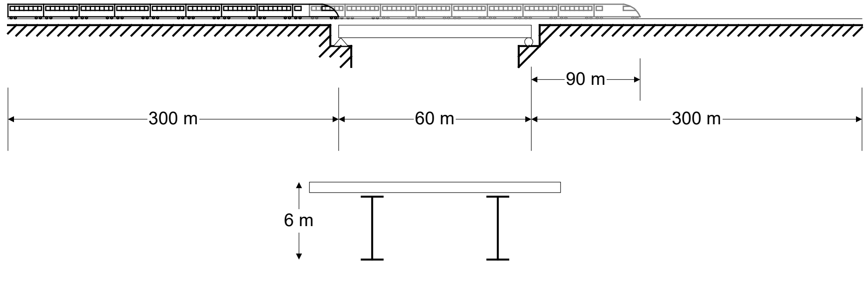
Rail Track-Structure Interaction to UIC774-3

For LUSAS version:	24.0
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. 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

This file below is intended for copying to a project folder if a rail track model is to be defined from scratch. It is provided in the C:\Program Files\<LUSAS>Programs\scripts\User folder.

- ❑ **UIC_Template.xlsx** UIC774-3 XLSX input spreadsheet (unpopulated) for copying to a projects folder and using with this worked example.

The other files are intended for copying to a projects folder if results processing only and not spreadsheet data input is of interest. They are contained within a zip file that can be downloaded from the user area of the LUSAS website.

- ❑ **UIC E1-3 Analysis.xlsx** - UIC774-3 XLSX 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** - UIC774-3 XLSX 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 Microsoft Excel XLSX format 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:

- Ensure the supplied XLSX spreadsheet named **UIC_Template.xlsx** is present in a working projects folder where the track-structure interaction model is to be built.
- Rename the spreadsheet to **UIC E1-3 Analysis.xlsx** .
- Open the spreadsheet in Microsoft Excel or an equivalent application that can edit the file.

The modelling spreadsheet contains six worksheets titled:

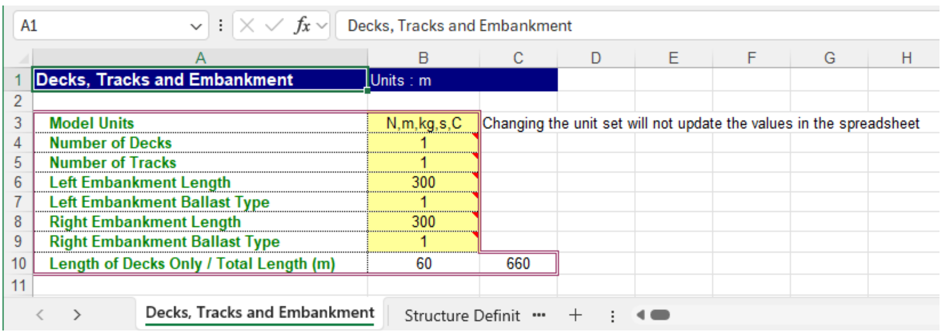
- ❑ **Decks, Tracks and Embankment**
- ❑ **Structure Definition**
- ❑ **Geometric Properties**
- ❑ **Material Properties**
- ❑ **Interaction and Expansion Joint**
- ❑ **Loading**

Note. Data should only be entered into the yellow regions of the XLSX 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 also 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.

Defining Decks, Tracks and Embankment Lengths

- Pick the **Decks, Tracks and Embankment** worksheet.



- Ensure that **Model Units** are set to **N,m,kg,s,C**.
- 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 300 m. Enter **300** for both the **Left Embankment Length** and **Right Embankment Length**.
- Only a single ballast type will be defined for both the track-embankment-interaction and the track-structure interaction in the model. Enter **1** for the ID number of the **Left Embankment Ballast Type** and the **Right Embankment Ballast Type**.

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.

Note. Model data is entered in "convenient" SI or US units. When the model is built from the data in the spreadsheet, all input is converted to consistent SI units of N,m,kg,s and C, or to consistent US units of kip,ft,kslug,s,F (if initially specified). The first row of each worksheet states the units in use. Note that, by design, changing the model units in use (on the 'Decks, Tracks and Embankments' worksheet) does not convert the values in the spreadsheet.

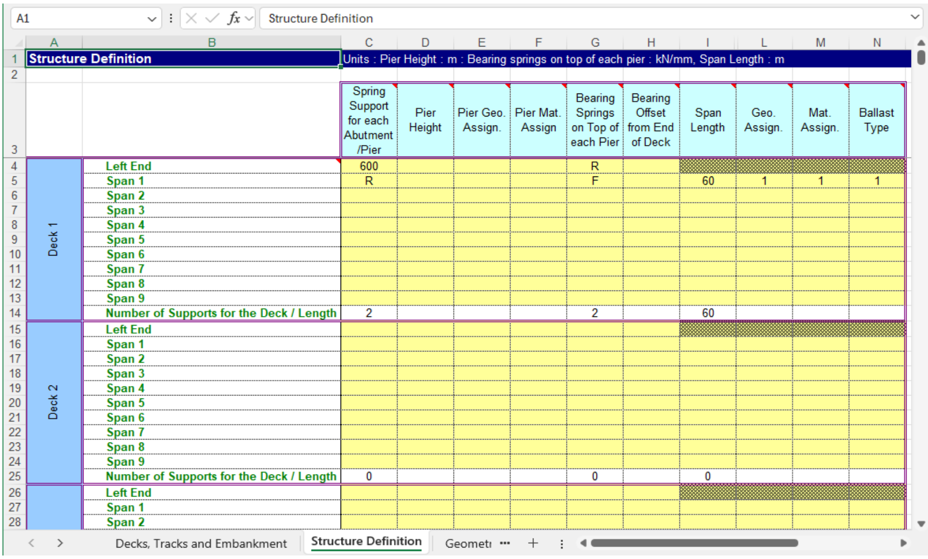
Defining the Structure

- Pick the **Structure Definition** worksheet.
- The left abutment has a stiffness of 600000 kN/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.
- Enter **1** for the **Ballast Type**. This ID will match a ballast definition in the **Interaction and Expansion Joint** 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:



A1 | Structure Definition

	A	B	C	D	E	F	G	H	I	L	M	N
1	Structure Definition		Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m									
2												
3			Spring Support for each Abutment /Pier	Pier Height	Pier Geo. Assign.	Pier Mat. Assign	Bearing Springs on Top of each Pier	Bearing Offset from End of Deck	Span Length	Geo. Assign.	Mat. Assign.	Ballast Type
4	Deck 1	Left End	600				R					
5		Span 1	R				F		60	1	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										
28		Span 2										

Decks, Tracks and Embankment | Structure Definition | Geometr

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

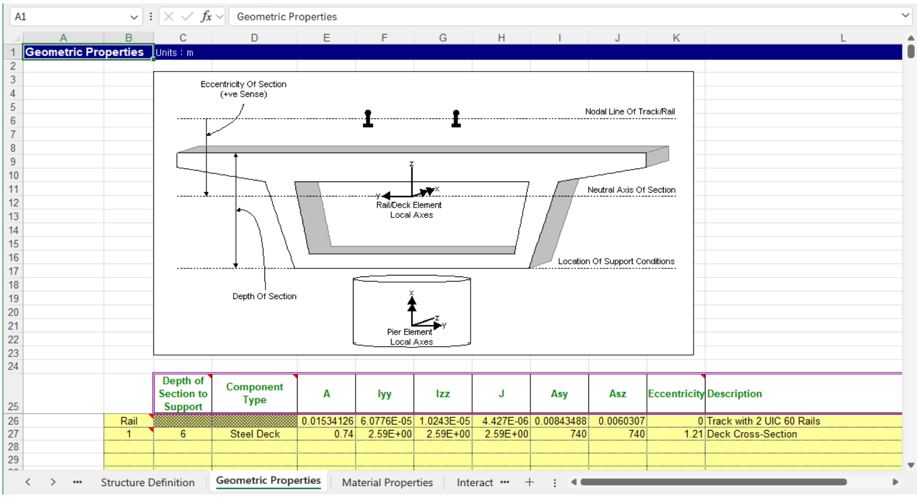
The UIC774-3 fundamental tests do not incorporate the modelling of piers as part of the structure, so these are not included in this example. LUSAS offers two methods of modelling piers when these need to be represented in the structure:

- 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.
- Select **Steel Deck** from the **Component Type** list. In the UIC774-3 E1-3 test case the deck section is primarily made from steel 'I' sections and the material properties (see next section) provided in the test case match this.
- 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 6 m and the neutral axis ordinate is 4.79 m giving an eccentricity of 6 – 4.79 = 1.21 m.
- Enter **Deck Cross-Section** in the **Description** for the deck.

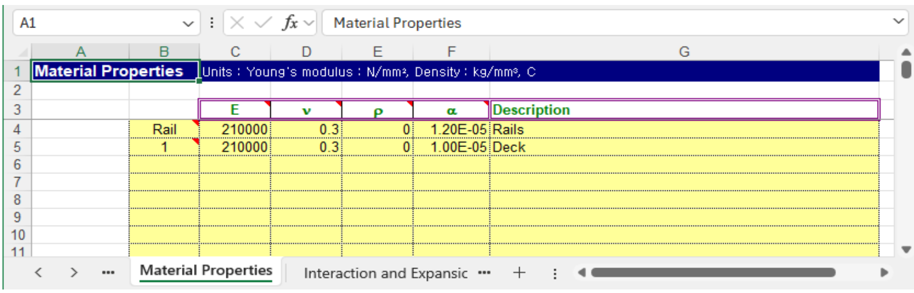
Modelling Discussion

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



	A	B	C	D	E	F	G
1	Material Properties	Units : Young's modulus : N/mm², Density : kg/mm³, C					
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

- 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.

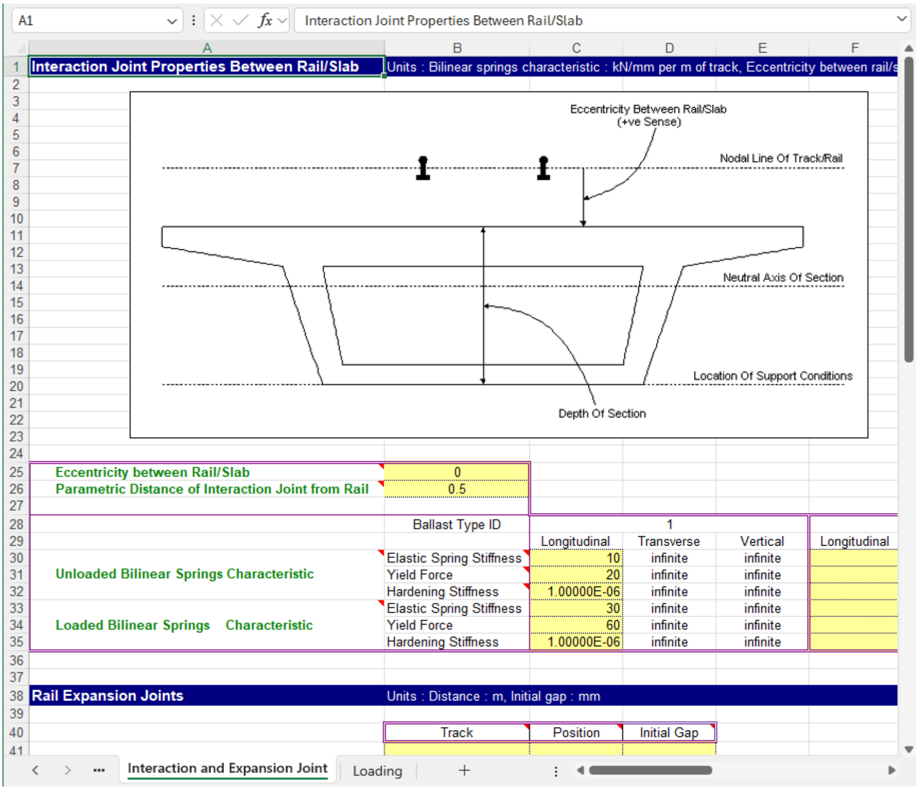
Enter the following values for the deck:

- 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 a value of 0.5 would place them halfway between the rail and slab for eccentric track.

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

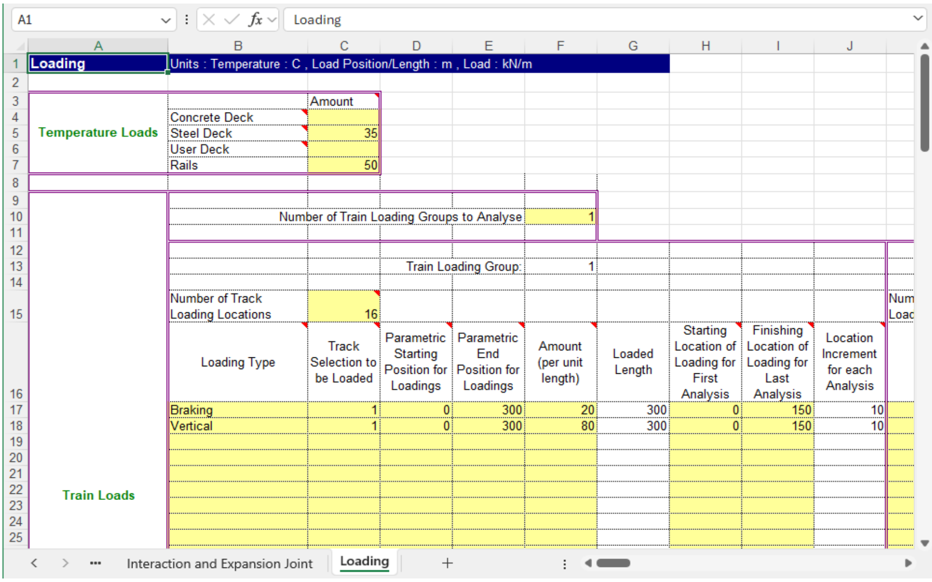
Enter the following values for the longitudinal bilinear spring characteristics for **Ballast Type ID 1** – (Only ballast type ID 1 has been assigned in the **Decks, Tracks and Embankment** and the **Structure Definition** worksheets):

- Enter **10** for the **Unloaded Elastic Spring Stiffness** in the longitudinal direction in kN/m/mm. The resistance parameter for the unloaded track is 20 kN/m in the test and this gives a stiffness of 20 kN/m / 2 mm = 10 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 kN/m / 2 mm = 30 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 Temperature and Trainset Loading for the Structure

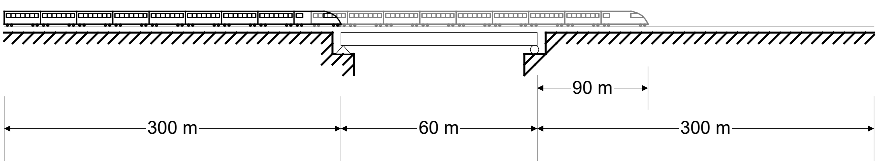


	A	B	C	D	E	F	G	H	I	J
1	Loading	Units : Temperature : C , Load Position/Length : m , Load : kN/m								
2										
3			Amount							
4		Concrete Deck								
5	Temperature Loads	Steel Deck	35							
6		User Deck								
7		Rails	50							
10		Number of Train Loading Groups to Analyse				1				
13		Train Loading Group:				1				
15		Number of Track Loading Locations	16							
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
17		Braking	1	0	300	20	300	0	150	10
18		Vertical	1	0	300	80	300	0	150	10
22	Train Loads									

- Pick the **Loading** worksheet.
- Enter **35** for the **Temperature** variation of the **Steel Deck** in °C (to match the **Component Type** in the **Geometric Properties** worksheet).
- Enter **50** for the **Temperature** variation of the **Rails** in °C.

Note. If both steel and concrete deck constructions were present within the structure, then these component types would be specified in the **Geometric Properties** worksheet and any appropriate temperature variations can then be specified and applied using the input for each component type.

For the UIC774-3 E1-3 test case the single 300 m long trainset travels from the left-hand abutment of the 60 m long deck to 90 m past the right-hand abutment of the deck, a total distance of 150 m. For the example this trainset passage will be broken up into 10 m 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 300 m long in the test case.
- Enter **20** for the **Amount (per unit length)** to apply 20 kN/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 300 m long.
- Enter **150** for the **Finishing Location of Loading for Last Analysis** to place the right-hand extent of the trainset 90 m past the 60 m 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 300 m 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 300 m long.

- Enter **150** for the **Finishing Location of Loading for Last Analysis** to place the right-hand extent of the trainset 90 m past the 60 m deck span for the last analysis.
- **Save** the spreadsheet and close the Microsoft Excel (or equivalent) 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 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.

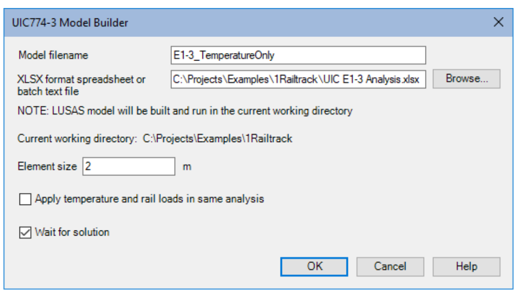
File
New…

- Enter **UIC774_testcase** for the model's 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.

Bridge
Rail Track Analysis >
Build UIC774-3 Model…

- Enter a model filename of **E1-3_TemperatureOnly**
- Enter the filename of the XLSX 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 XLSX format spreadsheet or batch text file

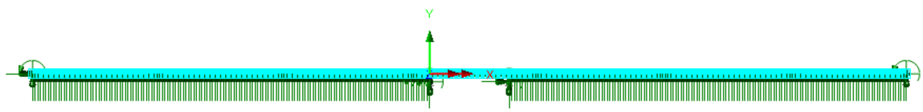


input. If the full folder information is not entered it will be assumed that the XLSX spreadsheet is in the current working folder which is reported in the dialog.

If wanting to build the model from a supplied spreadsheet, select the file **UIC E1-3 Analysis.xlsx** that was downloaded and placed in a folder of your choosing.

- Ensure an Element size of **2** is specified which will create elements of a maximum length of 2 m 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 XLSX 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.

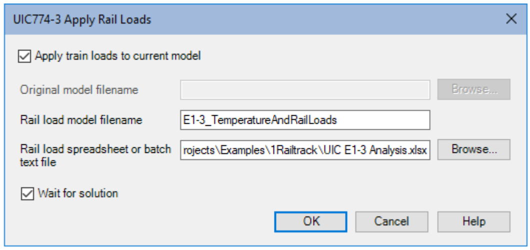
Note. If the intention was to only perform this analysis and investigate the thermal effects, then post-processing could be performed on the results of the analysis. In addition, if the **Apply temperature and rail loads in same analysis** option was selected the combined temperature and rail track loading 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 >
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. If this option is not selected the original temperature only analysis model name would need to be supplied.



- Enter **E1-3_TemperatureAndRailLoads** as the **Rail load model filename**.

- Enter the **UIC E1-3 Analysis.xlsx** filename of the XLSX spreadsheet created for the analysis or browse for it using the **Browse...** button in the **Rail load spreadsheet or batch text file** input. If the full folder information is not entered it will be assumed that the XLSX 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** that was downloaded and placed in a folder of your choosing.

- 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 definition for the XLSX 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. You may download this file from the user area of the LUSAS website.

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

The spreadsheet 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.

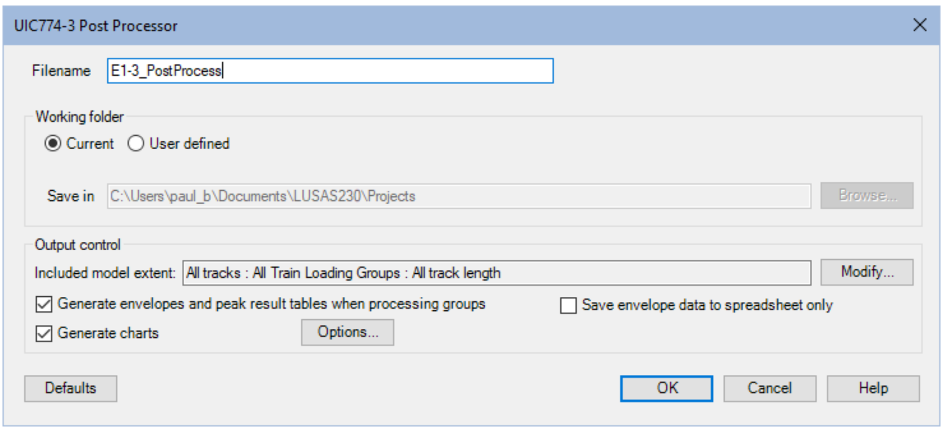
Viewing the Results

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 an Excel Spreadsheet

The Rail Track Analysis option provides a post-processing tool that automatically extracts the results of the analyses into tabular form to a Microsoft Excel XLSX format spreadsheet 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 >
Extract Results to Excel…



- Enter **E1-3_PostProcess** for the **Filename**. Note that no *.xlsx extension is required.
- Ensure the **Working folder** is set to **Current** to place the post-processing spreadsheet into the same folder as the analyses.
- Ensure the **Output Control** is reporting that “**All tracks : All Train Loading Groups : All track length**” are included in the model extent.

For a new model being post-processed for the first time this should always be the case. If previous selective post-processing has been carried out on the model, and the model saved, that choice will have been stored for use again by the post-processor. The included model extent must be updated by clicking the **Modify** button and revising the selection. Clicking the **Defaults** button in the **Modify Included Output** dialog will return the included model extent to “All tracks : All Train Loading Groups : All track length” if needed.

- Ensure the **Output Control** is reporting that the **Generate envelopes and peak result tables when processing groups** option is selected.
- Ensure the **Output Control** is reporting that the **Generate charts** option is selected.

  If previous customised post-processing has been carried out on the model and the model saved the choice of charts created may have been changed from the defaults and will have been stored for use again by the post-processor. The choice of charts created must be updated by clicking the **Options** button and the included charts revised. Clicking the **Defaults** button in the **Chart Options** dialog will return the chart options to the defaults.

- Click the **OK** button.

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

Note. The post-processing for this example will take less than 30 seconds. For much larger Rail Track Analyses (larger structures with more tracks / more train positions / group considerations) 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 the time that the post-processing is being carried out.

- Open the spreadsheet **E1-3_PostProcess** in Microsoft Excel (or an equivalent application).

Since the creation of envelopes was specified earlier the spreadsheet will contain seven worksheets that contain the results from the analyses. Note that some spreadsheet applications may only show the tabs for the last created worksheets and hide the previous worksheets. If this is the case, other worksheets can typically 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

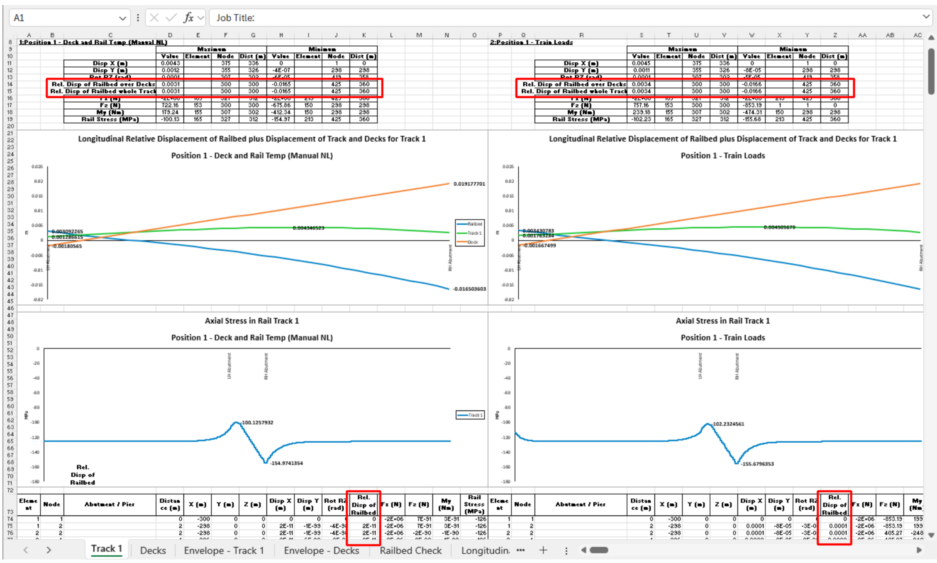
For a continuously welded rail (CWR) track the typical criteria to be met for the relative railbed displacements is quoted in Clause 1.5.3 of UIC774-3 which states that:

"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 railbed displacements are included in the **Track 1** worksheet which reports all 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.



Since the option to create envelopes 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.

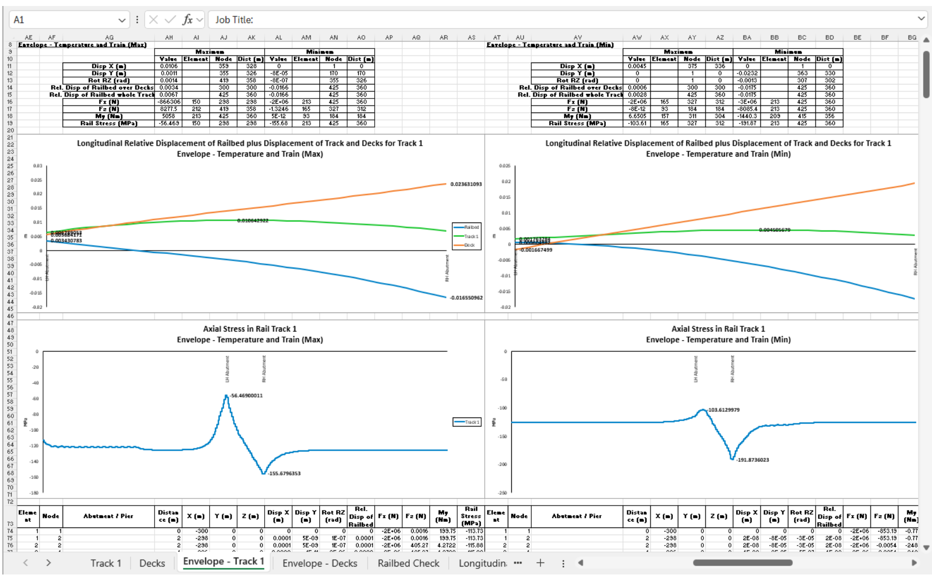
For the envelopes worksheet the output is identical to the tabular and chart output for the individual results in the analyses. Six envelopes are generated by the post-processor, namely:

- ❑ **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 also 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.

Model Filename: E1-3_TemperatureAndRailLoads.mdl
Model Directory: C:\Projects\Examples\1Railtrack\
Model Date: 11/20/2024
Model Units: N,m,kg,s,C

Envelope - Temperature and Train (Max)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.01064292		359	328	0		1	0
Disp Y (m)	0.00106425		355	326	-8E-05		170	170
Rot RZ (rad)	0.00140178		419	358	-7.831E-07		355	326
Rel. Disp of Railbed over Decks (m)	0.00343078		300	300	-0.016551		425	360
Rel. Disp of Railbed whole Track (m)	0.00674793		425	360	-0.016551		425	360
Fx (N)	-866305.61	150	298	298	-2388321.8	213	425	360
Fz (N)	8277.53037	212	419	358	-1.3246189	165	327	312
My (Nm)	5057.96222	213	425	360	4.9889E-12	93	184	184
Rail Stress (MPa)	-56.469	150	298	298	-155.67964	213	425	360

Envelope - Temperature and Train (Min)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00450568		375	336	0		1	0
Disp Y (m)	0		1	0	-0.0231701		363	330
Rot RZ (rad)	0		1	0	-0.0013208		307	302
Rel. Disp of Railbed over Decks (m)	0.00060488		300	300	-0.0174726		425	360
Rel. Disp of Railbed whole Track (m)	0.00275129		425	360	-0.0174726		425	360
Fx (N)	-1589553.9	165	327	312	-2943582.8	213	425	360
Fz (N)	-8.493E-12	93	184	184	-8085.4243	213	425	360
My (Nm)	6.65048423	157	311	304	-1440.2933	209	415	356
Rail Stress (MPa)	-103.613	165	327	312	-191.8736	213	425	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 halfway 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\Examples\1Railtrack
Analysis Date: 20/11/2024 --> 20/11/2024
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 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	E1_3_TemperatureAndRailLoads~Position 1.mys	Temperature Only			0.016503603	1	60	RH Abutment
1	E1_3_TemperatureAndRailLoads~Position 1.mys	Braking	0	300	0.016550962	1	60	RH Abutment
2	E1_3_TemperatureAndRailLoads~Position 2.mys	Braking	10	310	0.016837929	1	60	RH Abutment
3	E1_3_TemperatureAndRailLoads~Position 3.mys	Braking	20	320	0.017203	1	60	RH Abutment
4	E1_3_TemperatureAndRailLoads~Position 4.mys	Braking	30	330	0.017438819	1	60	RH Abutment
5	E1_3_TemperatureAndRailLoads~Position 5.mys	Braking	40	340	0.017472569	1	60	RH Abutment
6	E1_3_TemperatureAndRailLoads~Position 6.mys	Braking	50	350	[illegible]	1	60	RH Abutment
7	E1_3_TemperatureAndRailLoads~Position 7.mys	Braking	60	360	0.016883163	1	60	RH Abutment
8	E1_3_TemperatureAndRailLoads~Position 8.mys	Braking	70	370	0.017253077	1	60	RH Abutment
9	E1_3_TemperatureAndRailLoads~Position 9.mys	Braking	80	380	0.017358542	1	60	RH Abutment
10	E1_3_TemperatureAndRailLoads~Position 10.mys	Braking	90	390	0.017338041	1	60	RH Abutment
11	E1_3_TemperatureAndRailLoads~Position 11.mys	Braking	100	400	0.017325447	1	60	RH Abutment
12	E1_3_TemperatureAndRailLoads~Position 12.mys	Braking	110	410	0.017319896	1	60	RH Abutment
13	E1_3_TemperatureAndRailLoads~Position 13.mys	Braking	120	420	0.017317668	1	60	RH Abutment
14	E1_3_TemperatureAndRailLoads~Position 14.mys	Braking	130	430	0.017316801	1	60	RH Abutment
15	E1_3_TemperatureAndRailLoads~Position 15.mys	Braking	140	440	0.017316468	1	60	RH Abutment
16	E1_3_TemperatureAndRailLoads~Position 16.mys	Braking	150	450	0.017316341	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

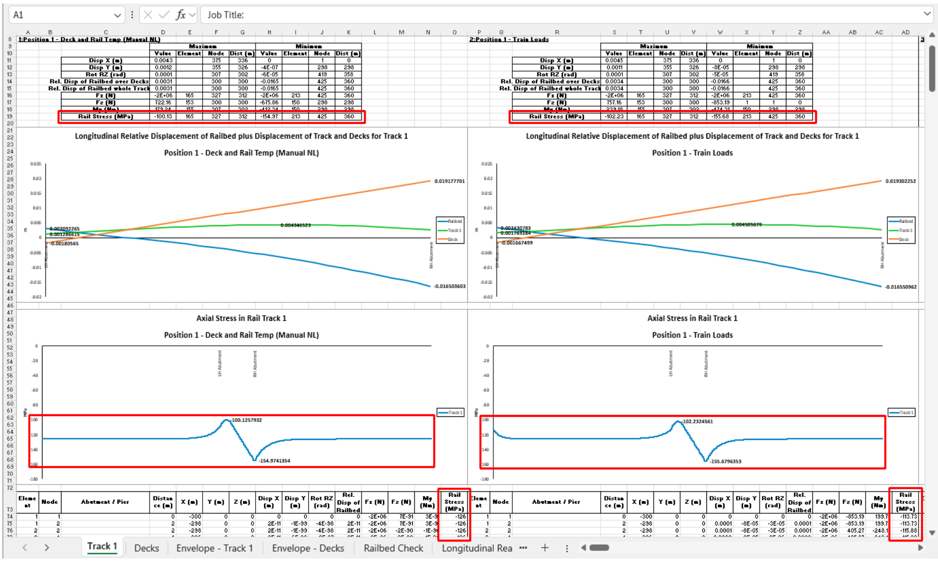
"The maximum permissible additional tensile rail stress is 92 N/mm^2"

To permit checking of these criteria rail axial stress values are included in the **Track 1** 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 ("Deck and Rail Temp (Manual NL)") the maximum and minimum stresses observed in the rail track were -100.13 MPa in compression and -154.97 MPa in compression (lower graph). This most compressive value compares well with the value of -156.67 MPa from the E1-3 test case (equal to -126 MPa from the temperature in the rail and -30.67 MPa from the temperature in the deck) with a percentage difference of -1.08%. For the temperature and trainset rail loading loadcase ("Train Loads") for the first position of the train loading the maximum and minimum stresses observed in the rail track were -102.23 MPa in compression and -155.68 MPa 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 -56.47 MPa in compression and -191.87 MPa in compression. The value of -191.87 MPa compares well with the UIC774-3 E1-3 test case published results of -182.4 MPa to -190.07 MPa with a difference of between 0.95% and 5.19% (depending upon the calculation method).

Model Filename: E1-3_TemperatureAndRailLoads.mdl
Model Directory: C:\Projects\Examples\1Railtrack\
Model Date: 11/20/2024
Model Units: N,m,kg,s,C

Envelope - Temperature and Train (Max)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.01064292		359	328	0		1	0
Disp Y (m)	0.00106425		355	326	-8E-05		170	170
Rot RZ (rad)	0.00140178		419	358	-7.831E-07		355	326
Rel. Disp of Railbed over Decks (m)	0.00343078		300	300	-0.016551		425	360
Rel. Disp of Railbed whole Track (m)	0.00674793		425	360	-0.016551		425	360
Fx (N)	-866305.61	150	298	298	-2388321.8	213	425	360
Fz (N)	8277.53037	212	419	358	-1.3246189	165	327	312
My (Nm)	5057.96222	213	425	360	4.9889E-12	93	184	184
Rail Stress (MPa)	-56.469	150	298	298	-155.67964	213	425	360

Envelope - Temperature and Train (Min)

	Maximum				Minimum			
	Value	Element	Node	Dist (m)	Value	Element	Node	Dist (m)
Disp X (m)	0.00450568		375	336	0		1	0
Disp Y (m)	0		1	0	-0.0231701		363	330
Rot RZ (rad)	0		1	0	-0.0013208		307	302
Rel. Disp of Railbed over Decks (m)	0.00060488		300	300	-0.0174726		425	360
Rel. Disp of Railbed whole Track (m)	0.00275129		425	360	-0.0174726		425	360
Fx (N)	-1589553.9	165	327	312	-2943582.8	213	425	360
Fz (N)	-8.493E-12	93	184	184	-8085.4243	213	425	360
My (Nm)	6.65048423	157	311	304	-1440.2933	209	415	356
Rail Stress (MPa)	-103.613	165	327	312	-191.8736	213	425	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 191.87 MPa occurs when the braking trainset is placed at the 9th position in the analysis when the front of the 300 m long trainset is 20 m 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\Examples\1Railtrack
Analysis Date: 20/11/2024 --> 20/11/2024
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 Loading (m)	Track 1: Distance from Left End of the Model to the Finishing 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)
1	E1_3_TemperatureAndRailLoads~Position 1.mys	Temperature Only			-100.1257932	1	12	Within Deck 1	-154.9741354
1	E1_3_TemperatureAndRailLoads~Position 1.mys	Braking	0	300	-102.2324561	1	12	Within Deck 1	-155.6796353
2	E1_3_TemperatureAndRailLoads~Position 2.mys	Braking	10	310	-103.4861748	1	6	Within Deck 1	-157.7755699
3	E1_3_TemperatureAndRailLoads~Position 3.mys	Braking	20	320	-90.91005377	1	0	LH Abutment	-161.7864547
4	E1_3_TemperatureAndRailLoads~Position 4.mys	Braking	30	330	-78.11961103	1	-2	LH Embankment	-166.9982786
5	E1_3_TemperatureAndRailLoads~Position 5.mys	Braking	40	340	-67.08755442	1	-2	LH Embankment	-172.3094668
6	E1_3_TemperatureAndRailLoads~Position 6.mys	Braking	50	350	-59.7157604	1	-2	LH Embankment	-177.1054211
7	**E1_3_TemperatureAndRailLoads~Position 7.mys**	**Braking**	**60**	**360**	**-56.46900011**	**1**	**-2**	**LH Embankment**	-181.358069
8	E1_3_TemperatureAndRailLoads~Position 8.mys	Braking	70	370	-57.8989748	1	-2	LH Embankment	-189.7053427
9	**E1_3_TemperatureAndRailLoads~Position 9.mys**	**Braking**	**80**	**380**	-58.30667853	1	-2	LH Embankment	**-191.8736023**
10	E1_3_TemperatureAndRailLoads~Position 10.mys	Braking	90	390	-58.22742607	1	-2	LH Embankment	-191.4521198
11	E1_3_TemperatureAndRailLoads~Position 11.mys	Braking	100	400	-58.17873968	1	-2	LH Embankment	-191.1931946
12	E1_3_TemperatureAndRailLoads~Position 12.mys	Braking	110	410	-58.15728285	1	-2	LH Embankment	-191.0790826
13	E1_3_TemperatureAndRailLoads~Position 13.mys	Braking	120	420	-58.14866784	1	-2	LH Embankment	-191.0332671
14	E1_3_TemperatureAndRailLoads~Position 14.mys	Braking	130	430	-58.14531743	1	-2	LH Embankment	-191.0154515
15	E1_3_TemperatureAndRailLoads~Position 15.mys	Braking	140	440	-58.14402872	1	-2	LH Embankment	-191.0086047
16	E1_3_TemperatureAndRailLoads~Position 16.mys	Braking	150	450	-58.14353264	1	-2	LH Embankment	-191.0059846

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 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 695.8 kN. This compares well with the E1-3 test case published value of 700.12 kN 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 300 m long trainset is 20 m past the right-hand abutment side of the deck. This trainset position gives a reaction of 929.1 kN which compares well with the UIC774-3 E1-3 test case published result of 874.42 kN 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\Examples\1Railtrack
Analysis Date: 20/11/2024 --> 20/11/2024
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 Loading (m)	Track 1 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			695792.3193	LH Abutment
1	E1_3_TemperatureAndRailLoads~Position 1.mys	Braking	0	300	647273.6978	LH Abutment
2	E1_3_TemperatureAndRailLoads~Position 2.mys	Braking	10	310	634883.1645	LH Abutment
3	E1_3_TemperatureAndRailLoads~Position 3.mys	Braking	20	320	726051.7645	LH Abutment
4	E1_3_TemperatureAndRailLoads~Position 4.mys	Braking	30	330	823510.7514	LH Abutment
5	E1_3_TemperatureAndRailLoads~Position 5.mys	Braking	40	340	874236.7204	LH Abutment
6	E1_3_TemperatureAndRailLoads~Position 6.mys	Braking	50	350	860905.3138	LH Abutment
7	E1_3_TemperatureAndRailLoads~Position 7.mys	Braking	60	360	807342.5183	LH Abutment
8	E1_3_TemperatureAndRailLoads~Position 8.mys	Braking	70	370	902075.7657	LH Abutment
9	**E1_3_TemperatureAndRailLoads~Position 9.mys**	**Braking**	**80**	**380**	**929084.9103**	**LH Abutment**
10	E1_3_TemperatureAndRailLoads~Position 10.mys	Braking	90	390	923834.6697	LH Abutment
11	E1_3_TemperatureAndRailLoads~Position 11.mys	Braking	100	400	920609.3417	LH Abutment
12	E1_3_TemperatureAndRailLoads~Position 12.mys	Braking	110	410	919187.8957	LH Abutment
13	E1_3_TemperatureAndRailLoads~Position 13.mys	Braking	120	420	918617.1921	LH Abutment
14	E1_3_TemperatureAndRailLoads~Position 14.mys	Braking	130	430	918395.2779	LH Abutment
15	E1_3_TemperatureAndRailLoads~Position 15.mys	Braking	140	440	918310.0106	LH Abutment
16	E1_3_TemperatureAndRailLoads~Position 16.mys	Braking	150	450	918277.4247	LH Abutment

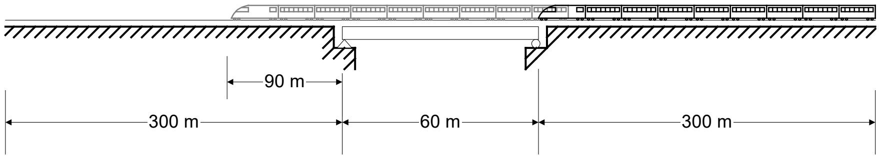
- Close the Microsoft Excel (or equivalent) application.

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.

This ability to reuse a temperature only model to apply different trainset configurations becomes particularly useful if the temperature only model has been modified to include such things as additional structural member modelling (such as a Warren truss) and applied loading considerations (such as the additional load from friction that acts at a bearing in the "Rail Track-Structure with Zero Longitudinal Resistance" Worked Example).

Applying Alternative Trainset Rail Loading



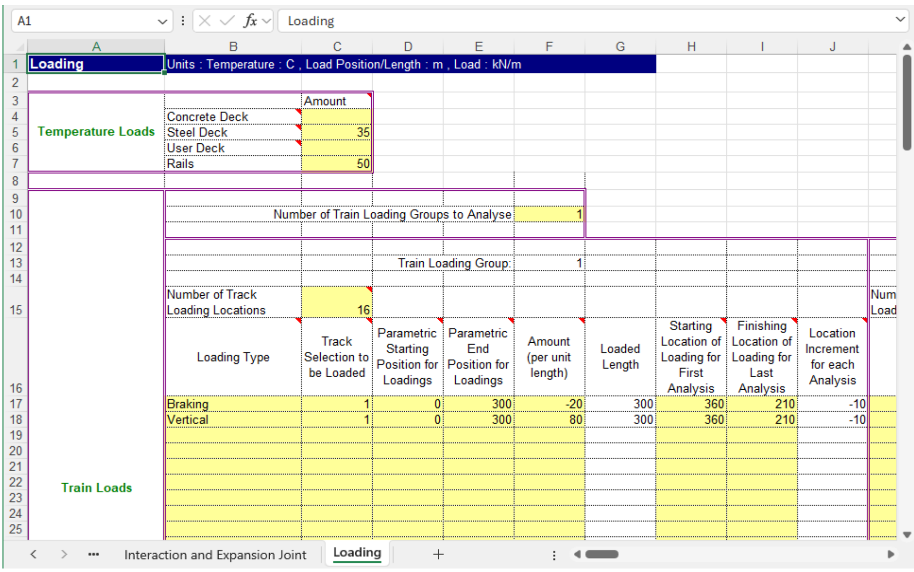
UIC774-3 test case E4-6 (shown above) is very similar to the one for test case E1-3. The only difference between the two tests is the direction that the braking trainset is travelling. As a result, the temperature only model from test case E1-3 can and will be used as the starting point for the application 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 example continue at the section entitled *Applying the Trainset Rail Loading to the Analysis*.

Otherwise:

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

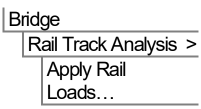


Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis
Braking	1	0	300	-20	300	360	210	-10
Vertical	1	0	300	80	300	360	210	-10

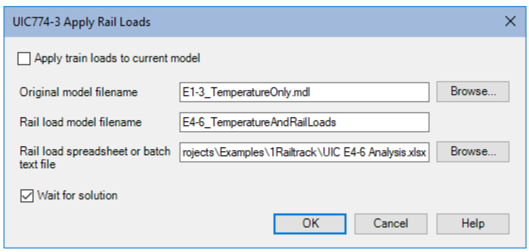
- Pick the **Loading** worksheet.
- Enter **-20** in the **Amount (per unit length)** for the trainset braking loading to indicate that the braking load is now acting to the left for a trainset that is travelling from right to left.
- Enter **360** for the **Starting Location of Loading for First Analysis** 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 300 m 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 90 m past the 60 m deck span for the last analysis.
- Save the spreadsheet and close the Microsoft Excel (or equivalent) 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 <u>not</u> 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** filename of the XLSX spreadsheet created for the analysis or browse for it using the **Browse...** button in the **Rail load spreadsheet or batch text file** input. If the full folder information is not entered it will be assumed that the spreadsheet or batch text file 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 trainset loading definition for the XLSX spreadsheet the Rail Track Analysis software option will automatically generate a LUSAS model from the data and run a rail track analysis for the alternative trainset positions defined by the loading data.

If errors were detected...

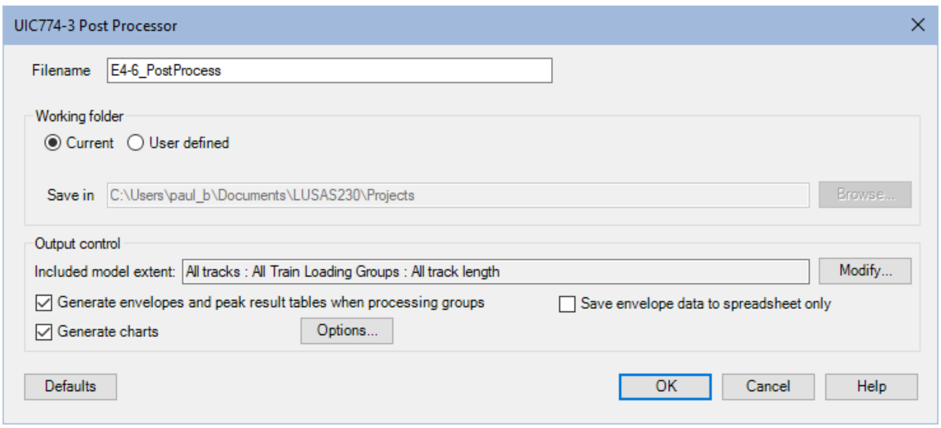
If errors were detected with the modelling data or the post-processing in the next section gives different results the values in the spreadsheet should be corrected before re-selecting the previous Rail Track Analysis menu item. If it proves impossible for you to correct the errors reported a populated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

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

The spreadsheet 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 an Excel Spreadsheet

Bridge
Rail Track Analysis >
Extract Results to Excel…



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

- Ensure the **Output Control** is reporting that "**All tracks : All Train Loading Groups : All track length**" are included in the model extent.
- Ensure the **Output Control** is reporting that the **Generate envelopes and peak result tables when processing groups** option is selected.
- Ensure the **Output Control** is reporting that the **Generate charts** 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.

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

- In your project folder, open the spreadsheet **E4-6_PostProcess** in Microsoft Excel (or an equivalent application).
- If necessary, in the application you are using, press the 'back' arrow (usually 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\Examples\1Railtrack
Analysis Date: 21/11/2024 --> 21/11/2024
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 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			0.016503603	1	60	RH Abutment
1	E4_6_TemperatureAndRailLoads~Position 1.mys	Braking	360	660	0.016966619	1	60	RH Abutment
2	E4_6_TemperatureAndRailLoads~Position 2.mys	Braking	350	650	0.016943256	1	60	RH Abutment
3	E4_6_TemperatureAndRailLoads~Position 3.mys	Braking	340	640	0.016955824	1	60	RH Abutment
4	E4_6_TemperatureAndRailLoads~Position 4.mys	Braking	330	630	0.01703961	1	60	RH Abutment
5	E4_6_TemperatureAndRailLoads~Position 5.mys	Braking	320	620	0.01718383	1	60	RH Abutment
6	**E4_6_TemperatureAndRailLoads~Position 6.mys**	**Braking**	**310**	**610**	**0.017314401**	**1**	**60**	**RH Abutment**
7	E4_6_TemperatureAndRailLoads~Position 7.mys	Braking	300	600	0.01725644	1	60	RH Abutment
8	E4_6_TemperatureAndRailLoads~Position 8.mys	Braking	290	590	0.017156034	1	60	RH Abutment
9	E4_6_TemperatureAndRailLoads~Position 9.mys	Braking	280	580	0.017135107	1	60	RH Abutment
10	E4_6_TemperatureAndRailLoads~Position 10.mys	Braking	270	570	0.017129079	1	60	RH Abutment
11	E4_6_TemperatureAndRailLoads~Position 11.mys	Braking	260	560	0.017127056	1	60	RH Abutment
12	E4_6_TemperatureAndRailLoads~Position 12.mys	Braking	250	550	0.017126324	1	60	RH Abutment
13	E4_6_TemperatureAndRailLoads~Position 13.mys	Braking	240	540	0.017126051	1	60	RH Abutment
14	E4_6_TemperatureAndRailLoads~Position 14.mys	Braking	230	530	0.017125947	1	60	RH Abutment
15	E4_6_TemperatureAndRailLoads~Position 15.mys	Braking	220	520	0.017125908	1	60	RH Abutment
16	E4_6_TemperatureAndRailLoads~Position 16.mys	Braking	210	510	0.017125893	1	60	RH Abutment

From this worksheet the peak relative railbed displacement is shown to be 0.01731 m 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
Analysis Filename: E4_6_TemperatureAndRailLoads~Position 1 --> E4_6_TemperatureAndRailLoads~Position 16
Model Directory: C:\Projects\Examples\1Railtrack
Analysis Date: 21/11/2024 --> 21/11/2024
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 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)
1	E4_6_TemperatureAndRailLoads~Position 1.mys	Temperature Only			-100.1257932	1	12	Within Deck 1	-154.9741354
1	E4_6_TemperatureAndRailLoads~Position 1.mys	Braking	360	660	-101.3885958	1	12	Within Deck 1	-157.4083283
2	E4_6_TemperatureAndRailLoads~Position 2.mys	Braking	350	650	-101.9663552	1	10	Within Deck 1	-154.6566193
3	E4_6_TemperatureAndRailLoads~Position 3.mys	Braking	340	640	-101.986506	1	10	Within Deck 1	-154.7080619
4	E4_6_TemperatureAndRailLoads~Position 4.mys	Braking	330	630	-100.659386	1	8	Within Deck 1	-157.4687193
5	E4_6_TemperatureAndRailLoads~Position 5.mys	Braking	320	620	-97.7176975	1	6	Within Deck 1	-161.3876644
6	E4_6_TemperatureAndRailLoads~Position 6.mys	Braking	310	610	-94.74916584	1	4	Within Deck 1	-164.5521041
7	E4_6_TemperatureAndRailLoads~Position 7.mys	Braking	300	600	-93.12439869	1	0	LH Abutment	-163.6875374
8	E4_6_TemperatureAndRailLoads~Position 8.mys	Braking	290	590	-86.36436717	1	0	LH Abutment	-161.7287489
9	E4_6_TemperatureAndRailLoads~Position 9.mys	Braking	280	580	-84.95540191	1	0	LH Abutment	-161.320488
10	E4_6_TemperatureAndRailLoads~Position 10.mys	Braking	270	570	-84.54952995	1	0	LH Abutment	-161.202883
11	E4_6_TemperatureAndRailLoads~Position 11.mys	Braking	260	560	-84.41332572	1	0	LH Abutment	-161.1634166
12	E4_6_TemperatureAndRailLoads~Position 12.mys	Braking	250	550	-84.36405134	1	0	LH Abutment	-161.1491389
13	E4_6_TemperatureAndRailLoads~Position 13.mys	Braking	240	540	-84.3456417	1	0	LH Abutment	-161.1438044
14	E4_6_TemperatureAndRailLoads~Position 14.mys	Braking	230	530	-84.33867425	1	0	LH Abutment	-161.1417854
15	E4_6_TemperatureAndRailLoads~Position 15.mys	Braking	220	520	-84.33602394	1	0	LH Abutment	-161.141017
16	E4_6_TemperatureAndRailLoads~Position 16.mys	Braking	210	510	-84.3350136	1	0	LH Abutment	-161.1407232

From this worksheet the peak axial rail stress is shown to be -164.55 MPa 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\Examples\1Railtrack
Analysis Date: 21/11/2024 --> 21/11/2024
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			695792.3193	LH Abutment
1	E4_6_TemperatureAndRailLoads~Position 1.mys	Braking	360	660	722725.1833	LH Abutment
2	E4_6_TemperatureAndRailLoads~Position 2.mys	Braking	350	650	868857.3834	LH Abutment
3	E4_6_TemperatureAndRailLoads~Position 3.mys	Braking	340	640	1107088.234	LH Abutment
4	E4_6_TemperatureAndRailLoads~Position 4.mys	Braking	330	630	1420173.503	LH Abutment
5	E4_6_TemperatureAndRailLoads~Position 5.mys	Braking	320	620	1767850.798	LH Abutment
6	E4_6_TemperatureAndRailLoads~Position 6.mys	Braking	310	610	2085588.033	LH Abutment
7	E4_6_TemperatureAndRailLoads~Position 7.mys	Braking	300	600	2322130.597	LH Abutment
8	E4_6_TemperatureAndRailLoads~Position 8.mys	Braking	290	590	2403546.202	LH Abutment
9	E4_6_TemperatureAndRailLoads~Position 9.mys	Braking	280	580	2420515.335	LH Abutment
10	E4_6_TemperatureAndRailLoads~Position 10.mys	Braking	270	570	2425403.531	LH Abutment
11	E4_6_TemperatureAndRailLoads~Position 11.mys	Braking	260	560	2427043.933	LH Abutment
12	E4_6_TemperatureAndRailLoads~Position 12.mys	Braking	250	550	2427637.378	LH Abutment
13	E4_6_TemperatureAndRailLoads~Position 13.mys	Braking	240	540	2427859.097	LH Abutment
14	E4_6_TemperatureAndRailLoads~Position 14.mys	Braking	230	530	2427943.008	LH Abutment
15	E4_6_TemperatureAndRailLoads~Position 15.mys	Braking	220	520	2427974.921	LH Abutment
16	E4_6_TemperatureAndRailLoads~Position 16.mys	Braking	210	510	2427987.07	LH Abutment

From this worksheet the peak reaction is shown to be 2427.99 kN when the braking trainset is placed at the last position where the front of it is 90 m past the left-hand abutment of the deck. This peak reaction compares well with the UIC774-3 E4-6 test case published result of 2196.1 kN 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 2373.47 kN (+2.3% difference).

- Close the Microsoft Excel (or equivalent) 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 built 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 2.0 m and trainset location increments of less than 10.0 m 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%

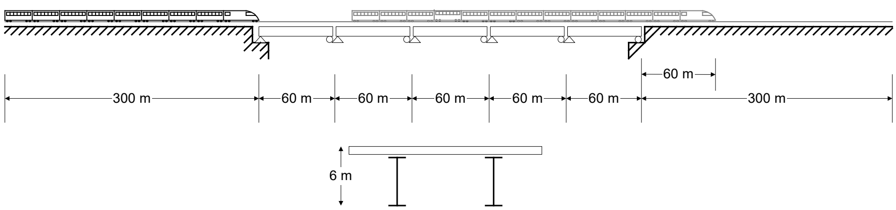
In the previous table the meshing and increment size can be seen to have a less significant effect on the railbed displacement and reactions obtained than on the rail stress values. This is because the Finite Element solution is a displacement method and reactions should be in equilibrium with the applied 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.

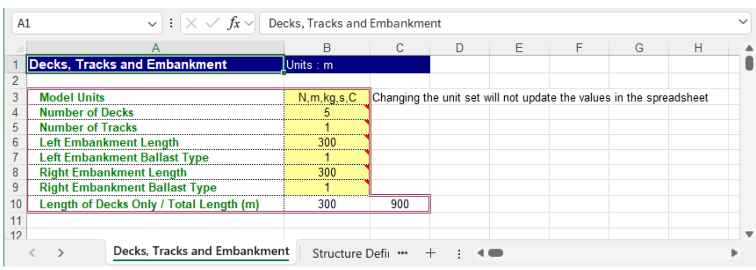
Modelling a Structure with Multiple Decks

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

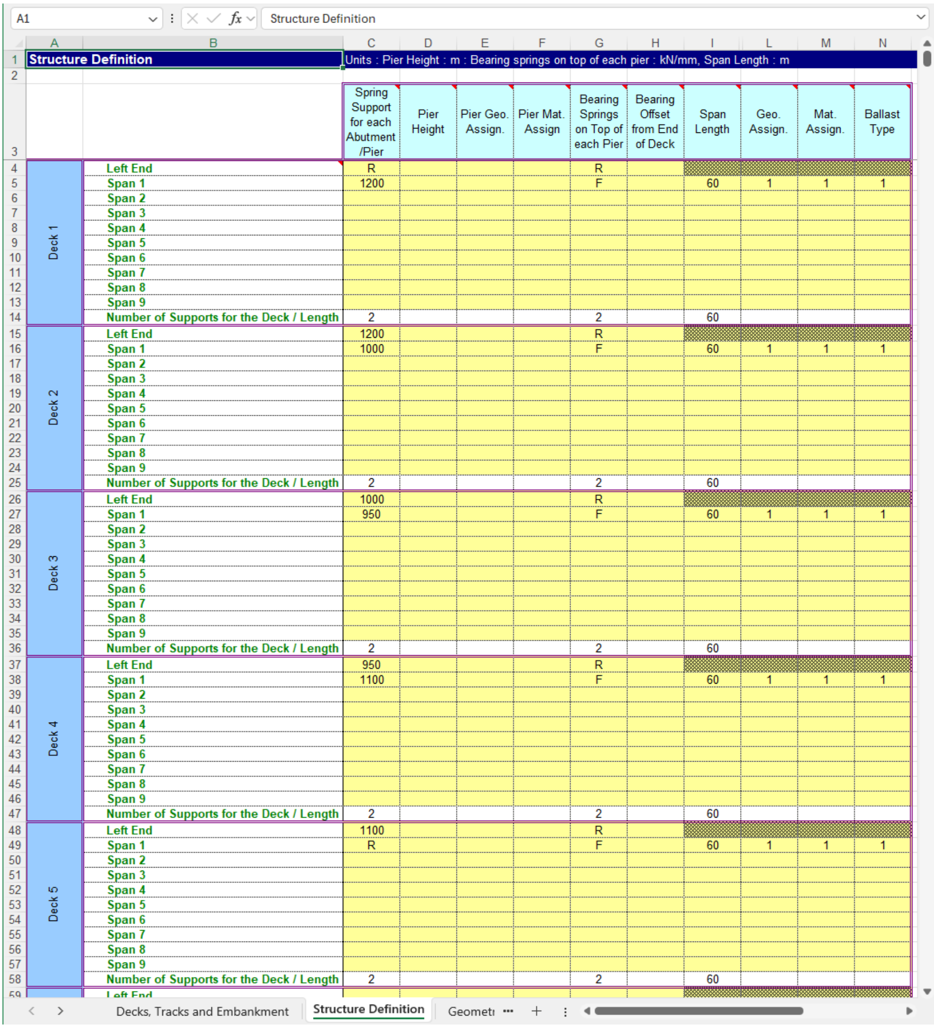
The input for the support conditions / pier at the end of one deck / start of the next deck must be identical or an input error will occur. Bearing conditions for the decks at the individual supports / piers can of course be different – see the Rail Track User Manual for more information on the input requirements.

Values are for illustration purposes only.





	A	B	C
1	Decks, Tracks and Embankment	Units : m	
2			
3	Model Units	N,m,kg,s,C	Changing the unit set will not update the values in the spreadsheet
4	Number of Decks	5	
5	Number of Tracks	1	
6	Left Embankment Length	300	
7	Left Embankment Ballast Type	1	
8	Right Embankment Length	300	
9	Right Embankment Ballast Type	1	
10	Length of Decks Only / Total Length (m)	300	900

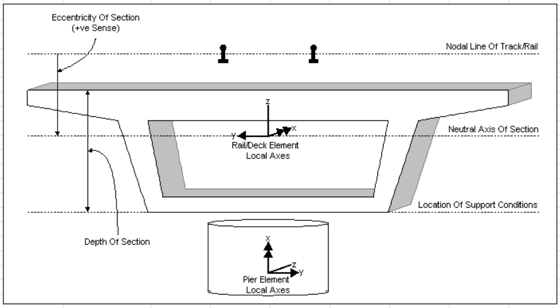


Structure Definition Units : Pier Height : m : Bearing springs on top of each pier : kN/mm, Span Length : m

Row	A	B	C: Spring Support for each Abutment /Pier	D: Pier Height	E: Pier Geo. Assign.	F: Pier Mat. Assign	G: Bearing Springs on Top of each Pier	H: Bearing Offset from End of Deck	I: Span Length	L: Geo. Assign.	M: Mat. Assign.	N: Ballast Type
4	Deck 1	Left End	R				R					
5		Span 1	1200				F		60	1	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	1200				R					
16		Span 1	1000				F		60	1	1	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	2				2		60			
26	Deck 3	Left End	1000				R					
27		Span 1	950				F		60	1	1	1
28		Span 2										
29		Span 3										
30		Span 4										
31		Span 5										
32		Span 6										
33		Span 7										
34		Span 8										
35		Span 9										
36		Number of Supports for the Deck / Length	2				2		60			
37	Deck 4	Left End	950				R					
38		Span 1	1100				F		60	1	1	1
39		Span 2										
40		Span 3										
41		Span 4										
42		Span 5										
43		Span 6										
44		Span 7										
45		Span 8										
46		Span 9										
47		Number of Supports for the Deck / Length	2				2		60			
48	Deck 5	Left End	1100				R					
49		Span 1	R				F		60	1	1	1
50		Span 2										
51		Span 3										
52		Span 4										
53		Span 5										
54		Span 6										
55		Span 7										
56		Span 8										
57		Span 9										
58		Number of Supports for the Deck / Length	2				2		60			
59		Left End										

A1 | Geometric Properties

Geometric Properties Units : m



	Depth of Section to Support	Component Type	A	Iyy	Izz	J	Asy	Asz	Eccentricity	Description
Rail			0.01534126	6.0776E-05	1.0243E-05	4.427E-06	0.00843488	0.0060307	0	Track with 2 UIC 60 Rails
1	6	Steel Deck	0.74	2.59E+00	2.59E+00	2.59E+00	740	740	1.21	Deck Cross-Section

Structure Definition | Geometric Properties | Material Properties | Interac

A1 | Material Properties

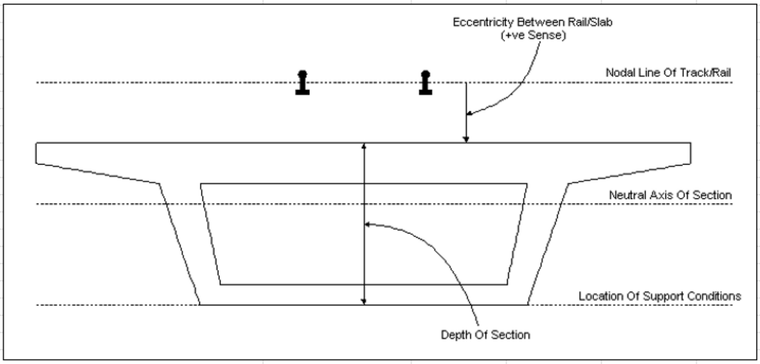
Material Properties Units : Young's modulus : N/mm², Density : kg/mm³, C

	E	ν	ρ	α	Description
Rail	210000	0.3	0	1.20E-05	Rails
1	210000	0.3	0	1.00E-05	Deck

Geometric Properties | Material Properties

A1 | Interaction Joint Properties Between Rail/Slab

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



Eccentricity between Rail/Slab	0				
Parametric Distance of Interaction Joint from Rail	0.5				
	Ballast Type ID		1		
		Longitudinal	Transverse	Vertical	Longitudinal
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	Position	Initial Gap

Material Properties | Interaction and Expansion Joint

A1 | Loading

Loading — Units : Temperature : C , Load Position/Length : m , Load : kN/m

Temperature Loads		Amount
	Concrete Deck	
	Steel Deck	35
	User Deck	
	Rails	0

Number of Train Loading Groups to Analyse: 1

Train Loading Group: 1

Number of Track Loading Locations: 73

Train Loads

Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis
Braking	1	0	300	20	300	0	360	5
Vertical1	1	0	300	80	300	0	360	5

Interaction and Expansion Joint | Loading