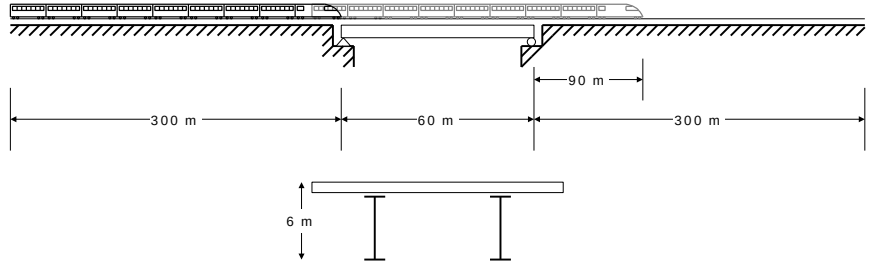
Track-Structure Interaction to UIC774-3

For LUSAS version:	17.0
For software product(s):	LUSAS *Bridge*
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 and considers the cases where the trainset is just about to enter the left-side side of 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

- **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.

The following files are 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 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.

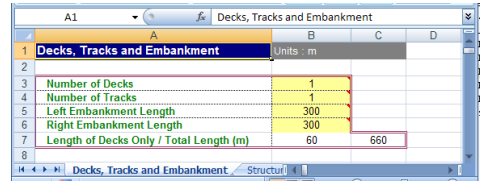
The modelling spreadsheet contains six worksheets titled:

- **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**.
- 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**.

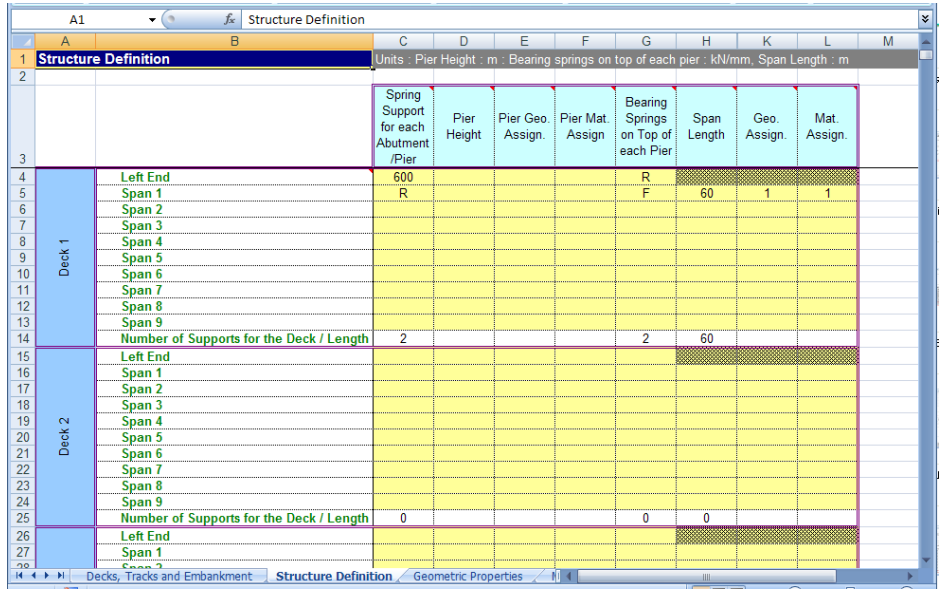
Note that the Length of Decks Only and Total Length cells are populated using data on this and another worksheet. These cells are protected on this worksheet.

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.

The worksheet should look like this:

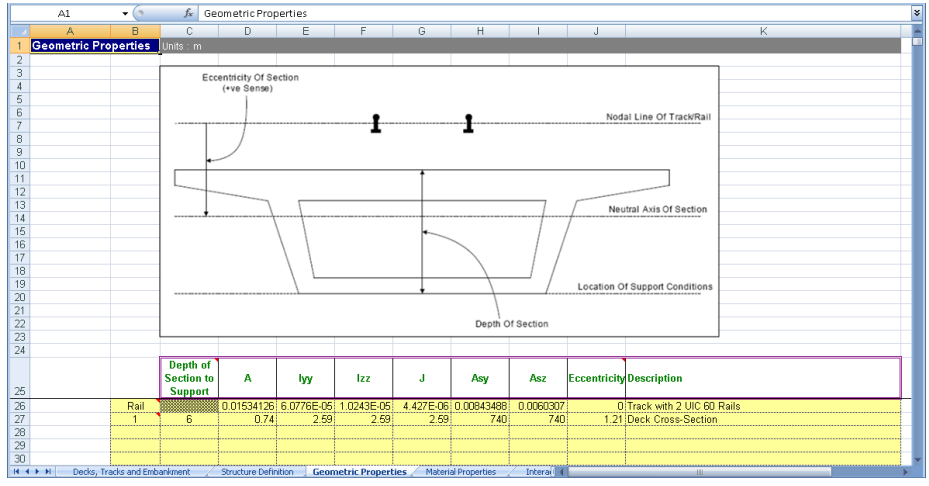


			Spring Support for each Abutment /Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign	Bearing Springs on Top of each Pier	Span Length	Geo. Assign.	Mat. Assign.
1	Structure Definition	Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m								
4	Deck 1	Left End	600				R			
5		Span 1	R				F	60	1	1
6		Span 2								
7		Span 3								
8		Span 4								
9		Span 5								
10		Span 6								
11		Span 7								
12		Span 8								
13		Span 9								
14		Number of Supports for the Deck / Length	2				2	60		
15	Deck 2	Left End								
16		Span 1								
17		Span 2								
18		Span 3								
19		Span 4								
20		Span 5								
21		Span 6								
22		Span 7								
23		Span 8								
24		Span 9								
25		Number of Supports for the Deck / Length	0				0	0		
26		Left End								
27		Span 1								

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^2.
- Enter **2.59** for the second moment of inertia about the horizontal y-axis (**Iyy**) in m^4.
- Enter **2.59** for the second moment of inertia about the vertical z-axis (**Izz**) in m^4.
- Enter **2.59** for the torsional constant (**J**) in m^4.
- Enter **740** for the shear area for the y-direction (**Asy**) in m^2. 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 (**Asz**) in m^2.

- 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 = 1.21m.
- Enter **Deck Cross-Section** in the **Description** for the deck.

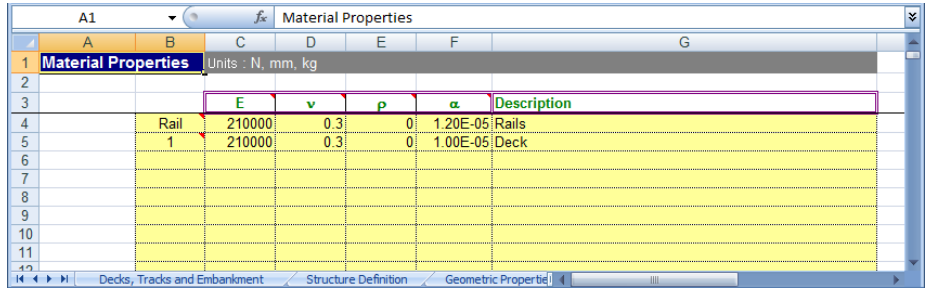
Modelling Discussion

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



- 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 N/mm^2 which is equivalent to a value of 210 GPa.
- Enter **0.3** for the Poisson's ratio (ν).
- Enter **0** for the mass density (ρ). 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 (α) – see note below.
- Enter **Rails** in the **Description** for the rails.

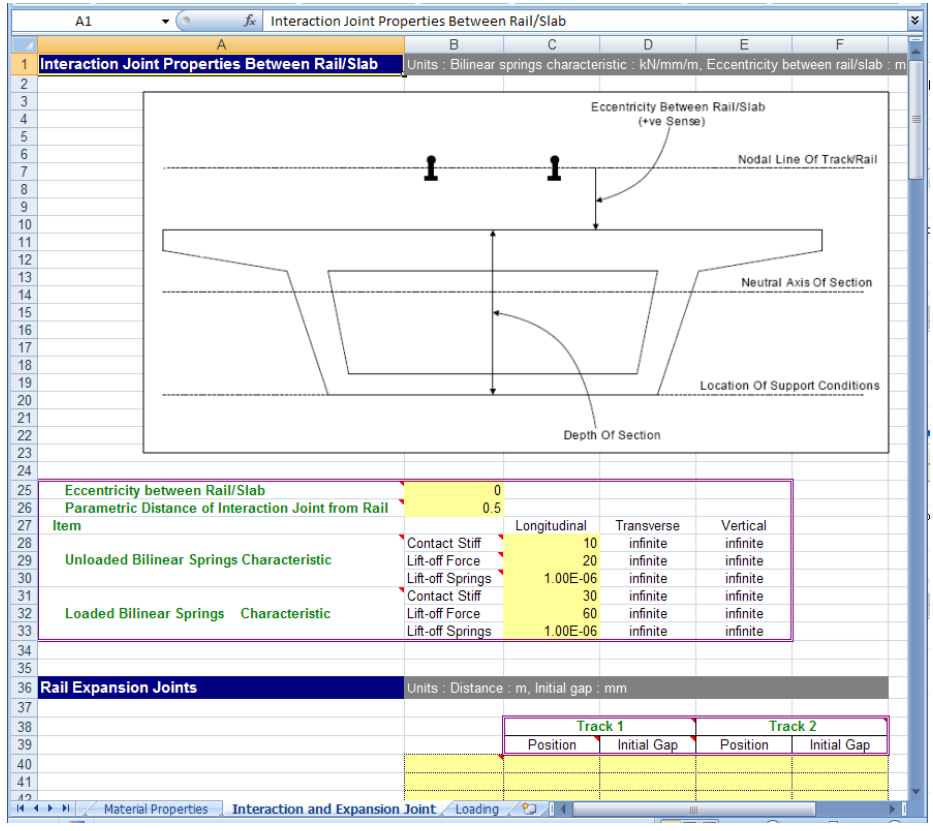
Enter the following values for the deck:

- 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^2.
- Enter **0.3** for the Poisson's ratio (ν).
- Enter **0** for the mass density (ρ).
- Enter **1.0E-5** for the coefficient of thermal expansion (α).
- 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



- 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

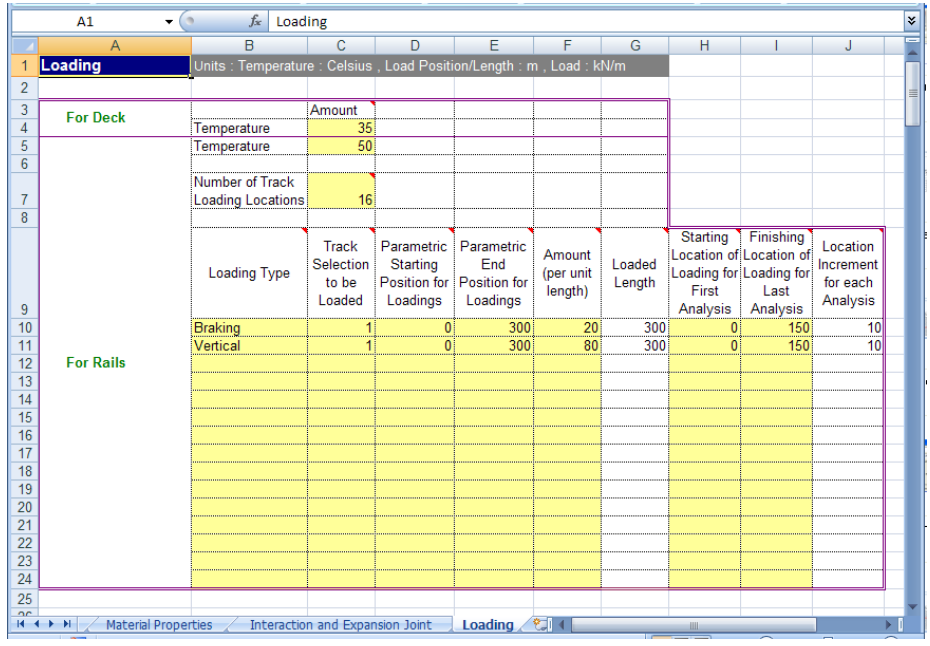
of u_0 in the test cases is equal to 2mm which is the representative value for a sleeper in ballast (as opposed to 'frozen' ballast track) indicated in Clause 1.2.1.2.

- Enter **10** for the **Unloaded Contact 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 20kN/m / 2mm = 10kN/m/mm (see note above).
- Enter **20** for the **Unloaded Lift-off Force** in the longitudinal direction in kN/m.
- Enter **1.0E-6** for the **Unloaded Lift-off Springs** in the longitudinal direction in kN/m/mm.
- Enter **30** for the **Loaded Contact 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 60kN/m / 2mm = 30 kN/m/mm (see note above).
- Enter **60** for the **Loaded Lift-off Force** in the longitudinal direction in kN/m.
- Enter **1.0E-6** for the **Loaded Lift-off Springs** 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 where the lift-off force is equivalent to the yield force and the lift-off spring is equivalent to the hardening stiffness. The lift-off spring 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.

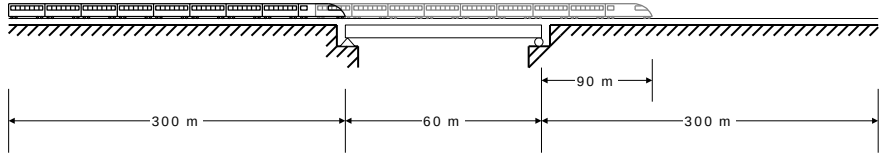
Defining the Trainset Loading for the Structure



	A	B	C	D	E	F	G	H	I	J
1	**Loading**	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
2										
3	For Deck		Amount							
4		Temperature	35							
5		Temperature	50							
6										
7		Number of Track Loading Locations	16							
8										
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	150	10
11		Vertical	1	0	300	80	300	0	150	10
12	For Rails									
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										

- 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 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 **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

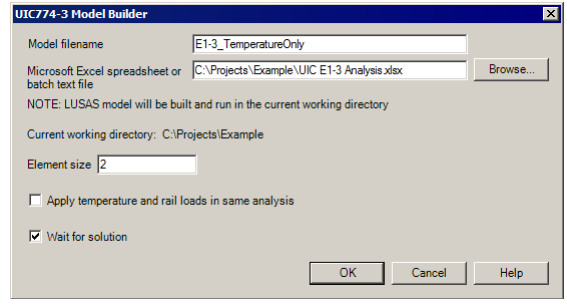
An initial temperature-only analysis can form the basis for carrying out more than one track-structure interaction analysis with different trainset loading configurations being used. For large analyses time savings can result from not having to re-run a temperature analysis for each trainset loading.

File
New…

- Enter **UIC774_testcase** for the model name and click OK.

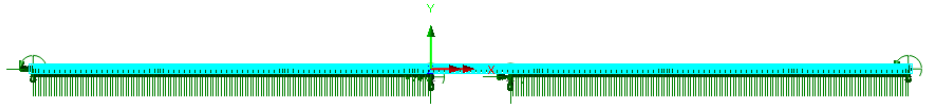
This model is created solely to allow the Rail Track Analysis option to be selected. It is not used after the option has been run.

Bridge
Rail Track Analysis
UIC774-3 >
Build Model…



- Enter **E1-3_TemperatureOnly** for the **Model filename**.
- Enter the filename of the Microsoft Excel spreadsheet 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.
- 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.



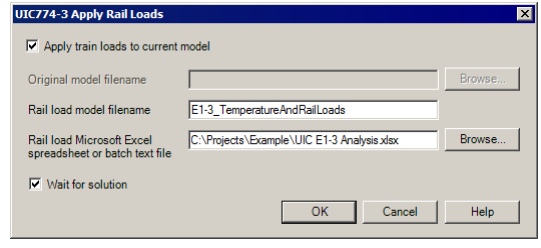
If the Rail Track Analysis software option detected errors with modelling data these will be reported and must be corrected prior to re-running the Rail Track Analysis option.

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.

Bridge
Rail Track Analysis
UIC774-3 >
Apply Rail Loads…



- 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.
- 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 program 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

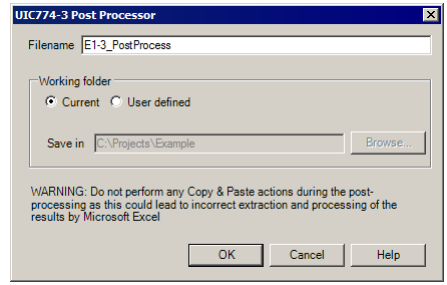
If the analyses were run from within LUSAS Modeller with the **Wait for solution** option the results for each train position analysis considered will be added to the Treeview.

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.

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

- 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

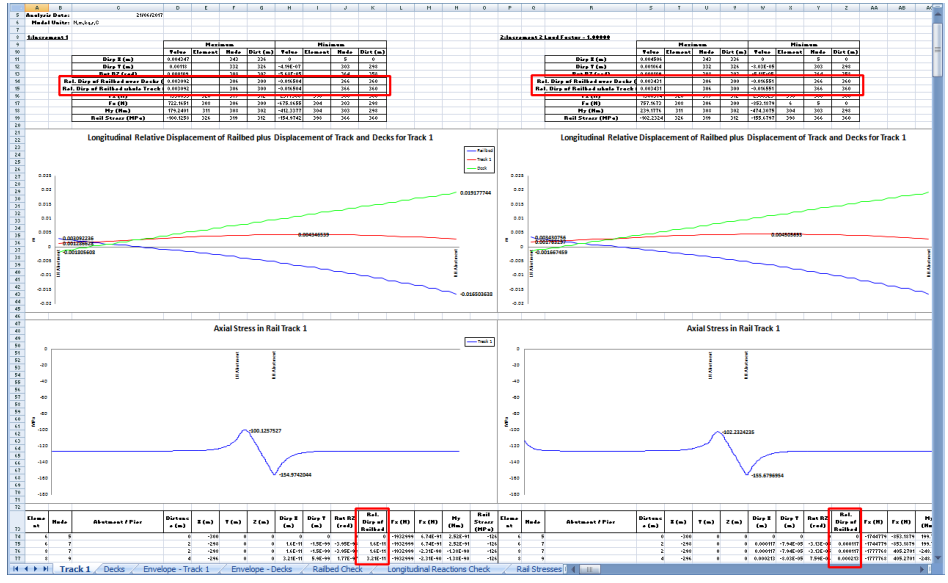
For a continuously welded rail (CWR) track the typical criteria to be met for the relative railbed displacements is quoted in Clause 1.5.3 of UIC774-3 which states that:

"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.

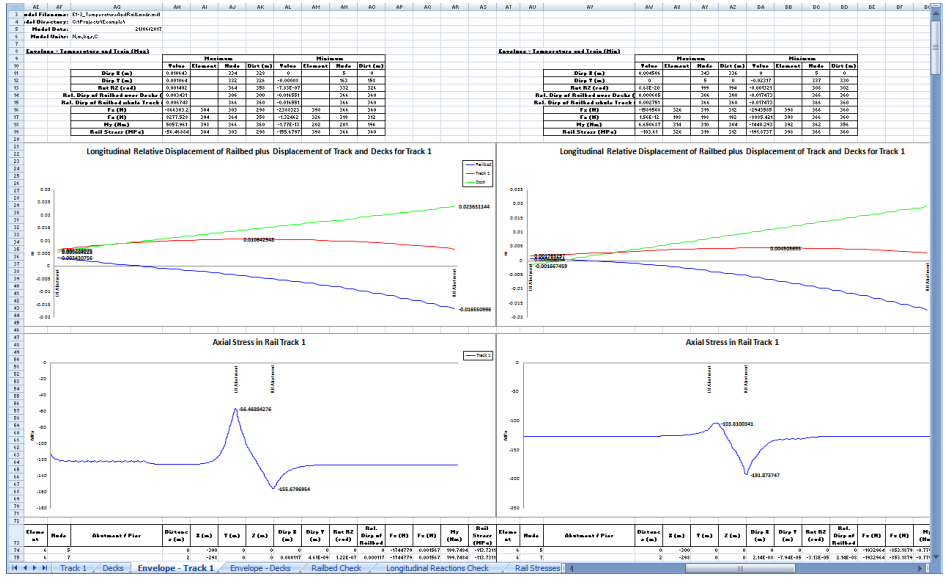
For the envelopes worksheet the output is identical to the tabular and chart output for the individual results in the analyses. Six envelopes are generated by the post-processor, namely:

- **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.

- 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.

	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1											
2											
3			**Model Filename:**	E1-3_TemperatureAndRailLoads.mdl							
4			**Model Directory:**	C:\Projects\Example\							
5			**Model Date:**	21/06/2017							
6			**Model Units:**	N,m,kg,s,C							
7											
8			**Envelope - Temperature and Train (Max)**								
9				**Maximum**				**Minimum**			
10				**Value**	**Element**	**Node**	**Dist (m)**	**Value**	**Element**	**Node**	**Dist (m)**
11			**Disp X (m)**	0.01064295		334	328	0		5	0
12			**Disp Y (m)**	0.00106426		332	326	-0.00008		163	158
13			**Rot RZ (rad)**	0.00140178		364	358	-7.827E-07		332	326
14			**Rel. Disp of Railbed over Decks (m)**	0.00343076		306	300	-0.016551		366	360
15			**Rel. Disp of Railbed whole Track (m)**	0.00674795		366	360	-0.016551		366	360
16			**Fx (N)**	-886303.2	304	303	298	-2388322.7	398	366	360
17			**Fz (N)**	8277.52791	394	364	358	-1.3246197	326	319	312
18			**My (Nm)**	5057.96072	398	366	360	-1.767E-13	202	201	196
19			**Rail Stress (MPa)**	-56.468843	304	303	298	-155.6797	398	366	360

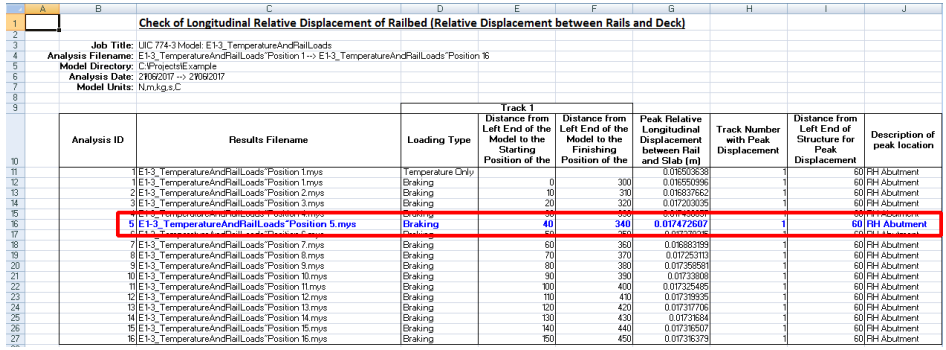
	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
1											
2											
3											
4											
5											
6											
7											
8			**Envelope - Temperature and Train (Min)**								
9				**Maximum**				**Minimum**			
10				**Value**	**Element**	**Node**	**Dist (m)**	**Value**	**Element**	**Node**	**Dist (m)**
11			**Disp X (m)**	0.00450569		343	336	0		5	0
12			**Disp Y (m)**	0		5	0	-0.02317		337	330
13			**Rot RZ (rad)**	8.685E-20		199	194	-0.0013289		308	302
14			**Rel. Disp of Railbed over Decks (m)**	0.00060485		306	300	-0.0174726		366	360
15			**Rel. Disp of Railbed whole Track (m)**	0.0027513		366	360	-0.0174726		366	360
16			**Fx (N)**	-1589508.5	326	319	312	-2349365	398	366	360
17			**Fz (N)**	1.5559E-12	198	198	192	-8085.4214	398	366	360
18			**My (Nm)**	6.65068684	314	310	304	-1440.2929	392	362	356
19			**Rail Stress (MPa)**	-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 5th 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.



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

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: 21/06/2017 --> 21/06/2017
Model Units: N,m,kg,s,C

			Track 1						
	Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the	Distance from Left End of the Model to the Finishing Position of the	Peak Relative Longitudinal Displacement between Rail and Slab (m)	Track Number with Peak Displacement	Distance from Left End of Structure for Peak Displacement	Description of peak location
11	1	E1-3_TemperatureAndRailLoads"Position 1.mys	Temperature Only			0.016503638	1	60	RH Abutment
12	1	E1-3_TemperatureAndRailLoads"Position 1.mys	Braking	0	300	0.016550996	1	60	RH Abutment
13	2	E1-3_TemperatureAndRailLoads"Position 2.mys	Braking	10	310	0.016837662	1	60	RH Abutment
14	3	E1-3_TemperatureAndRailLoads"Position 3.mys	Braking	20	320	0.017203035	1	60	RH Abutment
15	4	E1-3_TemperatureAndRailLoads"Position 4.mys	Braking	30	330	0.017436697	1	60	RH Abutment
16	**5**	**E1-3_TemperatureAndRailLoads"Position 5.mys**	**Braking**	**40**	**340**	**0.017472607**	**1**	**60**	**RH Abutment**
17	6	E1-3_TemperatureAndRailLoads"Position 6.mys	Braking	50	350	0.017372215	1	60	RH Abutment
18	7	E1-3_TemperatureAndRailLoads"Position 7.mys	Braking	60	360	0.016883199	1	60	RH Abutment
19	8	E1-3_TemperatureAndRailLoads"Position 8.mys	Braking	70	370	0.017253113	1	60	RH Abutment
20	9	E1-3_TemperatureAndRailLoads"Position 9.mys	Braking	80	380	0.017358581	1	60	RH Abutment
21	10	E1-3_TemperatureAndRailLoads"Position 10.mys	Braking	90	390	0.01733808	1	60	RH Abutment
22	11	E1-3_TemperatureAndRailLoads"Position 11.mys	Braking	100	400	0.017325485	1	60	RH Abutment
23	12	E1-3_TemperatureAndRailLoads"Position 12.mys	Braking	110	410	0.017319935	1	60	RH Abutment
24	13	E1-3_TemperatureAndRailLoads"Position 13.mys	Braking	120	420	0.017317706	1	60	RH Abutment
25	14	E1-3_TemperatureAndRailLoads"Position 14.mys	Braking	130	430	0.01731684	1	60	RH Abutment
26	15	E1-3_TemperatureAndRailLoads"Position 15.mys	Braking	140	440	0.017316507	1	60	RH Abutment
27	16	E1-3_TemperatureAndRailLoads"Position 16.mys	Braking	150	450	0.017316379	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^2"

and

"The maximum permissible additional tensile rail stress is 92 N/mm^2"

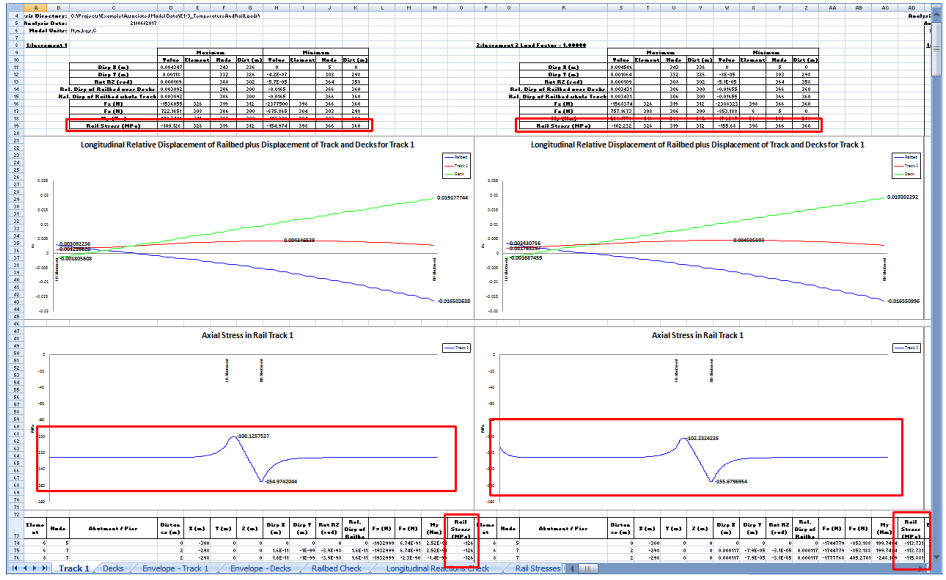
To permit checking of these criteria rail axial stress values are included in the **Track 1** Microsoft Excel worksheet.

- 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 to 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).

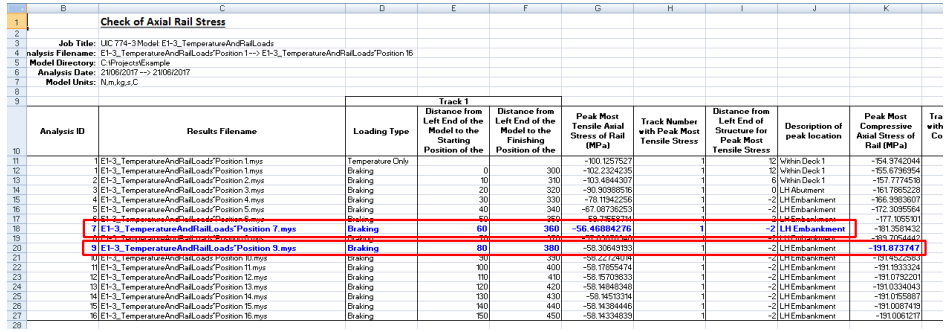
	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1											
2											
3			**Model Filename:**	E1-3_TemperatureAndRailLoads.mdl							
4			**Model Directory:**	C:\Projects\Example\							
5			**Model Date:**	21/06/2017							
6			**Model Units:**	N,m,kg,s,C							
7											
8			**Envelope - Temperature and Train (Max)**								
9				**Maximum**				**Minimum**			
10				**Value**	**Element**	**Node**	**Dist (m)**	**Value**	**Element**	**Node**	**Dist (m)**
11			**Disp X (m)**	0.01064295		334	328	0		5	0
12			**Disp Y (m)**	0.00106426		332	326	-0.00008		163	158
13			**Rot RZ (rad)**	0.00140178		364	358	-7.827E-07		332	326
14			**Rel. Disp of Railbed over Decks (m)**	0.00343076		306	300	-0.016551		366	360
15			**Rel. Disp of Railbed whole Track (m)**	0.00674795		366	360	-0.016551		366	360
16			**Fx (N)**	-866303.2	304	303	298	-2388322.7	398	366	360
17			**Fz (N)**	8277.52791	394	364	358	-1.3246197	326	319	312
18			**My (Nm)**	3657.58872	398	366	360	-1.767E-13	202	201	196
19			**Rail Stress (MPa)**	-56.468843	304	303	298	-155.6797	398	366	360

	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
1											
2											
3											
4											
5											
6											
7											
8			**Envelope - Temperature and Train (Min)**								
9				**Maximum**				**Minimum**			
10				**Value**	**Element**	**Node**	**Dist (m)**	**Value**	**Element**	**Node**	**Dist (m)**
11			**Disp X (m)**	0.00450569		343	336	0		5	0
12			**Disp Y (m)**	0		5	0	-0.02317		337	330
13			**Rot RZ (rad)**	8.685E-20		199	194	-0.0013208		308	302
14			**Rel. Disp of Railbed over Decks (m)**	0.00060485		306	300	-0.0174726		366	360
15			**Rel. Disp of Railbed whole Track (m)**	0.0027513		366	360	-0.0174726		366	360
16			**Fx (N)**	-1589508.5	326	319	312	-2943585	398	366	360
17			**Fz (N)**	1.5559E-12	198	198	192	-8085.4214	398	366	360
18			**My (Nm)**	6.65068684	314	310	304	-1440.2029	392	362	356
19			**Rail Stress (MPa)**	-103.61003	326	319	312	-191.87375	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 9th 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 7th position. Both peaks are highlighted in bold blue text in the worksheet.



Check of Axial Rail Stress

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: 21/06/2017 --> 21/06/2017
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Loading Type	Track 1 Distance from Left End of the Model to the Starting Position of the	Track 1 Distance from Left End of the Model to the Finishing Position of the	Peak Most Tensile Axial Stress of Rail (MPa)	Track Number with Peak Most Tensile Stress	Distance from Left End of Structure for Peak Most Tensile Stress	Description of peak location	Peak Most Compressive Axial Stress of Rail (MPa)	Tra with Co
1	E1-3_TemperatureAndRailLoads"Position 1.mys	Temperature Only			-100.1257527	1	12	Within Deck 1	-154.3742044	
1	E1-3_TemperatureAndRailLoads"Position 1.mys	Braking	0	300	-102.2324235	1	12	Within Deck 1	-155.6736954	
2	E1-3_TemperatureAndRailLoads"Position 2.mys	Braking	10	310	-103.4844307	1	6	Within Deck 1	-157.7774518	
3	E1-3_TemperatureAndRailLoads"Position 3.mys	Braking	20	320	-90.30988516	1	0	LH Abutment	-161.1865228	
4	E1-3_TemperatureAndRailLoads"Position 4.mys	Braking	30	330	-78.11942256	1	-2	LH Embankment	-166.3983607	
5	E1-3_TemperatureAndRailLoads"Position 5.mys	Braking	40	340	-67.08736253	1	-2	LH Embankment	-172.3095564	
6	E1-3_TemperatureAndRailLoads"Position 6.mys	Braking	50	350	-59.75583314	1	-2	LH Embankment	-177.1055101	
7	E1-3_TemperatureAndRailLoads"Position 7.mys	Braking	60	360	-56.46884276	1	-2	LH Embankment	-181.3581432	
8	E1-3_TemperatureAndRailLoads"Position 8.mys	Braking	70	370	-57.00000180	1	-2	LH Embankment	-183.3764443	
9	E1-3_TemperatureAndRailLoads"Position 9.mys	Braking	80	380	-58.30649183	1	-2	LH Embankment	-191.873747	
10	E1-3_TemperatureAndRailLoads"Position 10.mys	Braking	90	390	-58.22129019	1	-2	LH Embankment	-191.9522951	
11	E1-3_TemperatureAndRailLoads"Position 11.mys	Braking	100	400	-58.17655474	1	-2	LH Embankment	-191.1933324	
12	E1-3_TemperatureAndRailLoads"Position 12.mys	Braking	110	410	-58.15709833	1	-2	LH Embankment	-191.0752201	
13	E1-3_TemperatureAndRailLoads"Position 13.mys	Braking	120	420	-58.14948348	1	-2	LH Embankment	-191.0334043	
14	E1-3_TemperatureAndRailLoads"Position 14.mys	Braking	130	430	-58.14513314	1	-2	LH Embankment	-191.0155887	
15	E1-3_TemperatureAndRailLoads"Position 15.mys	Braking	140	440	-58.14384446	1	-2	LH Embankment	-191.0087419	
16	E1-3_TemperatureAndRailLoads"Position 16.mys	Braking	150	450	-58.14334839	1	-2	LH Embankment	-191.0061217	

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.

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 9th 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:	21/06/2017 --> 21/06/2017
Model Units:	N,m,kg,s,C

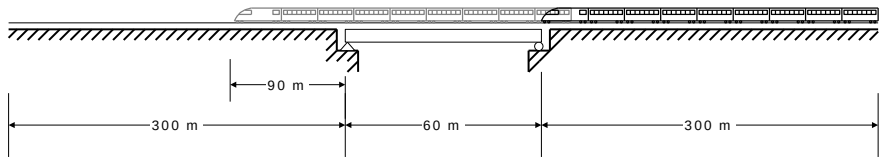
			Track 1			
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from Left End of the Model to the Finishing Position of the Loading (m)	Peak Longitudinal Reaction (N)	Abutment / Pier Number with Peak Reaction
1	E1-3_TemperatureAndRailLoads~Position 1.mys	Temperature Only			695795.7944	LH Abutment
1	E1-3_TemperatureAndRailLoads~Position 1.mys	Braking	0	300	647276.7736	LH Abutment
2	E1-3_TemperatureAndRailLoads~Position 2.mys	Braking	10	310	634918.2367	LH 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	823514.9025	LH Abutment
5	E1-3_TemperatureAndRailLoads~Position 5.mys	Braking	40	340	874241.0395	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	807346.0805	LH Abutment
8	E1-3_TemperatureAndRailLoads~Position 8.mys	Braking	70	370	902080.1657	LH Abutment
9	E1-3_TemperatureAndRailLoads~Position 9.mys	Braking	80	380	929089.9928	LH Abutment
10	E1-3_TemperatureAndRailLoads~Position 10.mys	Braking	90	390	923839.6467	LH Abutment
11	E1-3_TemperatureAndRailLoads~Position 11.mys	Braking	100	400	920614.2933	LH Abutment
12	E1-3_TemperatureAndRailLoads~Position 12.mys	Braking	110	410	919192.8348	LH Abutment
13	E1-3_TemperatureAndRailLoads~Position 13.mys	Braking	120	420	918622.1261	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	918314.9418	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



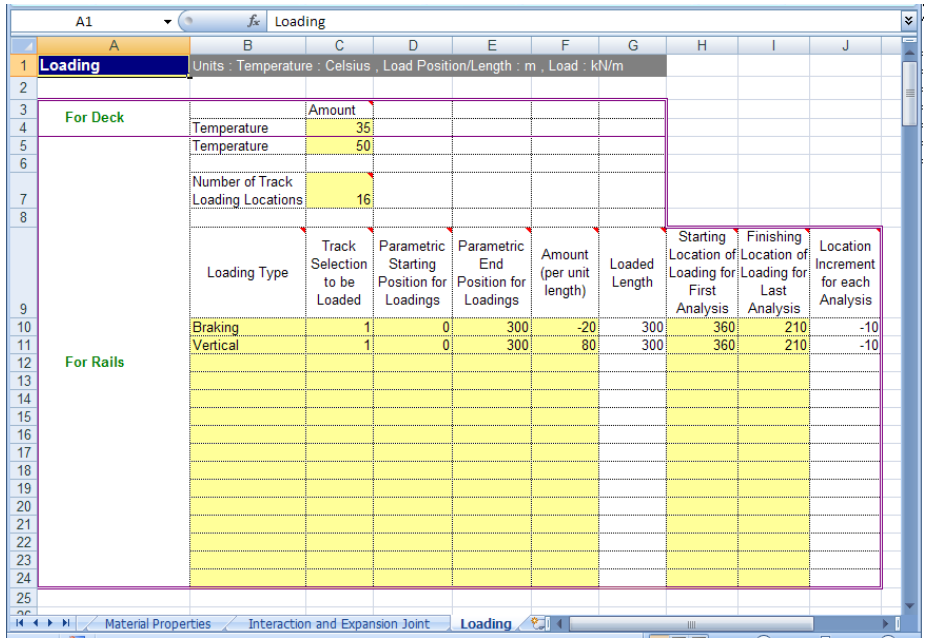
UIC774-3 test case E4-6 (shown above) is very similar to the one for test case E1-3. The only difference between the two tests is the direction that the braking trainset is travelling. As a result the temperature only model from test case E1-3 can and will be used as the starting point for the application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



	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
2										
3	For Deck		Amount							
4		Temperature	35							
5		Temperature	50							
6										
7		Number of Track Loading Locations	16							
8										
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	360	210	-10
11		Vertical	1	0	300	80	300	360	210	-10
12	For Rails									
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										

Material Properties | Interaction and Expansion Joint | Loading

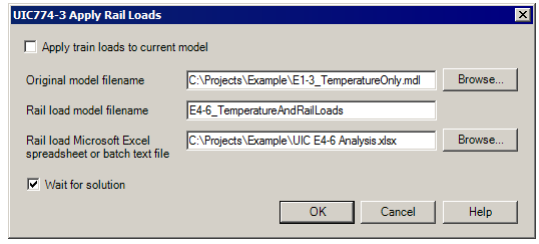
- Pick the **Loading** worksheet.
- Enter **-20** in the **Amount (per unit length)** for the trainset braking loading to indicate that the braking load is now acting to the left for a trainset that is travelling from right to left.
- Enter **360** for the **Starting Location of Loading for First Analysis**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

Bridge
Rail Track Analysis UIC774-3 >
Apply Rail Loads…

- 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.

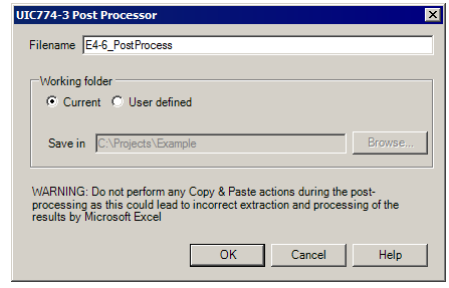
- **UIC E4-6 Analysis.xlsx (.xls)** is a populated spreadsheet containing all input data for this stage of the example.

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

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

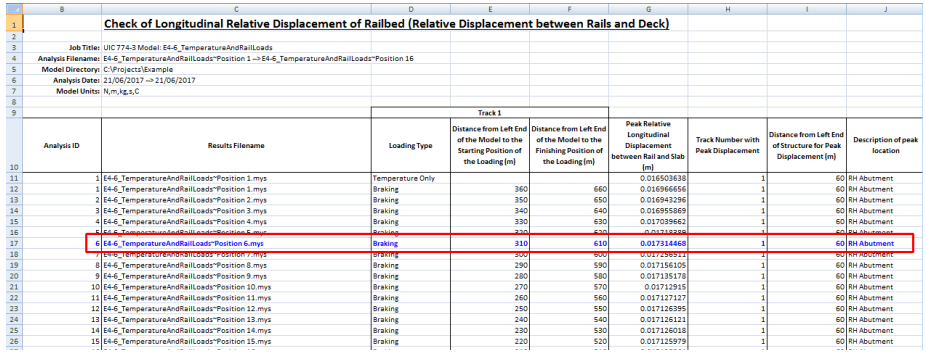
- Click the **OK** button and click on **Yes** when asked whether envelopes are to be created in Microsoft Excel.

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

- Open the spreadsheet 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.



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

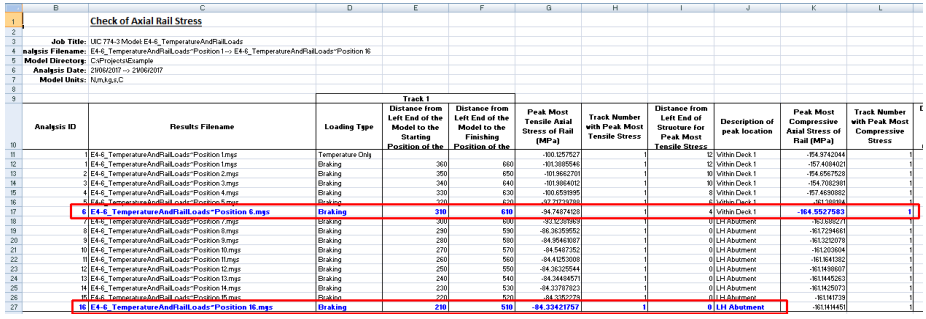
Job Title: UIC 774-3 Model: E4-6_TemperatureAndRailLoads
Analysis Filename: E4-6_TemperatureAndRailLoads~Position 1 --> E4-6_TemperatureAndRailLoads~Position 16
Model Directory: C:\Projects\Example
Analysis Date: 21/06/2017 --> 21/06/2017
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Track 1 Loading Type	Track 1 Distance from Left End of the Model to the Starting Position of the Loading (m)	Track 1 Distance from Left End of the Model to the Finishing Position of the Loading (m)	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
1	E4-6_TemperatureAndRailLoads~Position 1.mys	Temperature Only			0.016503638	1	60	RH Abutment
1	E4-6_TemperatureAndRailLoads~Position 1.mys	Braking	360	660	0.016966656	1	60	RH Abutment
2	E4-6_TemperatureAndRailLoads~Position 2.mys	Braking	350	650	0.016943296	1	60	RH Abutment
3	E4-6_TemperatureAndRailLoads~Position 3.mys	Braking	340	640	0.016955869	1	60	RH Abutment
4	E4-6_TemperatureAndRailLoads~Position 4.mys	Braking	330	630	0.01703966	1	60	RH Abutment
5	E4-6_TemperatureAndRailLoads~Position 5.mys	Braking	320	620	0.01718288	1	60	RH Abutment
6	**E4-6_TemperatureAndRailLoads~Position 6.mys**	**Braking**	**310**	**610**	**0.017314468**	**1**	**60**	**RH Abutment**
7	E4-6_TemperatureAndRailLoads~Position 7.mys	Braking	300	600	0.017256511	1	60	RH Abutment
8	E4-6_TemperatureAndRailLoads~Position 8.mys	Braking	290	590	0.017156105	1	60	RH Abutment
9	E4-6_TemperatureAndRailLoads~Position 9.mys	Braking	280	580	0.017135178	1	60	RH Abutment
10	E4-6_TemperatureAndRailLoads~Position 10.mys	Braking	270	570	0.01712915	1	60	RH Abutment
11	E4-6_TemperatureAndRailLoads~Position 11.mys	Braking	260	560	0.017127127	1	60	RH Abutment
12	E4-6_TemperatureAndRailLoads~Position 12.mys	Braking	250	550	0.017126395	1	60	RH Abutment
13	E4-6_TemperatureAndRailLoads~Position 13.mys	Braking	240	540	0.017126121	1	60	RH Abutment
14	E4-6_TemperatureAndRailLoads~Position 14.mys	Braking	230	530	0.017126018	1	60	RH Abutment
15	E4-6_TemperatureAndRailLoads~Position 15.mys	Braking	220	520	0.017125979	1	60	RH Abutment

From this worksheet the peak relative railbed displacement is shown to be 0.01731m when the braking trainset is placed at the 6th 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.



Check of Axial Rail Stress

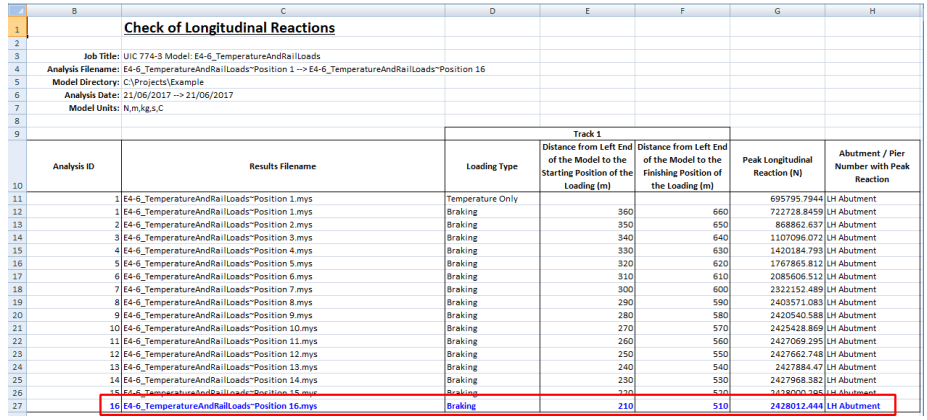
Job Title: UIC 774-3 Model E4-6_TemperatureAndRailLoads
nalysis Filename: E4-6_TemperatureAndRailLoads~Position 1 --> E4-6_TemperatureAndRailLoads~Position 16
Model Directory: C:\Projects\Example
Analysis Date: 21/06/2017 --> 21/06/2017
Model Units: N,m,kg,s,C

Analysis ID	Results Filename	Loading Type	Track 1 Distance from Left End of the Model to the Starting Position of the	Track 1 Distance from Left End of the Model to the Finishing Position of the	Peak Most Tensile Axial Stress of Rail (MPa)	Track Number with Peak Most Tensile Stress	Distance from Left End of Structure for Peak Most Tensile Stress	Description of peak location	Peak Most Compressive Axial Stress of Rail (MPa)	Track Number with Peak Most Compressive Stress
1	E4-6_TemperatureAndRailLoads~Position 1.mys	Temperature Only			-100.1257527	1	12	Within Deck 1	-154.9742044	1
1	E4-6_TemperatureAndRailLoads~Position 1.mys	Braking	360	660	-101.2885546	1	12	Within Deck 1	-157.4084021	1
2	E4-6_TemperatureAndRailLoads~Position 2.mys	Braking	350	650	-101.9662701	1	10	Within Deck 1	-154.6567528	1
3	E4-6_TemperatureAndRailLoads~Position 3.mys	Braking	340	640	-101.9864012	1	10	Within Deck 1	-154.7082981	1
4	E4-6_TemperatureAndRailLoads~Position 4.mys	Braking	330	630	-100.6559595	1	8	Within Deck 1	-157.4689882	1
5	E4-6_TemperatureAndRailLoads~Position 5.mys	Braking	320	620	-97.77219788	1	6	Within Deck 1	-161.198384	1
6	**E4-6_TemperatureAndRailLoads~Position 6.mys**	**Braking**	**310**	**610**	-94.74874428	1	4	Within Deck 1	**-164.5527583**	**1**
7	E4-6_TemperatureAndRailLoads~Position 7.mys	Braking	300	600	-90.92359367	1	0	LH Abutment	-161.936577	1
8	E4-6_TemperatureAndRailLoads~Position 8.mys	Braking	290	590	-86.36359552	1	0	LH Abutment	-161.7294681	1
9	E4-6_TemperatureAndRailLoads~Position 9.mys	Braking	280	580	-84.95461087	1	0	LH Abutment	-161.3212078	1
10	E4-6_TemperatureAndRailLoads~Position 10.mys	Braking	270	570	-84.5467352	1	0	LH Abutment	-161.2023604	1
11	E4-6_TemperatureAndRailLoads~Position 11.mys	Braking	260	560	-84.41253008	1	0	LH Abutment	-161.1041382	1
12	E4-6_TemperatureAndRailLoads~Position 12.mys	Braking	250	550	-84.36325544	1	0	LH Abutment	-161.1018607	1
13	E4-6_TemperatureAndRailLoads~Position 13.mys	Braking	240	540	-84.34464571	1	0	LH Abutment	-161.1145262	1
14	E4-6_TemperatureAndRailLoads~Position 14.mys	Braking	230	530	-84.33787823	1	0	LH Abutment	-161.1425073	1
15	E4-6_TemperatureAndRailLoads~Position 15.mys	Braking	220	520	-84.33522723	1	0	LH Abutment	-161.141739	1
16	**E4-6_TemperatureAndRailLoads~Position 16.mys**	**Braking**	**210**	**510**	**-84.33421757**	**1**	**0**	**LH Abutment**	-161.1414451	1

From this worksheet the peak axial rail stress is shown to be -164.55MPa when the braking trainset is placed at the 6th 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.



Check of Longitudinal Reactions

Job Title: UIC 774-3 Model: E4-6_TemperatureAndRailLoads
Analysis Filename: E4-6_TemperatureAndRailLoads~Position 1 --> E4-6_TemperatureAndRailLoads~Position 16
Model Directory: C:\Projects\Example
Analysis Date: 21/06/2017 --> 21/06/2017
Model Units: N,m,kg,s,C

			Track 1			
Analysis ID	Results Filename	Loading Type	Distance from Left End of the Model to the Starting Position of the Loading (m)	Distance from 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			695795.7944	LH Abutment
1	E4-6_TemperatureAndRailLoads~Position 1.mys	Braking	360	660	722728.8459	LH Abutment
2	E4-6_TemperatureAndRailLoads~Position 2.mys	Braking	350	650	868862.637	LH Abutment
3	E4-6_TemperatureAndRailLoads~Position 3.mys	Braking	340	640	1107096.072	LH Abutment
4	E4-6_TemperatureAndRailLoads~Position 4.mys	Braking	330	630	1420184.793	LH Abutment
5	E4-6_TemperatureAndRailLoads~Position 5.mys	Braking	320	620	1767865.812	LH Abutment
6	E4-6_TemperatureAndRailLoads~Position 6.mys	Braking	310	610	2085606.512	LH Abutment
7	E4-6_TemperatureAndRailLoads~Position 7.mys	Braking	300	600	2322152.489	LH Abutment
8	E4-6_TemperatureAndRailLoads~Position 8.mys	Braking	290	590	2403571.083	LH Abutment
9	E4-6_TemperatureAndRailLoads~Position 9.mys	Braking	280	580	2420540.588	LH Abutment
10	E4-6_TemperatureAndRailLoads~Position 10.mys	Braking	270	570	2425428.869	LH Abutment
11	E4-6_TemperatureAndRailLoads~Position 11.mys	Braking	260	560	2427069.295	LH Abutment
12	E4-6_TemperatureAndRailLoads~Position 12.mys	Braking	250	550	2427662.748	LH Abutment
13	E4-6_TemperatureAndRailLoads~Position 13.mys	Braking	240	540	2427884.47	LH Abutment
14	E4-6_TemperatureAndRailLoads~Position 14.mys	Braking	230	530	2427968.382	LH Abutment
15	E4-6_TemperatureAndRailLoads~Position 15.mys	Braking	220	520	2428009.285	LH Abutment
16	**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.

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.

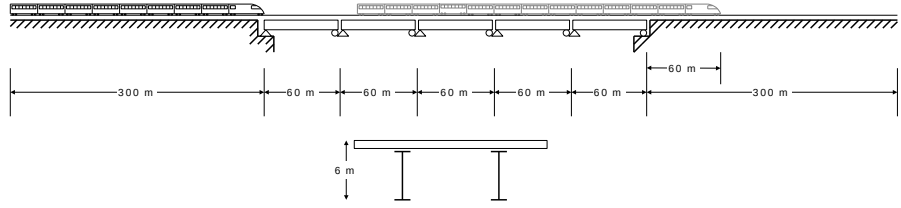
Refinement of the modelling will improve the accuracy of the solution at the cost of increased computer memory requirements and increased modelling / analysis and post-processing time. The following table shows the improvement of accuracy for the two test cases when element sizes of less than 2m and 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.

Description	Test Case	Railbed Displacement	Reaction	Rail Stress
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

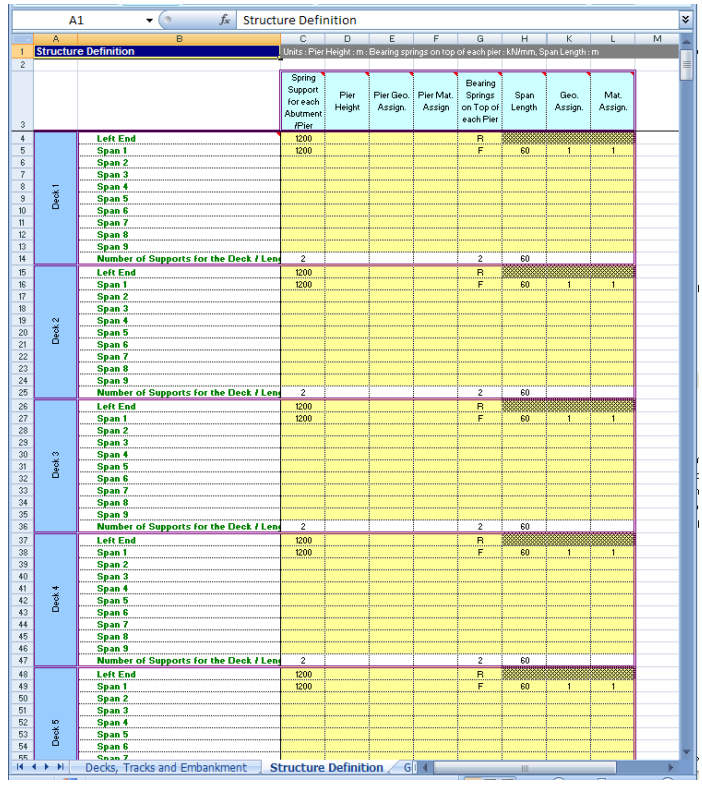
To model a structure with multiple decks spreadsheet data similar to that shown on the following pages would need to be defined.

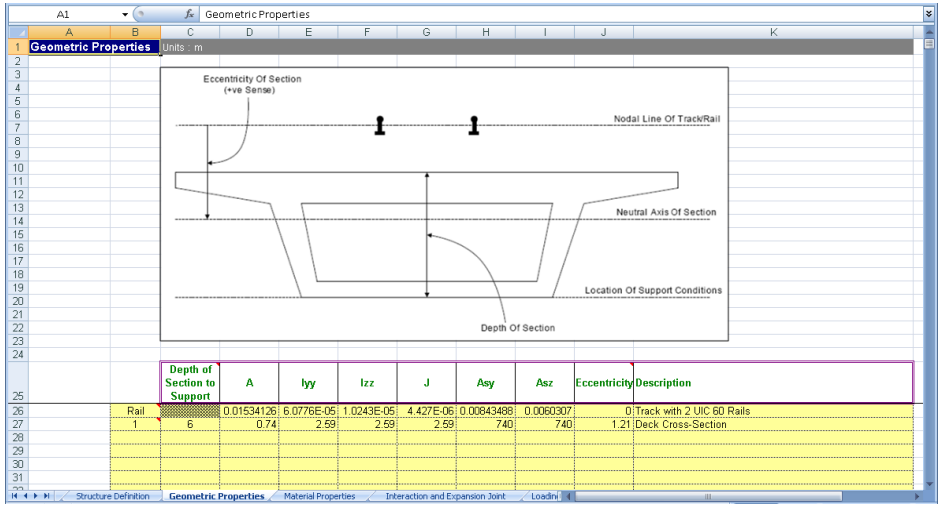


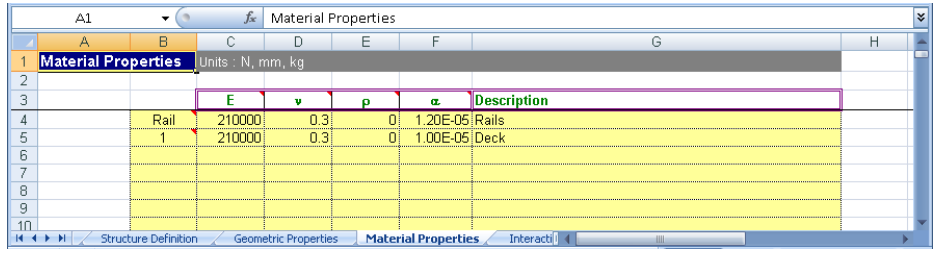
A1 | Decks, Tracks and Embankment

	A	B	C	D
1	Decks, Tracks and Embankment	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				

Decks, Tracks and Embankment | Structu


A1
Structure Definition
Structure Definition
Units : Pier Height : m ; Bearing springs on top of each pier : kN/mm, Span Length : m
Spring Support for each Abutment /Pier
Pier Height
Pier Geo. Assign.
Pier Mat. Assign
Bearing Springs on Top of each Pier
Span Length
Geo. Assign.
Mat. Assign.
Deck 1
Deck 2
Deck 3
Deck 4
Deck 5
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 / Lend
Decks, Tracks and Embankment
Structure Definition

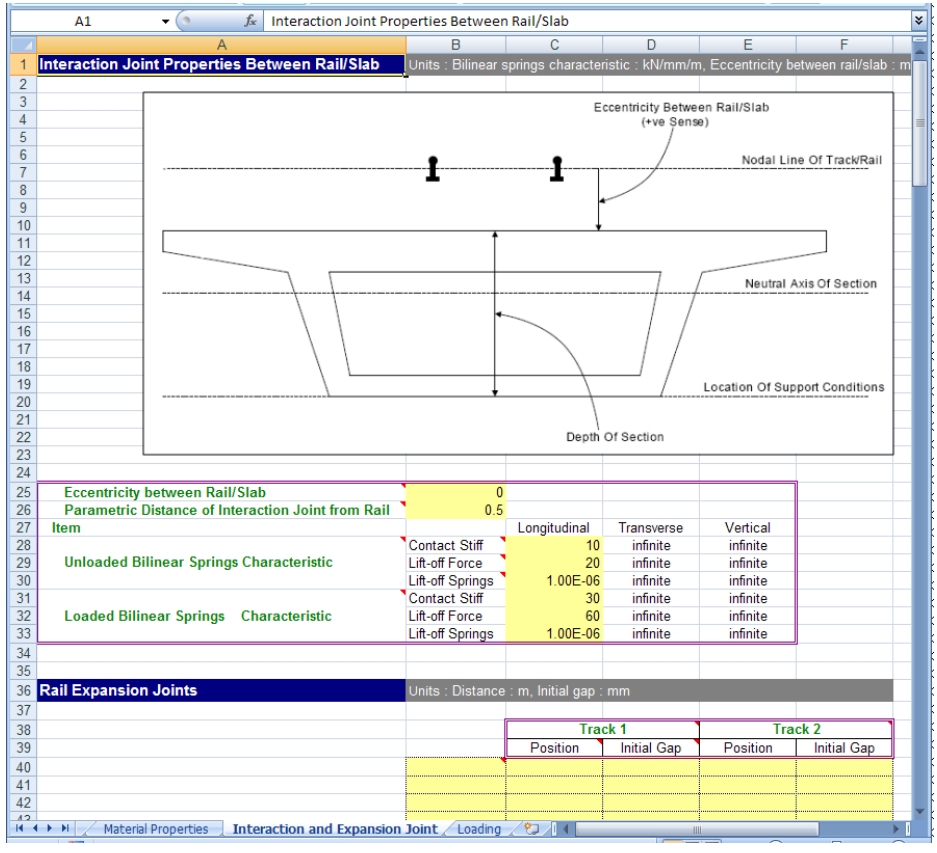

A1
Geometric Properties
Geometric Properties
Units : m
Eccentricity Of Section (+ve Sense)
Nodal Line Of Track/Rail
Neutral Axis Of Section
Location Of Support Conditions
Depth Of Section
Depth of Section to Support
A
Iyy
Izz
J
Asy
Asz
Eccentricity
Description
Rail
1
6
0.01534126
6.0776E-05
1.0243E-05
4.427E-06
0.00843488
0.0060307
0
0.74
2.59
2.59
2.59
740
740
1.21
Track with 2 UIC 60 Rails
Deck Cross-Section
Structure Definition
Geometric Properties
Material Properties
Interaction and Expansion Joint



A1 | Material Properties

	A	B	C	D	E	F	G	H
1	**Material Properties**	Units : N, mm, kg						
2								
3			E	ν	ρ	α	Description	
4		Rail	210000	0.3	0	1.20E-05	Rails	
5		1	210000	0.3	0	1.00E-05	Deck	
6								
7								
8								
9								
10								

Structure Definition | Geometric Properties | **Material Properties** | Interacti



A1 | Interaction Joint Properties Between Rail/Slab

	A	B	C	D	E	F
1	**Interaction Joint Properties Between Rail/Slab**	Units : Bilinear springs characteristic : kN/mm/m, Eccentricity between rail/slab : m				
2						
3						
4						
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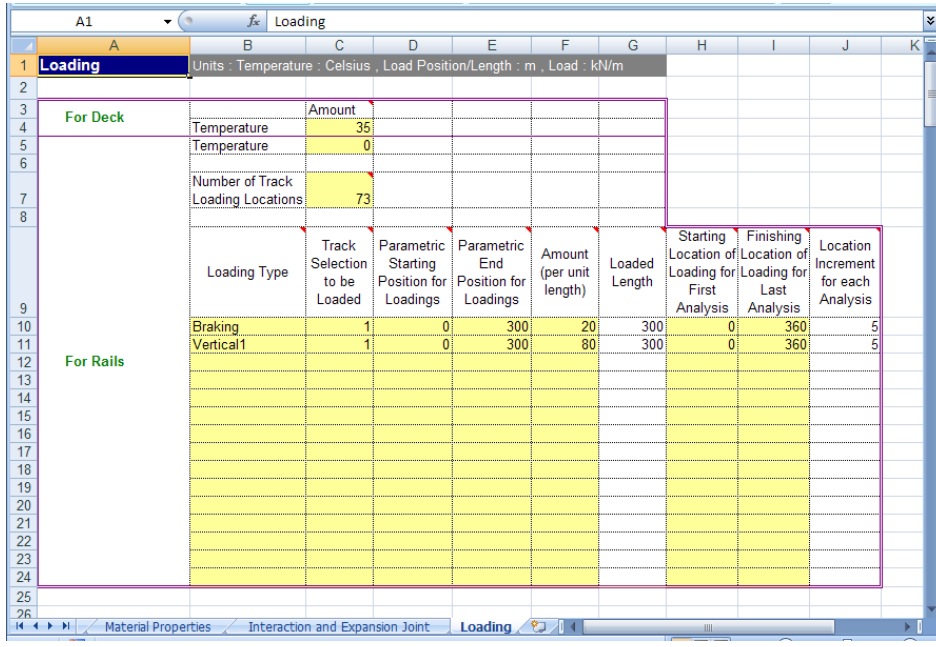
22						
23						
24						
25	**Eccentricity between Rail/Slab**	0				
26	**Parametric Distance of Interaction Joint from Rail**	0.5				
27	**Item**		Longitudinal	Transverse	Vertical	
28		Contact Stiff	10	infinite	infinite	
29	**Unloaded Bilinear Springs Characteristic**	Lift-off Force	20	infinite	infinite	
30		Lift-off Springs	1.00E-06	infinite	infinite	
31		Contact Stiff	30	infinite	infinite	
32	**Loaded Bilinear Springs Characteristic**	Lift-off Force	60	infinite	infinite	
33		Lift-off Springs	1.00E-06	infinite	infinite	
34						
35						
36	**Rail Expansion Joints**	Units : Distance : m, Initial gap : mm				
37						
38			Track 1		Track 2	
39			Position	Initial Gap	Position	Initial Gap
40						
41						
42						

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



A1 | Loading

	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : Celsius , Load Position/Length : m , Load : kN/m								
2										
3	For Deck		Amount							
4		Temperature	35							
5		Temperature	0							
6										
7		Number of Track Loading Locations	73							
8										
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	360	5
11		Vertical1	1	0	300	80	300	0	360	5
12	For Rails									
13										
14										
15										
16										
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19										
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22										
23										
24										
25										
26										

Material Properties | Interaction and Expansion Joint | Loading