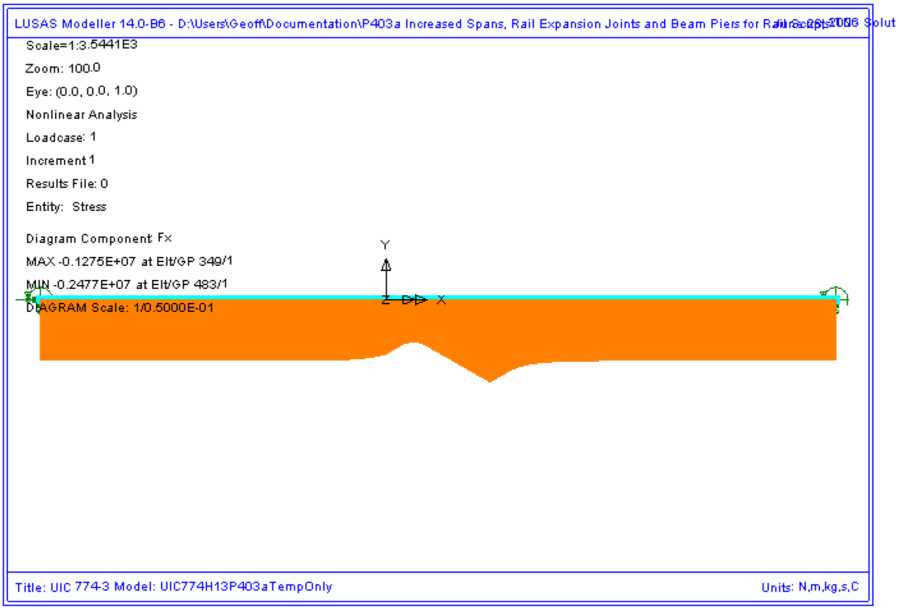


Figure 106: Axial Force In Rails Due To Temperature In Bridge And Rail

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.

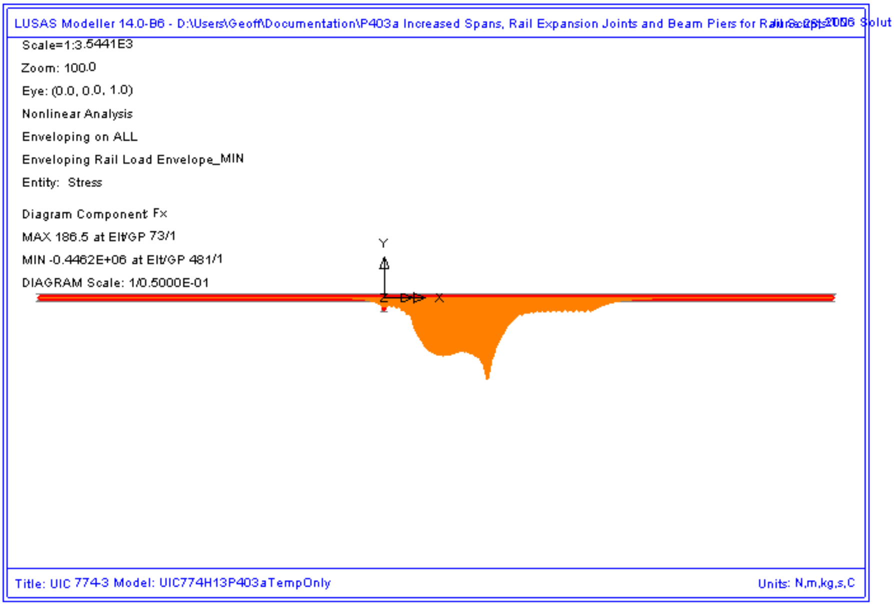


Figure 107: Envelope Of Axial Force In Rails Due To Rail Loading

Manual combination of the peaks would give a peak compressive rail stress of 190.57 N/mm^2 (ignoring locations of the peaks) and combination of the results in LUSAS gives 190.56 N/mm^2.

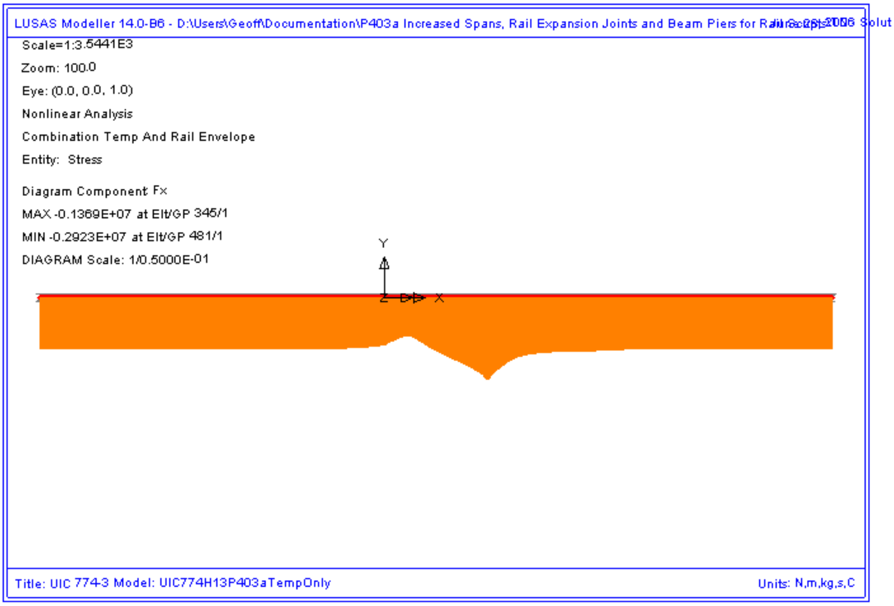


Figure 108: Axial Force In Rails Due To Combined Temperature And Rail Loading

Comparison of these results with the UIC774-3 code of practice test results shows that the result compares well with the 188.23 N/mm^2 compressive rail stress from the complex 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:	**161.48 N/mm^2**
Thermal & Rail:	**189.65 N/mm^2**

Comparison of the results shows that the rail stresses are in excellent agreement for both parts of the analysis with the compressive rail stress having a percentage error of 0.75% when compared against the target solution of 188.23 N/mm^2.

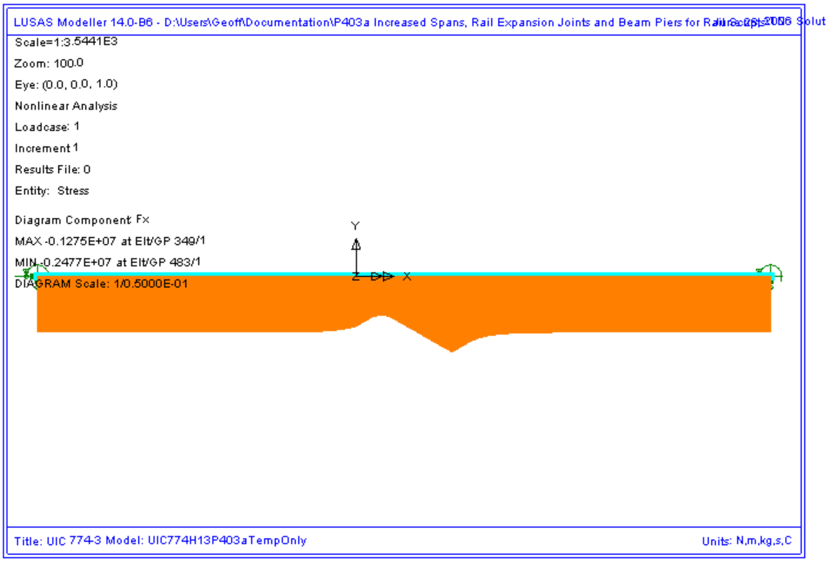


Figure 109: Axial Force In Rails Due To Temperature In Bridge And Rail

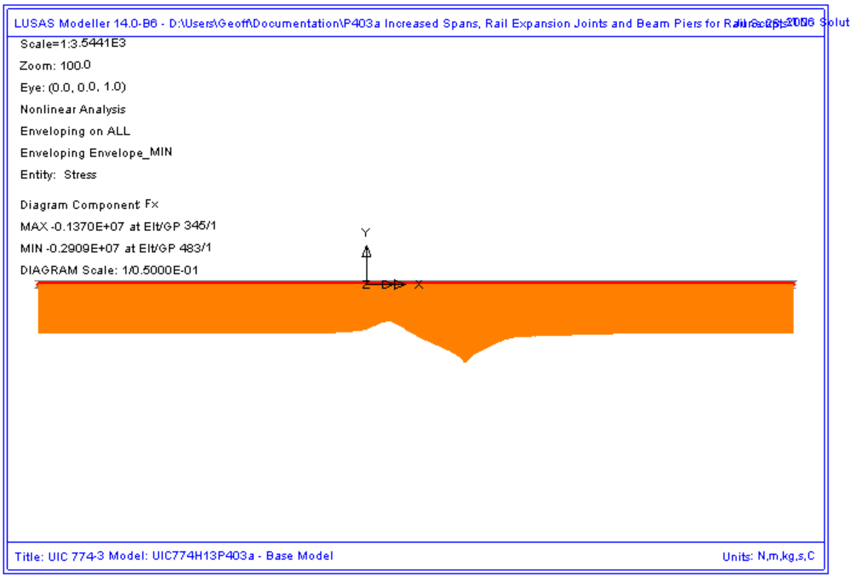


Figure 110: Axial Force In Rails Due To Combined Temperature And Enveloped Rail Loading

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:	**27.8 kN/m**
LUSAS:	**26.1 kN/m**

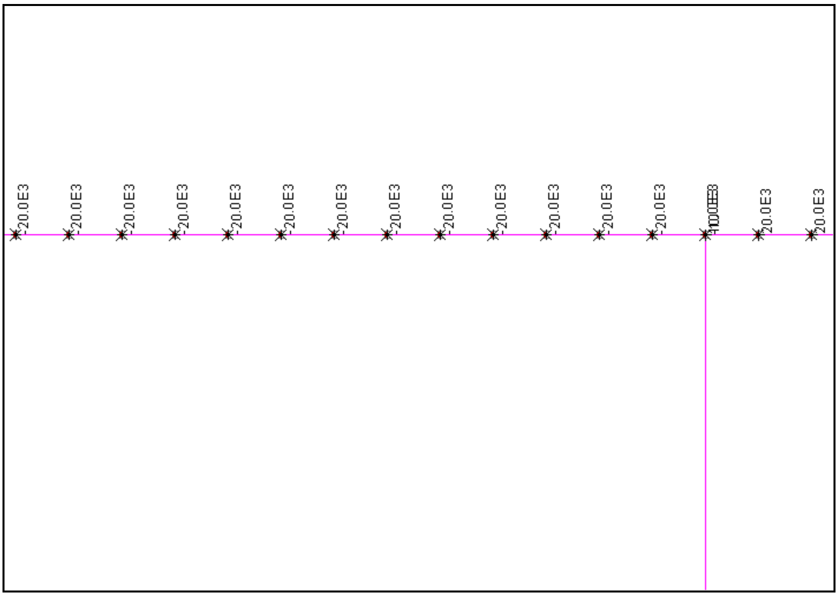


Figure 111: Force Per Metre Length In Interaction From Thermal Loading - Separate Analysis

Figure 112: Force Per Metre Length In Interaction From Train Loading - Separate Analysis

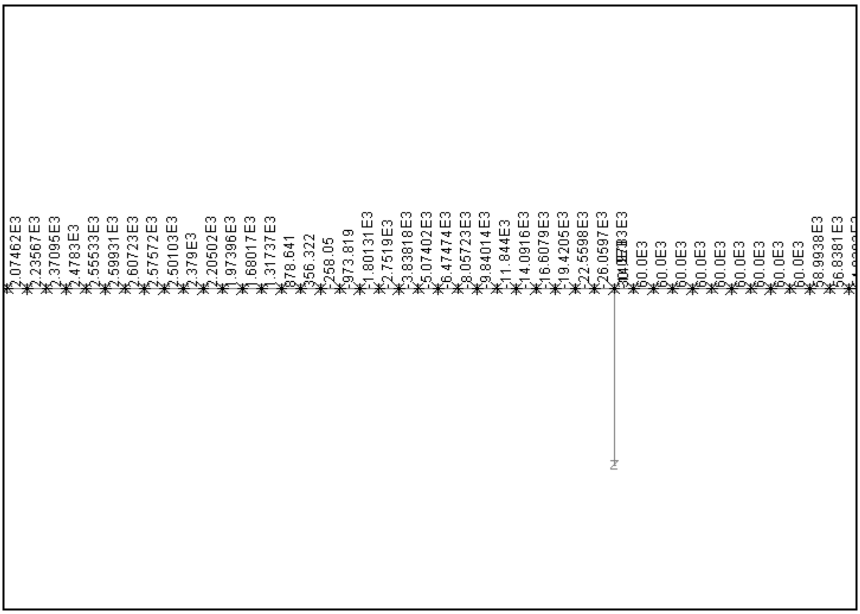


Figure 113: Force Per Metre Length In Interaction From Combined Loading - LUSAS Analysis

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 85 and Figure 86, the key issue with the separate analysis approach is the ability for the track resistance to be overestimated by the combination of the two nonlinear analyses and potentially cause the rail stresses to be overestimated. In the concurrent loading and LUSAS rail option analyses the limit of track resistance is correctly modelled as the value determined from the loaded bilinear curve and therefore this potentially leads to reduced rail stresses observed in the analyses. As the initial movement under pure thermal loading in the concurrent analysis uses the loaded track resistance this will give different results to the LUSAS rail option analysis. Referring back to the Hwashil Viaduct analyses, the rail stresses observed for the three analysis types are:

	Separate Analysis Of Thermal And Train Loading	Concurrent Thermal And Train Loading	LUSAS Nonlinear Thermal And Train Loading With Material Change
Track 1 (Braking)	94.99	85.6	79.08
Track 2 (Accelerating)	103.66	100.6	92.58

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