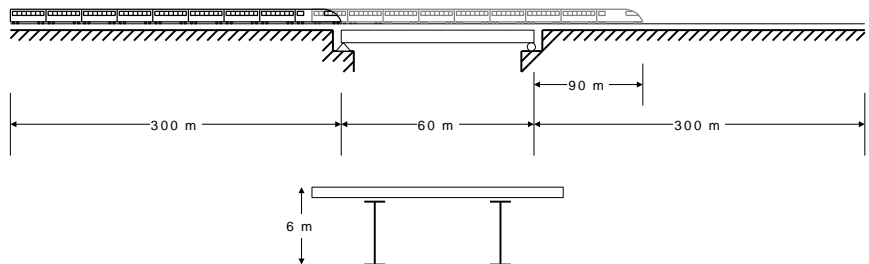


# Rail Track-Structure Interaction to UIC774-3

For LUSAS version:	19.0
For software product(s):	LUSAS <i>Bridge</i>
With product option(s):	Nonlinear, Rail Track
Note: The example exceeds the limits of the LUSAS Teaching and Training Version.	

## Description

This example examines the track-structure interaction between a braking train and a single span bridge. It considers the cases where the trainset is just about to enter the left-side side of the structure through to the front of the train being 90m beyond the right-hand side. It approximates (as far as the original test data allows) testcase E1-3 which can be found in Appendix D.1 of the UIC774-3 Code of Practice.



## Objectives

The output requirements of the analysis are:

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

- Peak axial rail stresses.
- Peak longitudinal reactions at the abutments.

### Keywords

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

### Associated Files



These two files are provided in the <LUSAS Installation Folder>\Programs\Scripts\User folder, and are intended for copying to a project folder if a rail track model is to be defined from scratch.

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

These files also provided in the <LUSAS Installation Folder>\Examples\Modeller folder and are intended for copying to a projects folder if results processing only and not spreadsheet data input is of interest:

- UIC E1-3 Analysis.xlsx** or **UIC E1-3 Analysis.xls** UIC774-3 Microsoft Excel input spreadsheet populated with data defined in this example. If used, continue at the section titled *Modelling / Running an Analysis*.
- UIC E4-6 Analysis.xlsx** or **UIC E4-6 Analysis.xls** UIC774-3 Microsoft Excel input spreadsheet populated with data defined in this example. This is for use for a further investigation with the same model as built by the preceding spreadsheet.

## Defining Model Data

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

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

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

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

- Rename the spreadsheet to **UIC E1-3 Analysis.xlsx** if using Microsoft Excel 2007 and above or rename to **UIC E1-3 Analysis.xls** if the other file was copied and you are using an older version of Microsoft Excel.
- Open the spreadsheet in Microsoft Excel.

The modelling spreadsheet contains six worksheets titled:

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



**Note.** Data should only be entered into the yellow regions of the Microsoft Excel spreadsheet to define the modelling and analysis requirements. Numeric values in the white cells are automatically populated according to data entered in other worksheets. These cells are protected from editing or user input. Data tips and other details relating to cells can often be seen by hovering over a cell.



**Note.** Whilst it is recommended that an unpopulated spreadsheet is used with this example, populated spreadsheets are supplied for those not wishing to enter all details as listed or for use if any errors are encountered with user-input into the general spreadsheet that cannot easily be fixed. Populated spreadsheets can be found in the \<LUSAS Installation Folder>\Examples\Modeller folder. A spreadsheet compatible for an installed version of version of Microsoft Excel should be copied to the working folder where the track-structure interaction example model is to be created.

## Defining Decks, Tracks and Embankment Lengths

- Pick the **Decks, Tracks and Embankment** worksheet.
- Enter **1** for the Number of Decks.
- Enter **1** for the Number of Tracks.

	A	B	C	D
1	<b>Decks, Tracks and Embankment</b>	Units : m		
2				
3	Number of Decks	1		
4	Number of Tracks	1		
5	Left Embankment Length	300		
6	Right Embankment Length	300		
7	Length of Decks Only / Total Length (m)	60	660	
8				
9				

- The UIC774-3 Code of Practice specifies the embankment lengths for the test cases to be 300m. Enter **300** for both the Left Embankment Length and Right Embankment Length.

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

### Defining the Structure

- Pick the **Structure Definition** worksheet.
- The left abutment has a stiffness of 600000kN/m according to test case E1-3. Enter **600** for the **Spring Support for each Abutment/Pier** for the left end of the deck because the units for the worksheet entry are kN/mm.
- No bearing behaviour is modelled in the E1-3 test case so enter **R** for the **Bearing Springs on Top of each Pier** for the left end of the deck.
- The first and only span of the deck has a free support in the longitudinal direction and can be specified through either no restraint in the spring support for the abutment / pier or through no restraint in the bearing springs. For this example the condition has been modelled using no restraint in the bearing springs.
- Enter **R** for the **Spring Support for each Abutment/Pier** for the first span of the deck.
- Enter **F** for the **Bearing Springs on Top of each Pier** for the first span of the deck.
- Enter **60** for the **Span Length**.
- Enter **1** for the **Geometric Assignment**. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.
- Enter **1** for the **Material Assignment**. This ID will match a material definition in the **Material Properties** worksheet covered later.



**Note.** No data is input for the **Bearing Offset from End of Deck** entry as the bearings in the UIC774-3 E1-3 test case are at the extreme ends of the deck. UIC774-3 only considers the situation where the bearings are at the extreme end of the deck but this is not the situation in reality and location of the bearings away from the ends can significantly affect the behaviour of the track-structure-interaction. The Rail Track Analysis in LUSAS allows the bearings to be placed inboard of the deck end which is demonstrated in another worked example.

The worksheet should look like this:

Structure Definition		Units : Pier Height : m ; Bearing springs on top of each pier : kN/mm, Span Length : m								
		Spring Support for each Abutment /Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign	Bearing Springs on Top of each Pier	Bearing Offset from End of Deck	Span Length	Geo. Assign.	Mat. Assign.
Deck 1	Left End	600				R				
	Span 1	R				F		60	1	1
	Span 2									
	Span 3									
	Span 4									
	Span 5									
	Span 6									
	Span 7									
	Span 8									
	Span 9									
Number of Supports for the Deck / Length		2				2		60		
Deck 2	Left End									
	Span 1									
	Span 2									
	Span 3									
	Span 4									
	Span 5									
	Span 6									
	Span 7									
	Span 8									
	Span 9									
Number of Supports for the Deck / Length		0				0		0		
Deck 3	Left End									
	Span 1									
	Span 2									



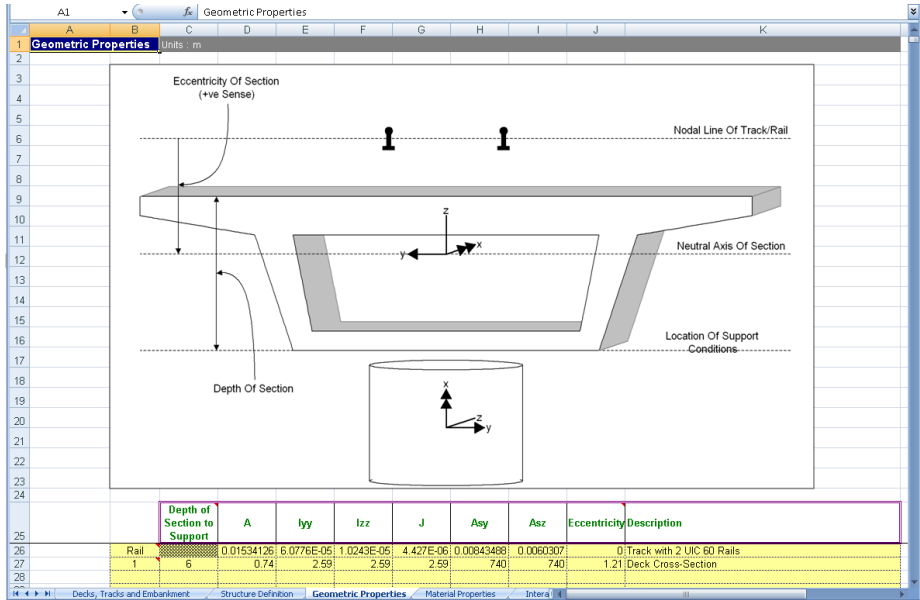
**Note.** If more spans were present in the deck or the structure consisted of multiple decks this information would be entered into this worksheet.

The UIC774-3 fundamental tests do not incorporate modelling of the piers of the structure, so are not included in this example. However, LUSAS offers two methods of modelling piers when this is required to be done.

- The first method represents the pier through the equivalent stiffness, which should be entered into the **Spring Support for each Abutment/Pier** entry and is calculated in accordance with Clause 1.3.2.2 in the UIC774-3 Code of Practice.
- The second method physically includes the pier in the finite element model and requires additional data entry into the columns for the **Pier Height**, **Pier Geometric Assignment** and **Pier Material Assignment**.

For further details see the Rail Track Analysis User Manual.

## Defining the Geometric Properties for the Structure



- Pick the **Geometric Properties** worksheet.

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

The details of the rail used in the UIC774-3 test cases are not provided so it has been assumed that the track is formed of two UIC 60 rails and for the purposes of this example the properties are obtained by doubling the values from the LUSAS section library to give the total value per track. Enter the following values for the rail track:

- Enter **0.01534126** for the area (**A**) in  $m^2$  of the two rails of the track.
- Enter **6.07756E-5** for the second moment of inertia about the horizontal y-axis (**Iyy**) in  $m^4$ .
- Enter **1.024324E-5** for the second moment of inertia about the vertical z-axis (**Izz**) in  $m^4$ .
- Enter **4.42698E-6** for the torsional constant (**J**) in  $m^4$ .
- Enter **8.43488E-3** for the shear area for the y-direction (**Asy**) in  $m^2$ .
- Enter **6.0307E-3** for the shear area for the z-direction (**Asz**) in  $m^2$ .

- Enter **0** for the **Eccentricity** in the rail in m.
- Enter **Track with 2 UIC 60 Rails** in the **Description** for the rails.



**Note.** The UIC774-3 Code of Practice assumes that a 2D analysis is performed where the longitudinal and vertical behaviours of the track and structure are of interest. The current rail track analysis also assumes a 2D analysis but for its solution it requires the features of an element type which is only available in 3D in LUSAS. The properties entered into the worksheet therefore require geometric properties for all freedoms of the 3D element and the lateral behaviour and torsion the properties for two rails have been assumed to be twice those of the single rail. This will be discussed further in the **Modelling Discussion** section that follows.

Some of the properties for the 2D bending behaviour of the deck are provided in Appendix D.1 of the code of practice. As for the track rails, while the analysis is 2D the elements used are 3D so dummy properties have been included for the lateral behaviour and torsion of the deck although these will not affect the results obtained. In the model it has therefore been assumed that these properties are equal to the values provided for the vertical behaviour. Enter the following values for the deck:

- Enter **1** for the ID in the first column to match the geometric assignment ID for the deck in the **Structure Definition** worksheet.
- Enter **6** for the **Depth of Section** in m.
- Enter **0.74** for the area (**A**) in m<sup>2</sup>.
- Enter **2.59** for the second moment of inertia about the horizontal y-axis (**I<sub>yy</sub>**) in m<sup>4</sup>.
- Enter **2.59** for the second moment of inertia about the vertical z-axis (**I<sub>zz</sub>**) in m<sup>4</sup>.
- Enter **2.59** for the torsional constant (**J**) in m<sup>4</sup>.
- Enter **740** for the shear area for the y-direction (**A<sub>sy</sub>**) in m<sup>2</sup>. The UIC774-3 test cases do not indicate whether shear deformations were included in the calculation of the target results so these have been ignored by setting the shear area to 1000\*A in accordance with the *Element Reference Manual*.
- Enter **740** for the shear area for the z-direction (**A<sub>sz</sub>**) in m<sup>2</sup>.
- Enter **1.21** for the **Eccentricity** in the deck in m. The UIC774-3 test cases assume that the track is at the top surface of the section and the neutral axis ordinate specified is from the base of the section. The depth of the section is 6m and the neutral axis ordinate is 4.79m giving an eccentricity of  $6 - 4.79 = 1.21$ m.
- Enter **Deck Cross-Section** in the **Description** for the deck.

## Modelling Discussion

While the UIC774-3 Code of Practice treats the track-structure interaction as a 2D problem the rail track analysis software uses 3D thick beam elements for the modelling of this problem but restrains the out of plane behaviour thus reducing it back to an equivalent 2D analysis. In the definition of the geometric properties for the track rails and structure the rail track analysis software therefore requires all of the 3D geometric properties to be defined for the worksheet. The properties entered for  $I_{zz}$ ,  $J$  and  $A_{sy}$  will be used in the analysis but these will not affect the results. They should however be set to similar magnitudes to the properties in  $I_{yy}$  and  $A_{sz}$  which are used for the bending deflection and shear deflection in the geometric properties to avoid mechanisms.

The properties for a single UIC 60 rail were taken from the LUSAS KS Rails section library. Since only the vertical bending of the track is considered the combined geometric section properties for the two rails of the track can be calculated by doubling the values for the single rail. These combined values are the ones entered into the **Rail** properties section of the Geometric Properties worksheet



**Note.** The doubling of the  $I_{zz}$ ,  $J$  and  $A_{sy}$  properties could be considered to be inappropriate but since these properties are not used in the effective 2D analysis their doubling is considered acceptable.

## Defining the Material Properties for the Structure

		E	$\nu$	$\rho$	$\alpha$	Description
1	Rail	210000	0.3	0	1.20E-05	Rails
5	1	210000	0.3	0	1.00E-05	Deck

- Pick the **Material Properties** worksheet.

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

Enter the following values for the rail:

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



- Enter **0.3** for the Poisson's ratio ( $\nu$ ).
- Enter **0** for the mass density ( $\rho$ ). Setting this to the representative value allows the self-weight deflections to be calculated for the structure and track system if they are required but it is not used for the track-structure interaction analysis.
- Enter **1.20E-5** for the coefficient of thermal expansion ( $\alpha$ ) – see note below.
- Enter **Rails** in the **Description** for the rails.

Enter the following values for the deck:

- Enter **1** for the ID in the first column to match the material assignment ID for the deck in the **Structure Definition** worksheet.
- Enter **210000** for the Young's modulus (**E**) in N/mm<sup>2</sup>.
- Enter **0.3** for the Poisson's ratio ( $\nu$ ).
- Enter **0** for the mass density ( $\rho$ ).
- Enter **1.0E-5** for the coefficient of thermal expansion ( $\alpha$ ).
- Enter **Deck** in the **Description** for the material properties.



**Note.** The documentation accompanying the UIC774-3 test cases does not mention the exact material properties that were used for the rail track in the target solutions and also does not mention the Poisson's ratio or coefficient of thermal expansion used for the track / deck. The Poisson's ratio has therefore been assumed to be identical for both and the coefficient of thermal expansion used for the deck is identical to the value mentioned in Example 1 in Appendix C.1 of the UIC774-3 Code of Practice and mentioned elsewhere within the Code of Practice.

From the temperature behaviour of a restrained bar it can, however, be back calculated that the coefficient of thermal expansion for the track was 1.2E-5 to obtain a target compressive stress of 126 MPa in the track alone under thermal loading. To replicate the exact test case the example has therefore used this coefficient of thermal expansion and accurate UIC60 track properties.

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

Interaction Joint Properties Between Rail/Slab				
Units : Bilinear springs characteristic : kN/mm/m, Eccentricity between rail/slab : m				
Eccentricity between Rail/Slab	0			
Parametric Distance of Interaction Joint from Rail	0.5			
Unloaded Bilinear Springs Characteristic	Elastic Spring Stiffness	10	infinite	infinite
	Yield Force	20	infinite	infinite
	Hardening Stiffness	1.00000E-06	infinite	infinite
Loaded Bilinear Springs Characteristic	Elastic Spring Stiffness	30	infinite	infinite
	Yield Force	60	infinite	infinite
	Hardening Stiffness	1.00000E-06	infinite	infinite

Rail Expansion Joints				
Units : Distance : m, Initial gap : mm				
	Track 1		Track 2	
	Position	Initial Gap	Position	Initial Gap

- Pick the **Interaction and Expansion Joint** worksheet.
- Enter **0** for the eccentricity between the rail and slab as the UIC774-3 test cases in Appendix D.1 are assumed to have their centre of gravity coincident with the top of the reinforced concrete slab of the deck.
- Enter **0.5** for the Parametric Distance of Interaction Joint from Rail. For modelling with no eccentricity between the rail and the slab this parameter is not used but they are placed halfway between the rail and slab by default for eccentric track if entry is blank.



**Note.** The UIC774-3 test cases assume that the track is ballasted without specifying the exact interaction properties that are to be used. It is therefore assumed that the value

of  $u_0$  in the test cases is equal to 2mm which is the representative value for a sleeper in ballast (as opposed to ‘frozen’ ballast track) indicated in Clause 1.2.1.2.

- Enter **10** for the **Unloaded Elastic Spring Stiffness** in the longitudinal direction in kN/m/mm. The resistance parameter for the unloaded track is 20kN/m in the test and this gives a stiffness of  $20\text{kN/m} / 2\text{mm} = 10\text{kN/m/mm}$  (see note above).
- Enter **20** for the **Unloaded Yield Force** in the longitudinal direction in kN/m.
- Enter **1.0E-6** for the **Unloaded Hardening Stiffness** in the longitudinal direction in kN/m/mm.
- Enter **30** for the **Loaded Elastic Spring Stiffness** in the longitudinal direction in kN/m/mm. The resistance parameter for the unloaded track is 60 kN/m in the test and this gives a stiffness of  $60\text{kN/m} / 2\text{mm} = 30\text{ kN/m/mm}$  (see note above).
- Enter **60** for the **Loaded Yield Force** in the longitudinal direction in kN/m.
- Enter **1.0E-6** for the **Loaded Hardening Stiffness** in the longitudinal direction in kN/m/mm.



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

- Ensure that there is no data specified in the **Rail Expansion Joints** region of the worksheet.

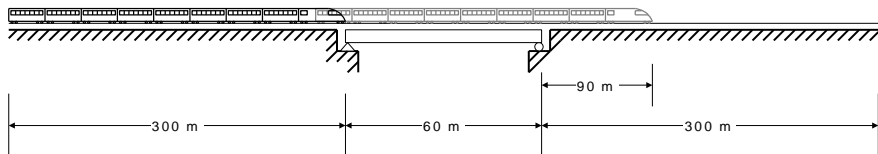
## Defining the Trainset Loading for the Structure

The screenshot shows a spreadsheet with the following data:

Row	Column	Value
1	A	Loading
4	B	Units: Temperature: Celsius, Load Position/Length: m, Load: kN/m
4	C	Amount: 35
5	C	Amount: 50
8	F	Number of Train Loading Groups to Analyse: 1
10	F	Train Loading Group: 1
13	C	Number of Track Loading Locations: 16
14	B	Loading Type
15	C	Track Selection to be Loaded: 1
15	D	Parametric Starting Position for Loadings: 0
15	E	Parametric End Position for Loadings: 300
15	F	Amount (per unit length): 20
15	G	Loaded Length: 300
15	H	Starting Location of Loading for First Analysis: 0
15	I	Finishing Location of Loading for Last Analysis: 150
15	J	Location Increment for each Analysis: 10
16	B	Vertical
16	C	Track Selection to be Loaded: 1
16	D	Parametric Starting Position for Loadings: 0
16	E	Parametric End Position for Loadings: 300
16	F	Amount (per unit length): 80
16	G	Loaded Length: 300
16	H	Starting Location of Loading for First Analysis: 0
16	I	Finishing Location of Loading for Last Analysis: 150
16	J	Location Increment for each Analysis: 10

- Pick the **Loading** worksheet.
- Enter **35** for the **Temperature** variation of the deck in °C.
- Enter **50** for the **Temperature** variation of the rail tracks in °C.

For the UIC774-3 E1-3 test case the single 300m long trainset travels from the left-hand abutment of the 60m long deck to 90m past the right-hand abutment of the deck, a total distance of 150m. For the example this trainset passage will be broken up into 10m increments.



- Enter **1** for the **Number of Train Loading Groups to Analyse** as only the single Train Loading Group is being considered. A Train Loading Group can consist of different trainsets on each track (usually one braking and one accelerating for a two track structure) and the Rail Track Analysis tool can analyse different trainsets / movements of trainsets within multiple Train Loading Groups in the same analysis – see another worked example.

- In the first Train Loading Group, enter **16** for the **Number of Track Loading Locations** based on the formula Number of track loading locations = Travel / Increment + 1 giving  $150 / 10 + 1 = 16$ .
- Enter **Braking** for the **Loading Type** in the first row of loading.
- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.
- Enter **0** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the trainset loading.
- Enter **300** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the trainset loading. The train is 300m long in the test case.
- Enter **20** for the **Amount (per unit length)** to apply 20kN/m horizontal braking forces acting to the right for the trainset moving from left to right.
- Enter **0** for the **Starting Location of Loading for First Analysis** to place the trainset in a location where it is just about to enter the deck structure for the first analysis, recalling that the left-hand embankment is 300m long.
- Enter **150** for the **Finishing Location of Loading for Last Analysis** to place the right-hand extent of the trainset 90m past the 60m deck span for the last analysis.
- Enter **Vertical** for the **Loading Type** in the second row of loading.
- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.
- Enter **0** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the trainset loading.
- Enter **300** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the trainset loading. The train is 300m long in the test case.
- Enter **80** for the **Amount (per unit length)** to apply 80 kN/m vertically downwards for the trainset.
- Enter **0** for the **Starting Location of Loading for First Analysis** to place the trainset in a location where it is just about to enter the deck structure for the first analysis, recalling that the left-hand embankment is 300m long.
- Enter **150** for the **Finishing Location of Loading for Last Analysis** to place the right-hand extent of the trainset 90m past the 60m deck span for the last analysis.
- **Save** the spreadsheet and close the Microsoft Excel application.



**Note.** The horizontal and vertical loading of the trainset in the test cases have identical configurations. More complex trainset loading configurations and acceleration loading can be also specified (see the *Rail Track Analysis User Manual* for more information).

## Modelling / Running an Analysis

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

### Running LUSAS Modeller

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

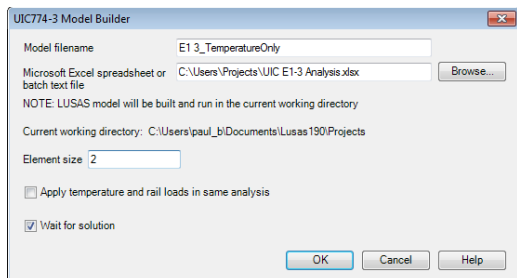
### Creating a Temperature-only Model

An initial temperature-only analysis can form the basis for carrying out more than one track-structure interaction analysis with different trainset loading configurations being used. For large analyses time savings can result from not having to re-run a temperature analysis for each trainset loading.

- Enter **UIC774\_testcase** for the model name.
- Select an analysis category of **3D** and click **OK**.

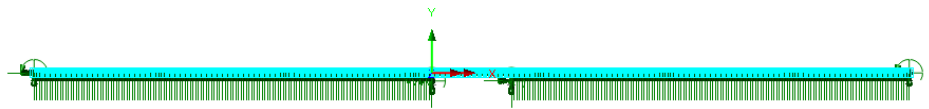
This model is created solely to allow the Rail Track Analysis option to be selected. It is not used after the option has been run.

- Enter a model filename of **E1-3\_TemperatureOnly**
- Enter the filename of the Microsoft Excel spreadsheet you created for the model building and analysis (e.g. **UIC E1-3 Analysis.xlsx**) or browse for it using the **Browse...** button in the Microsoft Excel spreadsheet or batch text file input. If the full folder information is not entered it will be assumed that the Microsoft Excel spreadsheet is in the current working folder which is reported in the dialog.



- If wanting to build the model from a supplied spreadsheet, select the file **UIC E1-3 Analysis.xlsx** located in the \<LUSAS Installation Folder>\Examples\Modeller directory.
- Ensure an Element size of **2** is specified which will create elements of a maximum length of 2m in the LUSAS model.
- Ensure that the **Apply temperature and rail loads in same analysis** option is not selected.
- Ensure the **Wait for solution option** is selected and click the **OK** button.

Assuming that there have been no errors in the input for the Microsoft Excel spreadsheet the Rail Track Analysis software option will automatically generate a LUSAS model (shown below) from the spreadsheet data and run a rail track analysis for temperature-only loading.



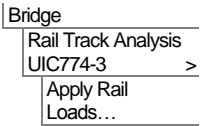
If the Rail Track Analysis software option detected errors with modelling data these will be reported and must be corrected prior to re-running the Rail Track Analysis option.



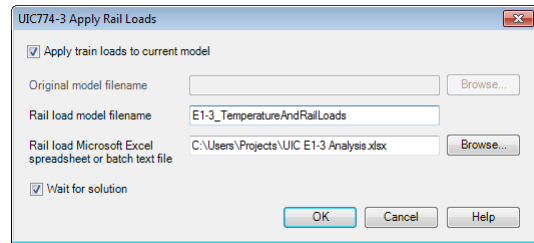
**Note.** If the intention was to only perform this analysis and investigate the thermal effects then post-processing could be performed on the results of the analysis. In addition, if the **Apply temperature and rail loads in same analysis** option was selected the combined temperature and rail track loading results would now be available. For this example we will however be using this temperature only analysis as a starting point for more than one track-structure interaction analysis so no post-processing will be performed at this stage.

### Applying Trainset Rail Loading to the Temperature Model

The temperature only model will now be used as the starting point for the application of the trainset rail loading that needs to be considered for the track-structure interaction analysis.



- Select the **Apply train loads to current model** option as we have just performed the temperature only analysis and will use this model as the base model for the application of the trainset rail loading.



- Enter **E1-3\_TemperatureAndRailLoads** as the Rail load model filename.
- Enter the **UIC E1-3 Analysis.xlsx** (or UIC E1-3 Analysis.xls) filename of the Microsoft Excel spreadsheet created for the analysis or browse for it using the **Browse...** button in the Microsoft Excel spreadsheet or batch text file input. If the full folder information is not entered it will be assumed that the Microsoft Excel spreadsheet is in the current working folder.
- If wanting to apply train loads from a supplied spreadsheet, select the file **UIC E1-3 Analysis.xlsx** located in the \<LUSAS Installation Folder>\Examples\Modeller directory.
- Ensure the **Wait for solution** option is selected.
- Click the **OK** button and choose **No** to saving the changes to the current model as no manual changes have been made.

Assuming that there have been no errors in the trainset loading input for the Microsoft Excel spreadsheet the Rail Track Analysis software option will now automatically generate a LUSAS model with a separate analysis for each train position being considered (16 in total) and run a track-structure analysis for the combined temperature and trainset rail loading using the trainset loading information defined in the spreadsheet.



**Note.** If both the temperature and trainset rail loads were applied to the original model the software would detect this and report that the original model is not a valid temperature-only model. If this were to happen, repeat the model building process above before reattempting to apply the trainset rail loading to the analysis.

### If errors were detected...

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






- ❑ **UIC E1-3 Analysis.xlsx (.xls)** is a populated spreadsheet containing all input data for the example.

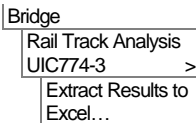
A spreadsheet compatible for an installed version of version of Microsoft Excel should be copied to the working project folder where the track-structure interaction example model is to be created, and the **Bridge > Rail Track Analysis UIC774-3 > Apply Rail Loads** menu item re-selected.

## Viewing the Results

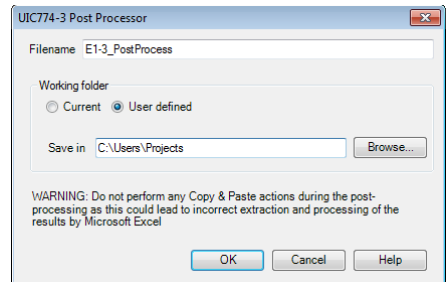
If the analyses were run from within LUSAS Modeller with the ‘Wait for solution’ option set, the results for each train position analysis considered will be added to the  Treeview.

### Automatic Extraction of Results into Microsoft Excel

The Rail Track Analysis option provides a post-processing tool that automatically extracts the results of the analyses into tabular form in Microsoft Excel and generates commonly required graphs and tables of quantities that can be compared against prescribed limits for the track-structure interaction.



- Enter **E1-3\_PostProcess** for the **Filename**. Note that no \*.xlsx or \*.xls extension is required.
- Ensure the **Working folder** is set to **Current** to place the post-processing Microsoft Excel spreadsheet into the same folder as the analyses.



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



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



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

- Click the **OK** button.
- Click on **Yes** when asked whether envelopes are to be created in Microsoft Excel.

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



**Note.** An estimate of the time to complete the post-processing for each worksheet can be obtained by watching the progress bar at the bottom of the Modeller window. Post-processing of all the results will occupy the LUSAS licence for this time.

- Open the spreadsheet **E1-3\_PostProcess** in Microsoft Excel.

Because the creation of envelopes was specified earlier the results spreadsheet will contain seven worksheets that contain the results from the analyses. Note that some versions of Excel may only show the tabs for the last created worksheets, and hide the previous worksheets. If this is the case, other worksheets can be seen by pressing the ‘back’ arrow at the bottom of the worksheet window.

The worksheets created are titled:

- Track 1**
- Decks**
- Envelope – Track 1**
- Envelope – Decks**
- Railbed Check**
- Longitudinal Reactions Check**
- Rail Stresses Check**

### **Peak Relative Railbed Displacement**

For a continuously welded rail (CWR) track the typical criteria to be met for the relative railbed displacements is quoted in Clause 1.5.3 of UIC774-3 which states that:

*“The maximum permissible displacement between rail and deck or embankment under braking and/or acceleration forces is 4 mm”*

To permit checking of this criteria rail bed displacements are included in the **Track 1** worksheet which reports all of the relative railbed displacements calculated for the track-structure interaction model.

- Click on the **Track 1** worksheet tab.

Maximum and minimum values are reported in the summaries at the top of the sets of results, values over the structure are graphed in the top chart, and individual values along the length of the track are reported in tabular form – as shown below.



Because the option to create envelopes in Microsoft Excel was chosen when the post-processor was run the spreadsheet includes additional post-processing of the relative railbed displacement in the form of envelopes and a table of peak values for each trainset position.

For the envelopes worksheet the output is identical to the tabular and chart output for the individual results in the analyses. Six envelopes are generated by the post-processor, namely:

- Envelope - Temperature Only (Max)
- Envelope - Temperature Only (Min)
- Envelope - Temperature and Train (Max)
- Envelope - Temperature and Train (Min)
- Envelope - All Configurations (Max)
- Envelope - All Configurations (Min)

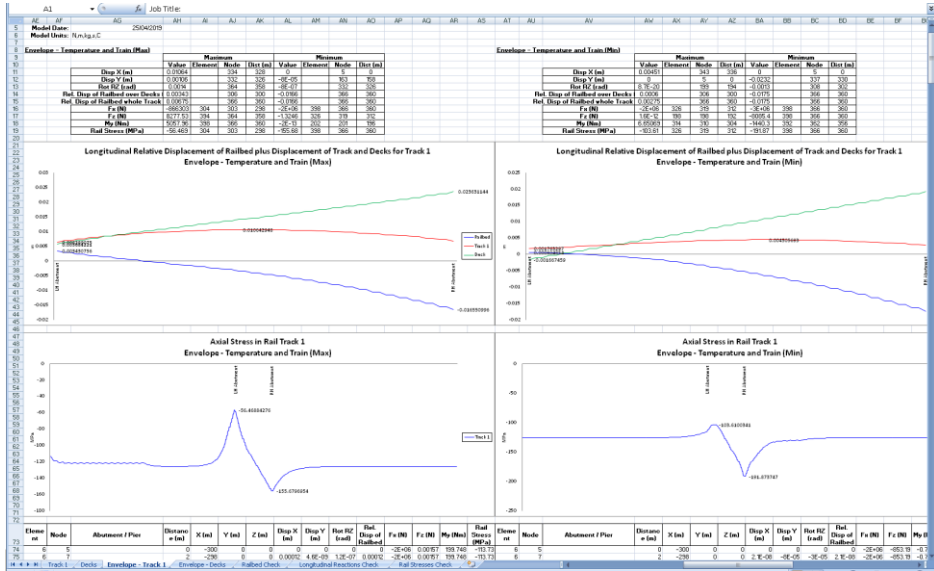


**Note.** The **All Configurations** envelope provides an envelope over all loading configurations that are present in the analysis which in this case is temperature only and combined temperature and train loading. If valid basic combinations were also present an additional maximum / minimum envelope would be presented for these results and the results from these basic combinations would be included within the **All Configurations** envelope.

Concentrating on the envelopes for the combination of the temperature and trainset loading, these are illustrated in the following figure.

# Rail Track-Structure Interaction to UIC774-3

- Click on the **Envelope - Track 1** worksheet tab.



Zooming into the summary tables at the top of the columns of results and charts (see images that follow) allows the extraction of the peak relative railbed displacements of +0.00343 m movement of the track to the right relative to the base of the ballast over the deck, +0.00675 m movement of the track to the right relative to the base of the ballast over the whole track length and -0.01747 m movement of the track to the left relative to the base of the ballast over the whole track length and deck.

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	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.01064295		334	328	0		5	0
Disp Y (m)	0.00106426		332	326	-0.000008		163	158
Rot RZ (rad)	-0.00140370		364	358	-7.827E-07		332	326
Rel. Disp of Railbed over Decks (m)	0.00343076		306	300	-0.016551		366	360
Rel. Disp of Railbed whole Track (m)	0.00674795		366	360	-0.016551		366	360
Fx (N)	-866.905.2		304	298	-2388322.7		398	366
Fz (N)	8277.52791		394	364	-1.3246197		326	319
My (Nm)	5057.96072		398	366	-1.767E-13		202	201
Rail Stress (MPa)	-56.468843		304	303	298		-155.6797	398

	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
1											
2											
3											
4											
5											
6											
7											
8	<b>Envelope - Temperature and Train (Min)</b>										
9				<b>Maximum</b>				<b>Minimum</b>			
10		<b>Value</b>	<b>Element</b>	<b>Node</b>	<b>Dist (m)</b>	<b>Value</b>	<b>Element</b>	<b>Node</b>	<b>Dist (m)</b>		
11		<b>Disp X (m)</b>	0.00450569		343	336	0		5	0	
12		<b>Disp Y (m)</b>	0		5	0	-0.02317		337	330	
13		<b>Rot RZ (rad)</b>	8.685E-20		199	194	<b>-0.0013300</b>		308	302	
14		<b>Rel. Disp of Railbed over Decks (m)</b>	0.00060485		306	300	<b>-0.0174726</b>		366	360	
15		<b>Rel. Disp of Railbed whole Track (m)</b>	0.0027513		366	360	<b>-0.0174726</b>		366	360	
16		<b>Fx (N)</b>	-1589508.5	326	319	312	-2943383	398	366	360	
17		<b>Fz (N)</b>	1.5559E-12	198	198	192	-8085.4214	398	366	360	
18		<b>My (Nm)</b>	6.65068684	314	310	304	-1440.2929	392	362	356	
19		<b>Rail Stress (MPa)</b>	-103.61003	326	319	312	-191.87375	398	366	360	

The peak relative railbed displacement is therefore -0.01747 m which compares well with the UIC774-3 E1-3 test case published result of -1.73E-2 m with a difference of +0.98%.

In addition to the envelope worksheet, the peak relative railbed displacement can also be found in the **Railbed Check** worksheet as shown below.

- Click on the **Railbed Check** worksheet tab.

This shows that the peak relative railbed displacement occurs when the braking trainset is placed at the 5<sup>th</sup> position when the front of the 300 m long trainset is just over half way across the 60 m deck. This is highlighted in bold blue text in the worksheet.

<b>Check of Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)</b>										
Job Title: UIC 774-3 Model: E1-3_TemperatureAndRailLoads Analysis Filename: E1_3_TemperatureAndRailLoads_Position 1 --> E1_3_TemperatureAndRailLoads_Position 16 Model Directory: C:\projects\516\envelope Analysis Date: 26/04/2019 --> 26/04/2019 Model Units: N,M,K,G,C										
Analysis ID	Results Filename	Loading Type	Track 1		Peak Relative Longitudinal Displacement between Rail and Slab (m)	Track Number with Peak Displacement	Distance from Left End of Structure for Peak Displacement (m)	Description of peak location		
			Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Ending Position of the Loading (m)						
10	1\E1_3_TemperatureAndRailLoads_Position 1.mys	Temperature Only	0	300	0.01650330	1	60	RH Abutment		
11	1\E1_3_TemperatureAndRailLoads_Position 1.mys	Braking	0	300	0.01650399	1	60	RH Abutment		
12	2\E1_3_TemperatureAndRailLoads_Position 2.mys	Braking	10	310	0.01681762	1	60	RH Abutment		
13	3\E1_3_TemperatureAndRailLoads_Position 3.mys	Braking	20	320	0.01703035	1	60	RH Abutment		
14	4\E1_3_TemperatureAndRailLoads_Position 4.mys	Braking	30	330	0.01715669	1	60	RH Abutment		
15	<b>5\E1_3_TemperatureAndRailLoads_Position 5.mys</b>	<b>Braking</b>	<b>40</b>	<b>340</b>	<b>0.01727607</b>	<b>1</b>	<b>60</b>	<b>RH Abutment</b>		
16	6\E1_3_TemperatureAndRailLoads_Position 6.mys	Braking	50	350	0.01727924	1	60	RH Abutment		
17	7\E1_3_TemperatureAndRailLoads_Position 7.mys	Braking	60	360	0.01680339	1	60	RH Abutment		
18	8\E1_3_TemperatureAndRailLoads_Position 8.mys	Braking	70	370	0.01705311	1	60	RH Abutment		
19	9\E1_3_TemperatureAndRailLoads_Position 9.mys	Braking	80	380	0.01705581	1	60	RH Abutment		
20	10\E1_3_TemperatureAndRailLoads_Position 10.mys	Braking	90	390	0.01703868	1	60	RH Abutment		
21	11\E1_3_TemperatureAndRailLoads_Position 11.mys	Braking	100	400	0.01702845	1	60	RH Abutment		
22	12\E1_3_TemperatureAndRailLoads_Position 12.mys	Braking	110	410	0.01701993	1	60	RH Abutment		
23	13\E1_3_TemperatureAndRailLoads_Position 13.mys	Braking	120	420	0.01701704	1	60	RH Abutment		
24	14\E1_3_TemperatureAndRailLoads_Position 14.mys	Braking	130	430	0.01701684	1	60	RH Abutment		
25	15\E1_3_TemperatureAndRailLoads_Position 15.mys	Braking	140	440	0.017016507	1	60	RH Abutment		
26	16\E1_3_TemperatureAndRailLoads_Position 16.mys	Braking	150	450	0.017016379	1	60	RH Abutment		



**Note.** The peak relative railbed displacement in test case E1-3 is 0.01747 m or 17.47 mm which would be greater than the limit stated in Clause 1.5.3 of the UIC774-3 code of practice. All of the test cases in Appendix D.1 of the code of practice exceed this limit.

### Peak Axial Rail Stresses

For a continuously welded rail track with UIC 60 rails the typical criteria to be met for the rail stress are quoted in Clause 1.5.2 of UIC774-3 which states that:

*“The maximum permissible additional compressive rail stress is 72 N/mm<sup>2</sup>”*

and

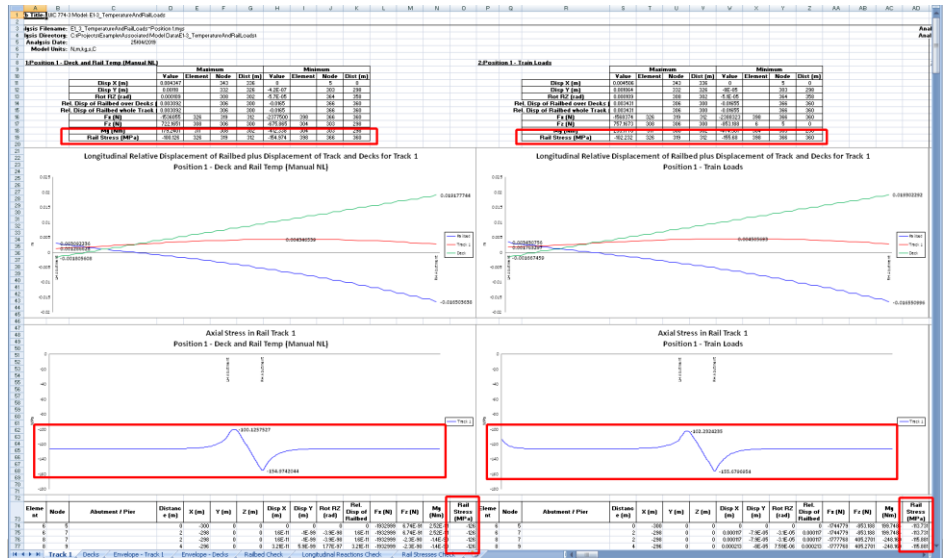
*“The maximum permissible additional tensile rail stress is 92 N/mm<sup>2</sup>”*

To permit checking of these criteria rail axial stress values are included in the **Track 1** Microsoft Excel worksheet.

- Click on the **Track 1** worksheet tab.

Maximum and minimum values are reported in the summaries at the top of the sets of results, values over the track length are graphed in the bottom chart, and the individual values along the length of the track are reported in tabular form – as highlighted in the following figure.

For the temperature-only loadcase (Increment 1) the maximum and minimum stresses observed in the rail track were -100.13MPa in compression and -154.97MPa in compression (lower graph). This most compressive value compares well with the value of -156.67MPa from the E1-3 test case (equal to -126MPa from the temperature in the rail and -30.67MPa from the temperature in the deck) with a percentage difference of -1.08%. For the temperature and trainset rail loading loadcase (Increment 2) for the first position of the train loading the maximum and minimum stresses observed in the rail track were -102.23MPa in compression and -155.68MPa in compression (lower graph), not too dissimilar to the temperature only results since the train loading is only just entering the bridge for this position.



Now, concentrating on the envelopes for the combination of the temperature and trainset loading to find the worst effects of all train loading positions:

- Click on the **Envelope - Track 1** worksheet tab.

Maximum and minimum stresses observed in the rail track were -56.47MPa in compression and -191.87MPa in compression. The value of -191.87MPa compares well with the UIC774-3 E1-3 test case published results of -182.4MPa to -190.07MPa with a difference of between 0.95% and 5.19% (depending upon the calculation method).

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# Rail Track-Structure Interaction to UIC774-3

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4												
5												
6												
7												
8	<b>Envelope - Temperature and Train (Min)</b>											
9				<b>Maximum</b>				<b>Minimum</b>				
10		<b>Value</b>	<b>Element</b>	<b>Node</b>	<b>Dist (m)</b>	<b>Value</b>	<b>Element</b>	<b>Node</b>	<b>Dist (m)</b>			
11	<b>Disp X (m)</b>	0.00450569		343	336	0		5	0			
12	<b>Disp Y (m)</b>	0		5	0	-0.02317			337	330		
13	<b>Rot RZ (rad)</b>	8.689E-20		199	194	-0.0013208			308	302		
14	<b>Rel. Disp of Railbed over Decks (m)</b>	0.00060485		306	300	-0.0174726			366	360		
15	<b>Rel. Disp of Railbed whole Track (m)</b>	0.0027513		366	360	-0.0174726			366	360		
16	<b>Fx (N)</b>	-1589508.5	326	319	312	-2943585	398	366	360			
17	<b>Fz (N)</b>	1.5559E-12	198	198	192	-8085.4214	398	366	360			
18	<b>My (Nm)</b>	6.65068684	314	310	304	<b>-1.440.2920</b>	392	362	356			
19	<b>Rail Stress (MPa)</b>	-103.61003	326	319	312	<b>-191.87375</b>	398	366	360			

In addition to the envelope worksheet, the peak axial stresses in the rails can also be found in the **Rail Stresses Check** worksheet.

- Click on the **Rail Stresses Check** worksheet tab.

This worksheet shows that the peak most compressive axial stress of 191.87MPa occurs when the braking trainset is placed at the 9<sup>th</sup> position when the front of the 300m long trainset is 20m past the right-hand abutment side of the deck. The peak most tensile axial stress occurs at the 7<sup>th</sup> position. Both peaks are highlighted in bold blue text in the worksheet.

Check of Axial Rail Stress											
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 Halving Position of the Loading (m)	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 (m)	Description of peak location	Peak Most Compressive Axial Stress of Rail (MPa)	Track	
1	EL_3_TemperatureAndRailLoad-Position 1.mys	Temperature Only	0	300	-100.1207927	1	12	Within Deck 1	-154.9712048		
2	EL_3_TemperatureAndRailLoad-Position 2.mys	Braking	0	300	102.2324295	1	12	Within Deck 1	-155.6709094		
3	EL_3_TemperatureAndRailLoad-Position 2.mys	Braking	10	310	-103.4044307	1		Within Deck 1	-157.7774618		
4	EL_3_TemperatureAndRailLoad-Position 3.mys	Braking	20	320	-90.9049516	1		At Abutment	-163.7965226		
5	EL_3_TemperatureAndRailLoad-Position 4.mys	Braking	30	330	-78.1348256	1		At Embankment	-166.9063651		
6	EL_3_TemperatureAndRailLoad-Position 5.mys	Braking	40	340	-67.0873925	1		At Embankment	-172.3095964		
7	EL_3_TemperatureAndRailLoad-Position 6.mys	Braking	50	350	-60.0000000	1		At Embankment	-177.1393151		
8	<b>EL_3_TemperatureAndRailLoad-Position 7.mys</b>	<b>Braking</b>	<b>60</b>	<b>360</b>	<b>-56.8688276</b>	<b>1</b>		<b>At Embankment</b>	<b>-181.3931432</b>		
9	<b>EL_3_TemperatureAndRailLoad-Position 8.mys</b>	<b>Braking</b>	<b>70</b>	<b>370</b>	<b>-52.9000000</b>	<b>1</b>		<b>At Embankment</b>	<b>-184.9334444</b>		
10	EL_3_TemperatureAndRailLoad-Position 9.mys	Braking	80	380	-50.5000000	1		At Embankment	-188.87375		
11	EL_3_TemperatureAndRailLoad-Position 10.mys	Braking	90	390	-50.2726214	1		At Embankment	-191.87375		
12	EL_3_TemperatureAndRailLoad-Position 11.mys	Braking	100	400	-50.1905474	1		At Embankment	-193.1393151		
13	EL_3_TemperatureAndRailLoad-Position 12.mys	Braking	110	410	-50.1500000	1		At Embankment	-193.6792201		
14	EL_3_TemperatureAndRailLoad-Position 13.mys	Braking	120	420	-50.1404348	1		At Embankment	-193.8304043		
15	EL_3_TemperatureAndRailLoad-Position 14.mys	Braking	130	430	-50.1403154	1		At Embankment	-193.8304043		
16	EL_3_TemperatureAndRailLoad-Position 15.mys	Braking	140	440	-50.1403446	1		At Embankment	-193.8304043		
17	EL_3_TemperatureAndRailLoad-Position 16.mys	Braking	150	450	-50.1403409	1		At Embankment	-193.8304043		

## Peak Longitudinal Reactions at the Abutments

The left-hand abutment provides all of the longitudinal restraint to the deck of the structure and the peak longitudinal reactions at this abutment are now investigated.

When post-processing, the option to create the envelopes in Microsoft Excel was chosen which caused an additional worksheet tabulating the peak longitudinal reactions for all of the analyses to be created.

- Click on the **Longitudinal Reactions Check** worksheet tab.



## Alternative Analyses with Same Temperature Only Model

The first row shows a longitudinal reaction for the left hand abutment under temperature only loading of 695.8kN. This compares well with the E1-3 test case published value of 700.12kN with a difference of -0.62%.

The worksheet also shows the longitudinal reactions for all of the train loading positions and indicates that the peak longitudinal reaction occurs when the braking trainset is placed at the 9<sup>th</sup> position (highlighted in bold blue text in the worksheet) when the front of the 300m long trainset is 20m past the right-hand abutment side of the deck. This trainset position gives a reaction of 929.1kN which compares well with the UIC774-3 E1-3 test case published result of 874.42kN with a difference of +6.25%.

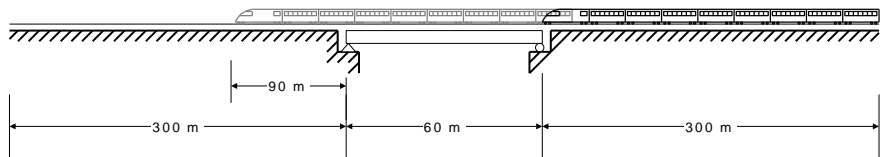
Check of Longitudinal Reactions							
Job Title: UIC 774-3 Model: E1-3_TemperatureAndRailLoads Analysis Filename: E1_3_TemperatureAndRailLoads*Position 1 -> E1_3_TemperatureAndRailLoads*Position 16 Model Directory: C:\Projects\Example Analysis Date: 25/04/2019 -> 25/04/2019 Model Units: N,m,kg,s,C							
Analysis ID	Results Filename	Loading type	Train 1		Peak Longitudinal Reaction (kN)	Abutment / Pier Number with Peak Reaction	
			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)			
1	E1_3_TemperatureAndRailLoads*Position 1.mys	Temperature Only			695795.7944	LH Abutment	
2	E1_3_TemperatureAndRailLoads*Position 2.mys	Braking	10	300	147276.7730	RH Abutment	
3	E1_3_TemperatureAndRailLoads*Position 3.mys	Braking	20	320	726055.4141	LH Abutment	
4	E1_3_TemperatureAndRailLoads*Position 4.mys	Braking	30	330	823514.3025	LH Abutment	
5	E1_3_TemperatureAndRailLoads*Position 5.mys	Braking	40	340	874241.9395	LH Abutment	
6	E1_3_TemperatureAndRailLoads*Position 6.mys	Braking	50	350	860909.3369	LH Abutment	
7	E1_3_TemperatureAndRailLoads*Position 7.mys	Braking	60	360	807246.8905	LH Abutment	
8	E1_3_TemperatureAndRailLoads*Position 8.mys	Braking	70	370	733006.4667	LH Abutment	
<b>9</b>	<b>E1_3_TemperatureAndRailLoads*Position 9.mys</b>	<b>Braking</b>	<b>80</b>	<b>380</b>	<b>929089.9920</b>	<b>LH Abutment</b>	
10	E1_3_TemperatureAndRailLoads*Position 10.mys	Braking	90	390	723395.9487	LH Abutment	
11	E1_3_TemperatureAndRailLoads*Position 11.mys	Braking	100	400	520614.2933	LH Abutment	
12	E1_3_TemperatureAndRailLoads*Position 12.mys	Braking	110	410	319192.8348	LH Abutment	
13	E1_3_TemperatureAndRailLoads*Position 13.mys	Braking	120	420	118622.1261	LH Abutment	
14	E1_3_TemperatureAndRailLoads*Position 14.mys	Braking	130	430	918400.2098	LH Abutment	
15	E1_3_TemperatureAndRailLoads*Position 15.mys	Braking	140	440	518514.9419	LH Abutment	
16	E1_3_TemperatureAndRailLoads*Position 16.mys	Braking	150	450	918282.3555	LH Abutment	

- Close the Microsoft Excel application.

## Alternative Analyses with Same Temperature Only Model

If further studies are required on the same structure for identical temperature conditions but with different trainset loading the Rail Track Analysis option can make use of the temperature only analysis from a previous analysis for a new one. For small structures the time saving from avoiding the reconstruction of an identical track-structure interaction model will generally not be significant but where the structure is very long and has many decks and spans this time saving can become significant.

### Applying Alternative Trainset Rail Loading



UIC774-3 test case E4-6 (shown above) is very similar to the one for test case E1-3. The only difference between the two tests is the direction that the braking trainset is travelling. As a result the temperature only model from test case E1-3 can and will be used as the starting point for the application of the alternative trainset rail loading that needs to be considered for the E4-6 track-structure interaction analysis.

### Defining the Trainset Loading for the Structure

If you wish to use the predefined populated spreadsheet for this part of the examples continue at the section entitled *Applying the Trainset Rail Loading to the Analysis*.

Otherwise:

- Copy the **UIC E1-3 Analysis.xlsx** (or **UIC E1-3 Analysis.xls**) Microsoft Excel spreadsheet created for the E1-3 test case and save it as a new Microsoft Excel spreadsheet with the filename **UIC E4-6 Analysis.xlsx** (or **UIC E4-6 Analysis.xls**).
- Open the spreadsheet in Microsoft Excel.

Loading									
Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m									
Temperature Loads			Amount						
	Deck		36						
	Rails		50						
Number of Train Loading Groups to Analyse				1					
Train Loading Group:				1					
Number of Track Loading Locations			16						
Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis	Numb Loadi
Braking	1	0	300	-20	300	360	210	-10	
Vertical	1	0	300	80	300	360	210	-10	
Train Loads									

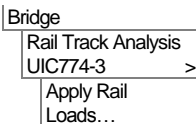
- Pick the **Loading** worksheet.
- Enter **-20** in the **Amount (per unit length)** for the trainset braking loading to indicate that the braking load is now acting to the left for a trainset that is travelling from right to left.
- Enter **360** for the **Starting Location of Loading for First Analysis** of both the **Braking** and **Vertical** loading to place the trainset in a location where it is just

about to enter the deck structure for the first analysis, recalling that the left-hand embankment is 300m long and the deck is 60m long.

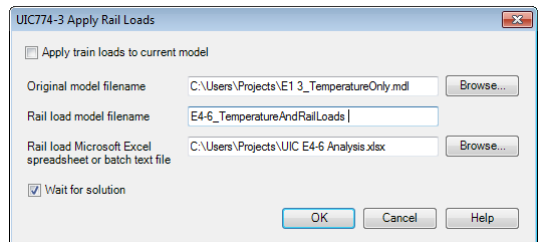
- Enter **210** for the **Finishing Location of Loading for Last Analysis** of both the **Braking** and **Vertical** loading to place the left-hand extent of the trainset 90m past the 60m deck span for the last analysis.
- Save the spreadsheet and close the Microsoft Excel application.

### Applying the Trainset Rail Loading to the Analysis

The E1-3 temperature only model can now be specified along with the updated rail load spreadsheet containing the revised trainset loading for the Rail Track Analysis software option to carry out an analysis for this test case.



- Ensure that the **Apply train loads to current model** option is not selected. The current model loaded is a combined temperature and trainset rail loads model for the E1-3 analysis and should not be used.



- Enter **E1-3\_TemperatureOnly.mdl** for the **Original model filename** which holds the temperature only analysis from the previous section or browse for it using the **Browse...** button. If the full folder is not specified then it will be assumed that the model is in the current working folder.
- Enter **E4-6\_TemperatureAndRailLoads** as the **Rail load model filename**.
- Enter the **UIC E4-6 Analysis.xlsx** (or **UIC E4-6 Analysis.xls**) filename of the Microsoft Excel spreadsheet created for the analysis or browse for it using the **Browse...** button in the **Microsoft Excel spreadsheet or batch text file** input. If the full folder information is not entered it will be assumed that the Microsoft Excel spreadsheet is in the current working folder.
- Ensure the **Wait for solution** option is selected.
- Click the **OK** button and choose **No** when asked to save the changes to the current model since there have been no manual changes to it.

Assuming that there have been no errors in the input for the Microsoft Excel spreadsheet the Rail Track Analysis software option will automatically generate a LUSAS model from the spreadsheet data and run a rail track analysis for the alternative trainset positions defined by the spreadsheet data.

### If errors were detected...

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

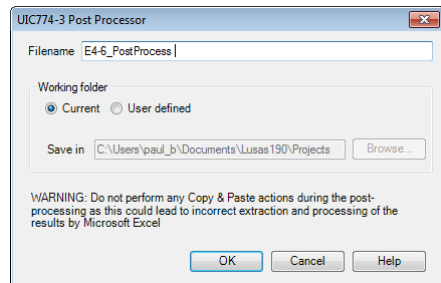



- ❑ **UIC E4-6 Analysis.xlsx (.xls)** is a populated spreadsheet containing all input data for this stage of the example.

A spreadsheet compatible for an installed version of version of Microsoft Excel should be copied to the working folder where the track-structure interaction example model is to be created, and the **Bridge > Rail Track Analysis UIC774-3 > Apply Rail Loads** menu item re-selected.

### Automatic Extraction of Results into Microsoft Excel

- Enter **E4-6\_PostProcess** for the Filename.
- Ensure the Working folder is set to **Current** to place the post-processing Microsoft Excel spreadsheet into the same folder as the analyses.



 **Caution.** As previously noted earlier in this example, prior to clicking the OK button ensure that no Excel applications are open and no copying and pasting of data in any application is done whilst the post-processing is carried out.

- Click the **OK** button and click on **Yes** when asked whether envelopes are to be created in Microsoft Excel, and choose **No** when asked to save the changes to the current model since there have been no manual changes to it.

The automatic post-processor will now extract the results from the loaded analysis results and generate a new Microsoft Excel spreadsheet in the working folder.

- In your project folder, open the spreadsheet **E4-6\_PostProcess.xlsx** in Microsoft Excel.
- If necessary pressing the ‘back’ arrow at the bottom of the worksheet window to see all the worksheets created.

### Peak Relative Railbed Displacement

- Click on the **Railbed Check** worksheet tab.

Bridge  
Rail Track Analysis  
UIC774-3 >  
Extract Results to  
Excel...

# Alternative Analyses with Same Temperature Only Model

Check of Longitudinal Relative Displacement of Railbed (Relative Displacement between Rails and Deck)									
Job Title: UIC 774-3 Model: E4-6_TemperatureAndRailLoads									
Analysis Filename: E4-6_TemperatureAndRailLoads'Position 1-->E4-6_TemperatureAndRailLoads'Position 16									
Model Directory: C:\Users\paul_w\Documents\Ucas190\Projects									
Analysis Date: 11/02/2020 --> 11/02/2020									
Model Units: N,m,g,c									
Analysis ID	Results Filename	Loading Type	Track 1		Peak Relative Longitudinal Displacement between Rail and Slab (m)	Track Number with Peak Displacement	Distance from Left End of Structure for Peak Displacement (m)	Description of peak location	
			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)					
10	10E4_6_TemperatureAndRailLoads'Position 1.mys	Temperature Only			0.026050388	1		60 Rail Abutment	
11	11E4_6_TemperatureAndRailLoads'Position 1.mys	Braking	300	600	0.018999056	1		60 Rail Abutment	
12	12E4_6_TemperatureAndRailLoads'Position 1.mys	Braking	300	600	0.019042296	1		60 Rail Abutment	
13	13E4_6_TemperatureAndRailLoads'Position 3.mys	Braking	340	640	0.018955869	1		60 Rail Abutment	
14	14E4_6_TemperatureAndRailLoads'Position 4.mys	Braking	330	630	0.017018643	1		60 Rail Abutment	
15	15E4_6_TemperatureAndRailLoads'Position 5.mys	Braking	320	620	0.017781388	1		60 Rail Abutment	
16	16E4_6_TemperatureAndRailLoads'Position 6.mys	Braking	300	600	0.017314648	1		60 Rail Abutment	
17	17E4_6_TemperatureAndRailLoads'Position 7.mys	Braking	300	600	0.017266111	1		60 Rail Abutment	
18	18E4_6_TemperatureAndRailLoads'Position 8.mys	Braking	290	590	0.017246105	1		60 Rail Abutment	
19	19E4_6_TemperatureAndRailLoads'Position 9.mys	Braking	280	580	0.017329176	1		60 Rail Abutment	
20	20E4_6_TemperatureAndRailLoads'Position 10.mys	Braking	270	570	0.017219151	1		60 Rail Abutment	
21	21E4_6_TemperatureAndRailLoads'Position 11.mys	Braking	260	560	0.017272127	1		60 Rail Abutment	
22	22E4_6_TemperatureAndRailLoads'Position 12.mys	Braking	250	550	0.017283935	1		60 Rail Abutment	
23	23E4_6_TemperatureAndRailLoads'Position 13.mys	Braking	240	540	0.017291211	1		60 Rail Abutment	
24	24E4_6_TemperatureAndRailLoads'Position 14.mys	Braking	230	530	0.017299218	1		60 Rail Abutment	
25	25E4_6_TemperatureAndRailLoads'Position 15.mys	Braking	220	520	0.017329279	1		60 Rail Abutment	
26	26E4_6_TemperatureAndRailLoads'Position 16.mys	Braking	210	510	0.017329264	1		60 Rail Abutment	

From this worksheet the peak relative railbed displacement is shown to be 0.01731m when the braking trainset is placed at the 6<sup>th</sup> position where it is 10 m from the left-hand abutment of the deck. This peak relative railbed displacement compares well with the UIC774-3 E4-6 test case published result of 1.78E-2 m with a difference of -2.75%.

## Peak Axial Rail Stresses

- Click on the **Rail Stresses Check** worksheet tab.

Job Title: UIC 774-3 Model: E4-6_TemperatureAndRailLoads									
Analysis Filename: E4-6_TemperatureAndRailLoads'Position 1-->E4-6_TemperatureAndRailLoads'Position 16									
Model Directory: C:\Users\paul_w\Documents\Ucas190\Projects									
Analysis Date: 11/02/2020 --> 11/02/2020									
Model Units: N,m,g,c									
Analysis ID	Results Filename	Loading Type	Track 1		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 (m)	Description of peak location	Peak Most Compressive Axial Stress of Rail (MPa)
			Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)					
10	10E4_6_TemperatureAndRailLoads'Position 1.mys	Temperature Only			-100.1257527	1		12 Within Deck 1	-154.9742044
11	11E4_6_TemperatureAndRailLoads'Position 1.mys	Braking	300	600	-101.3895346	1		12 Within Deck 1	-157.4034061
12	12E4_6_TemperatureAndRailLoads'Position 1.mys	Braking	300	600	-101.5962701	1		13 Within Deck 1	-154.4097238
13	13E4_6_TemperatureAndRailLoads'Position 3.mys	Braking	340	640	-101.5966212	1		10 Within Deck 1	-154.5922861
14	14E4_6_TemperatureAndRailLoads'Position 4.mys	Braking	330	630	-100.6393395	1		8 Within Deck 1	-157.4690682
15	15E4_6_TemperatureAndRailLoads'Position 5.mys	Braking	320	620	-97.7172789	1		4 Within Deck 1	-161.5891244
16	16E4_6_TemperatureAndRailLoads'Position 6.mys	Braking	300	600	-94.7676120	1		4 Within Deck 1	-164.9372682
17	17E4_6_TemperatureAndRailLoads'Position 7.mys	Braking	300	600	-93.1238169	1		0 In Abutment	-163.4882721
18	18E4_6_TemperatureAndRailLoads'Position 8.mys	Braking	290	590	-98.3079552	1		0 In Abutment	-163.7248661
19	19E4_6_TemperatureAndRailLoads'Position 9.mys	Braking	280	580	-94.9545087	1		0 In Abutment	-161.5212078
20	20E4_6_TemperatureAndRailLoads'Position 10.mys	Braking	270	570	-94.5487352	1		0 In Abutment	-161.2039064
21	21E4_6_TemperatureAndRailLoads'Position 11.mys	Braking	260	560	-94.6235000	1		0 In Abutment	-161.2441362
22	22E4_6_TemperatureAndRailLoads'Position 12.mys	Braking	250	550	-84.36325444	1		0 In Abutment	-161.1498667
23	23E4_6_TemperatureAndRailLoads'Position 13.mys	Braking	240	540	-84.34464573	1		0 In Abutment	-161.1445269
24	24E4_6_TemperatureAndRailLoads'Position 14.mys	Braking	230	530	-84.31787623	1		0 In Abutment	-161.1425076
25	25E4_6_TemperatureAndRailLoads'Position 15.mys	Braking	220	520	-84.3332279	1		0 In Abutment	-161.1417199
26	26E4_6_TemperatureAndRailLoads'Position 16.mys	Braking	210	510	-84.3342151	1		0 In Abutment	-161.1414451

From this worksheet the peak axial rail stress is shown to be -164.55MPa when the braking trainset is placed at the 6<sup>th</sup> position where it is 10 m from the left-hand abutment of the deck. This peak rail stress compares well with the UIC774-3 E4-6 test case published result of -162.06 MPa with a difference of 1.5%.

## Peak Longitudinal Reactions at the Abutments

- Click on the **Longitudinal Reactions Check** worksheet tab.

# Rail Track-Structure Interaction to UIC774-3

Track 1							
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction	
1	E4_6_TemperatureAndRailLoads"Position 1.mys	Temperature Only	360	660	695795.7944	LH Abutment	
2	E4_6_TemperatureAndRailLoads"Position 1.mys	Braking	350	650	722728.8459	LH Abutment	
3	E4_6_TemperatureAndRailLoads"Position 2.mys	Braking	340	640	868862.637	LH Abutment	
4	E4_6_TemperatureAndRailLoads"Position 3.mys	Braking	330	630	1107096.072	LH Abutment	
5	E4_6_TemperatureAndRailLoads"Position 4.mys	Braking	320	620	1420184.793	LH Abutment	
6	E4_6_TemperatureAndRailLoads"Position 5.mys	Braking	310	610	1767865.812	LH Abutment	
7	E4_6_TemperatureAndRailLoads"Position 6.mys	Braking	300	600	2085606.512	LH Abutment	
8	E4_6_TemperatureAndRailLoads"Position 7.mys	Braking	290	590	2322132.489	LH Abutment	
9	E4_6_TemperatureAndRailLoads"Position 8.mys	Braking	280	580	2403571.003	LH Abutment	
10	E4_6_TemperatureAndRailLoads"Position 9.mys	Braking	270	570	2420546.588	LH Abutment	
11	E4_6_TemperatureAndRailLoads"Position 10.mys	Braking	260	560	2423428.869	LH Abutment	
12	E4_6_TemperatureAndRailLoads"Position 11.mys	Braking	250	550	2427069.295	LH Abutment	
13	E4_6_TemperatureAndRailLoads"Position 12.mys	Braking	240	540	2427662.748	LH Abutment	
14	E4_6_TemperatureAndRailLoads"Position 13.mys	Braking	230	530	2427884.47	LH Abutment	
15	E4_6_TemperatureAndRailLoads"Position 14.mys	Braking	220	520	2427968.382	LH Abutment	
16	E4_6_TemperatureAndRailLoads"Position 15.mys	Braking	210	510	2428000.295	LH Abutment	
17	E4_6_TemperatureAndRailLoads"Position 16.mys	Braking	210	510	2428012.444	LH Abutment	

From this worksheet the peak reaction is shown to be 2428.01kN when the braking trainset is placed at the last position where the front of it is 90m past the left-hand abutment of the deck. This peak reaction compares well with the UIC774-3 E4-6 test case published result of 2196.1kN with a difference of +10.56% which is within the 20% limit specified in the code of practice. The maximum reaction is also comparable with the alternative calculation method which gives 2373.47kN (+2.3% difference).

- Close the Microsoft Excel application.

File  
Close

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

This completes the example.

A general discussion follows, along with information about how to model a structure with multiple decks.



**General Modelling Discussion and Accuracy of Results**

The modelling of the structure and approach embankments in this example is relatively crude to ensure that the track-structure analysis is carried out within a reasonable length of time. As a result the accuracy of some results, such as the rail stresses, may have been reduced slightly.

Refinement of the modelling will improve the accuracy of the solution at the cost of increased computer memory requirements and increased modelling / analysis and post-processing time. The following table shows the improvement of accuracy for the two test cases when element sizes of less than 2m and trainset location increments of less than 10m are used. For the UIC774-3 code of practice the computed values should be within -10% and +20% (if on the safe side) and based on this all results pass the criterion when compared against the UIC774-3 global / complete analyses results.

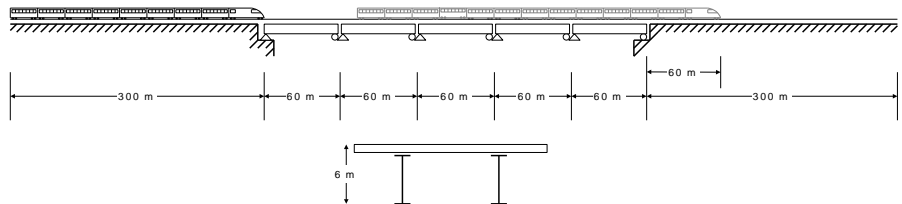
<b>Description</b>	<b>Test Case</b>	<b>Railed Displacement</b>	<b>Reaction</b>	<b>Rail Stress</b>
2m Elements 16 Location Increments of 10m	E1-3	0.01747 m +0.98%	929.09 kN +6.25%	-191.87 MPa +5.19%
	E4-6	0.01731 m -2.75%	2428.0 kN +10.56%	-164.55 MPa +1.54%
1m Elements 16 Location Increments of 10m	E1-3	0.01747 m +0.98%	927.45 kN +6.06%	-193.06 MPa +5.84%
	E4-6	0.01732 m -2.70%	2428.1 kN +10.56%	-165.37 MPa +2.04%
2m Elements 31 Location Increments of 5m	E1-3	0.01748 m +1.04%	929.09 kN +6.25%	-191.87 MPa +5.19%
	E4-6	0.01733 m -2.64%	2428.0 kN +10.56%	-165.04 MPa +1.84%
1m Elements 31 Location Increments of 5m	E1-3	0.01748 m +1.04%	927.45 kN +6.06%	-193.06 MPa +5.84%
	E4-6	0.01733 m -2.64%	2428.1 kN +10.56%	-165.78 MPa +2.30%
2m Elements 151 Location Increments of 1m	E1-3	0.01748 m +1.04%	929.64 kN +6.32%	-191.92 MPa +5.22%
	E4-6	0.01733 m -2.64%	2428.0 kN +10.56%	-165.04 MPa +1.84%
1m Elements 151 Location Increments of 1m	E1-3	0.01748 m +1.04%	927.61 kN +6.08%	-193.07 MPa +5.85%
	E4-6	0.01733 m -2.64%	2428.1 kN +10.56%	-165.80 MPa +2.31%
0.5m Elements 301 Location Increments of 0.5m	E1-3	0.01748 m +1.04%	927.00 kN +6.01%	-193.65 MPa +6.17%
	E4-6	0.01733 m -2.64%	2428.1 kN +10.56%	-166.23 MPa +2.57%



In the previous table the meshing and increment size can be seen to have a less significant effect on the railbed displacement and reactions obtained than on the rail stress values. This is because the Finite Element solution is a displacement method and reactions should be in equilibrium with the applied load which is constant. All element sizes shown can be seen to satisfy the accuracy of the rail stresses against the fundamental test cases in UIC774-3 but a refinement of both the mesh and the train position incrementation potentially allows a more accurate capture of the value of the maximum stress and location of the trainset where the maximum rail stress occurs but at the cost of analysis time. All results in the table are very similar, however, for the range of element sizes presented from 0.5 m up to the UIC774-3 maximum recommended element size of 2.0 m.

## Modelling a Structure with Multiple Decks

To model a structure with multiple decks spreadsheet data similar to that shown on the following pages would need to be defined.

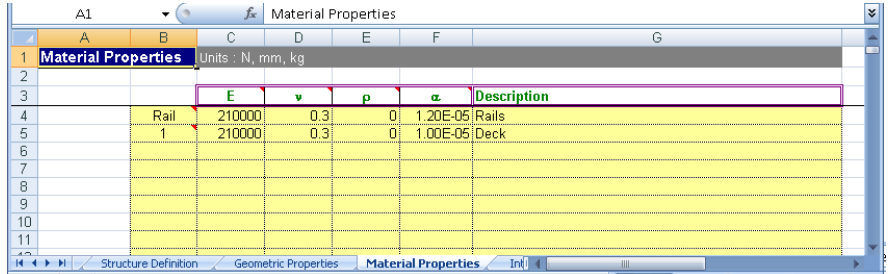
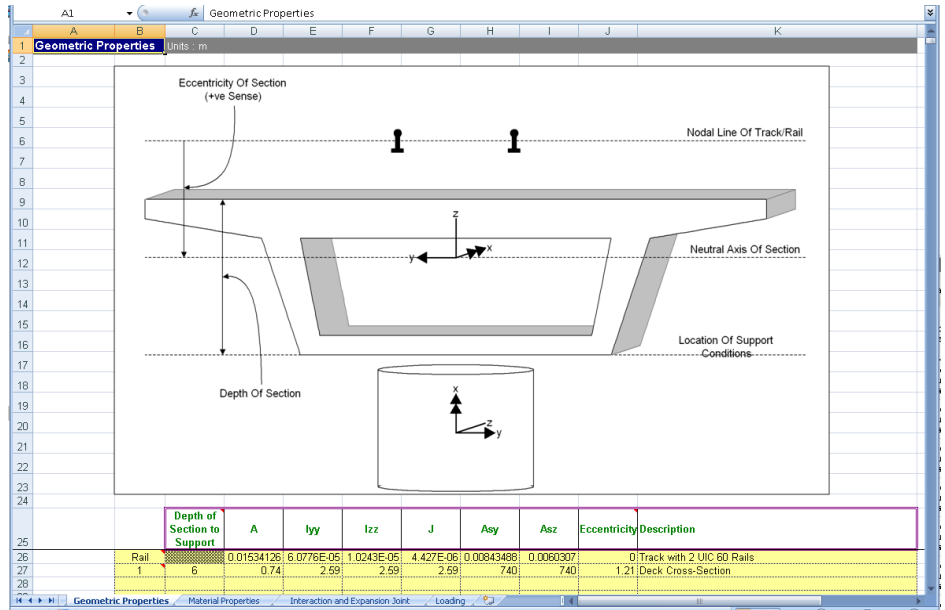


A1 Decks, Tracks and Embankment			
	A	B	C
1	<b>Decks, Tracks and Embankment</b>	Units : m	
2			
3	Number of Decks	5	
4	Number of Tracks	1	
5	Left Embankment Length	300	
6	Right Embankment Length	300	
7	Length of Decks Only / Total Length (m)	300	900
8			
9			

# Rail Track-Structure Interaction to UIC774-3

A1		Structure Definition									
A	B	C	D	E	F	G	H	I	L	M	
1 Structure Definition		Units: Pier Height : m ; Bearing springs on top of each pier : kN/mm, Span Length : m									
		Spring Support for each Abutment / Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign.	Bearing Springs on Top of each Pier	Bearing Offset from End of Deck	Span Length	Geo. Assign.	Mat. Assign.	
Deck 1	Left End	1200				R					
	Span 1	1200				F		60	1	1	
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
Number of Supports for the Deck / Length		2				2		60			
Deck 2	Left End	1200				R					
	Span 1	1200				F		60	1	1	
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
Number of Supports for the Deck / Length		2				2		60			
Deck 3	Left End	1200				R					
	Span 1	1200				F		60	1	1	
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
Number of Supports for the Deck / Length		2				2		60			
Deck 4	Left End	1200				R					
	Span 1	1200				F		60	1	1	
	Span 2										
	Span 3										
	Span 4										
	Span 5										
	Span 6										
	Span 7										
	Span 8										
	Span 9										
Number of Supports for the Deck / Length		2				2		60			
Deck 5	Left End	1200				R					
	Span 1	1200				F		60	1	1	
	Span 2										
Span 3											

# Modelling a Structure with Multiple Decks



# Rail Track-Structure Interaction to UIC774-3

Interaction Joint Properties Between Rail/Slab

Units : Bilinear springs characteristic : kN/mm/m, Eccentricity between rail/slab : m

25	Eccentricity between Rail/Slab	0			
26	Parametric Distance of Interaction Joint from Rail	0.5			
27	Item		Longitudinal	Transverse	Vertical
28	Unloaded Bilinear Springs Characteristic	Elastic Spring Stiffness	10	infinite	infinite
29		Yield Force	20	infinite	infinite
30		Hardening Stiffness	1.00000E-06	infinite	infinite
31	Loaded Bilinear Springs Characteristic	Elastic Spring Stiffness	30	infinite	infinite
32		Yield Force	60	infinite	infinite
33		Hardening Stiffness	1.00000E-06	infinite	infinite

Rail Expansion Joints

Units : Distance : m, Initial gap : mm

Track 1		Track 2	
Position	Initial Gap	Position	Initial Gap

Material Properties    Interaction and Expansion Joint    Loading

# Modelling a Structure with Multiple Decks

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

Temperature Loads		Amount								
Deck		35								
Rails		0								
			Number of Train Loading Groups to Analyse		1					
			Train Loading Group		1					
			Number of Track Loading Locations		73					
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	Num of Loadings	
Braking	1	0	300	20	300	0	360	5		
Vertical1	1	0	300	80	300	0	360	5		
Train Loads										

