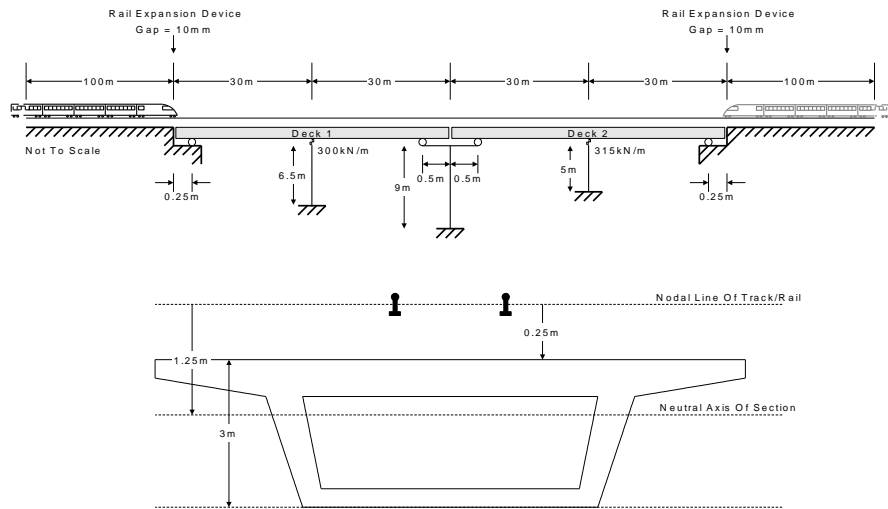# Rail Track-Structure Interaction with Offset Bearings and Train Loading Groups

For LUSAS version:	20.0
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 three braking train configurations and a double span bridge with bearings inboard of the ends of the decks. It considers the cases where the trainsets are just about to enter the left-side side of the structure through to the rear of the train exiting the right-hand side for each of the trainsets.

Objectives

The modelling requirements of the analysis are:

- ❑ Accurate modelling of the offset of the deck bearings from the ends of the decks.
- ❑ Modelling of expansion joints within the track at the start and end of the structure.
- ❑ Modelling of three train configurations (EuroCode SW/0, SW/2 and HSLM-A1).

The output requirements of the analysis for all train configurations passing across the structure are:

- ❑ Maximum relative displacement between the track and the structure in the longitudinal direction (relative railbed displacement).
- ❑ Peak longitudinal displacements between the deck ends / abutments.
- ❑ Peak longitudinal reactions at the abutments and piers.
- ❑ Peak axial rail stresses.

Keywords

UIC774-3, Track-Structure Interaction, TSI, Rail, Railbed, Offset Bearings, Train Loading Groups.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.

The following files are intended for copying to a project folder if a rail track model is to be built from scratch.

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

These files are intended for the definition of the HSLM-A1 loading:

❑ **HSLM-A1.xlsx** or **HSLM-A1.xls** Microsoft Excel spreadsheet defining the loading layout for a HSLM-A1 train to be used with this worked example.

These are intended for copying to a projects folder if results processing only and not spreadsheet data input is of interest:

❑ **RTA_2DeckBearingOffset_3TLG.xlsx**   or **RTA_2DeckBearingOffset_3TLG.xls** UIC774-3 Microsoft Excel input spreadsheet populated with data defined in this example. If used, continue at the section titled *Modelling / Running an Analysis*.

❑ **RTA_2DeckBearingOffset_3TLG-300mEmbankments.xlsx** or **RTA_2DeckBearingOffset_3TLG-300mEmbankments.xls** UIC774-3 Microsoft Excel input spreadsheet populated with data defined in this example but with 300m long approach embankments. This is for confirmation of the correct rail stresses away from the structure for the temperature loading.

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 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) to a working projects folder where the track-structure interaction model is to be built.

- Rename the spreadsheet to **RTA_2DeckBearingOffset_3TLG.xlsx** if using Microsoft Excel 2007 and above or rename to **RTA_2DeckBearingOffset_3TLG.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. 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 **2** for the **Number of Decks**.

- Enter **1** for the **Number of Tracks**.

- The UIC774-3 Code of Practice specifies the minimum embankment lengths for the modelling should be 100m and this will be used in this example. Enter **100** 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**.

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

Referring back to the illustration at the start of the example the structure definition will now be entered into the Microsoft Excel spreadsheet.

- Pick the **Structure Definition** worksheet.

- The left-hand abutment is modelled as fully restrained. Enter **R** for the **Spring Support for each Abutment/Pier** for the left end of the deck.

- The bearing at the left-hand abutment for Deck 1 is free so enter **F** for the **Bearing Springs on Top of each Pier** for the left end of the deck.

- The bearing at the left-hand abutment is not located at the extreme end of the deck but instead is located 0.25m inboard of the end of the deck. Enter **0.25** for the **Bearing Offset from End of Deck** for the left end of Deck 1.

Deck 1 is comprised of two spans of 30m and has a pier located halfway along its total length. The pier is 6.5m high with a fully fixed base and supports a sprung bearing for the deck. The definition of this pier will now be entered.

- Enter **R** for the **Spring Support for each Abutment/Pier** for the pier located at the end of Span 1 of Deck 1.

- Enter **6.5** for the **Pier Height** at the end of Span 1.

- Enter **2** for the **Pier Geometric Assignment**. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **2** for the **Pier Material Assignment**. This ID will match a material definition in the **Material Properties** worksheet covered later.

- The bearing on the top of the pier has a longitudinal stiffness of 300 MN/m. Enter **300** for the **Bearing Springs on Top of each Pier** because the units for the worksheet entry are kN/mm.

- Enter **30** for the **Span Length** of Span 1 of Deck 1.

- Enter **1** for the **Geometric Assignment** for the span of the deck. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. 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.

The right-hand end of Deck 1 (and the left-hand end of Deck 2) are supported by a 9m high pier with a fully fixed base. The bearings for both decks are free and inboard of the ends of the decks. The structure definition for Deck 1 will be defined first.

- Enter **R** for the **Spring Support for each Abutment/Pier** for the pier located at the end of Span 2 of Deck 1 (the end of Deck 1 as there are no further spans).

- Enter **9** for the **Pier Height** at the end of Deck 1.

- Enter **2** for the **Pier Geometric Assignment**. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **2** for the **Pier Material Assignment**. This ID will match a material definition in the **Material Properties** worksheet covered later.

- The bearing for the right-hand end of Deck 1 is free so enter **F** for the **Bearing Springs on Top of each Pier** for the end of the deck.

- The bearing at the right-hand end of Deck 1 is not located at the extreme end of the deck but instead is located 0.5m inboard of the end of the deck. Enter **0.5** for the **Bearing Offset from End of Deck** for the right-hand end of Deck 1.

- Enter **30** for the **Span Length** of Span 2 of Deck 1.

- Enter **1** for the **Geometric Assignment** for the span of the deck. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. 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.

This completes the structure definition for the first deck of the structure. The same procedure is followed for the definition of the second deck of the structure. The structure definition for the supporting pier at start of the next deck must exactly match the definition for the previous deck and therefore the **Spring Support for each Abutment/Pier**, **Pier Height**, **Pier Geometric Assignment** and **Pier Material Assignment** must be identical for the left-hand end of Deck 2 and the last span of Deck 1.

- For the left-hand end of Deck 2, enter **R** for the **Spring Support for each Abutment/Pier**, enter **9** for the **Pier Height**, enter **2** for the **Pier Geometric Assignment** and enter **2** for the **Pier Material Assignment** to match the data entered for the right-hand end of Deck 1.

- The bearing for the left-hand end of Deck 2 is free so enter **F** for the **Bearing Springs on Top of each Pier** for the end of the deck.

- The bearing at the left-hand end of Deck 2 is not located at the extreme end of the deck but instead is located 0.5m inboard of the end of the deck. Enter **0.5** for the **Bearing Offset from End of Deck** for the left-hand end of Deck 2.

Deck 2 is also comprised of two spans of 30m and has a pier located halfway along its total length. The pier is 5m high with a fully fixed base and supports a sprung bearing for the deck. The definition of this pier will now be entered.

- Enter **R** for the **Spring Support for each Abutment/Pier** for the pier located at the end of Span 1 of Deck 2.

- Enter **5** for the **Pier Height** at the end of Span 1.

- Enter **2** for the **Pier Geometric Assignment**. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **2** for the **Pier Material Assignment**. This ID will match a material definition in the **Material Properties** worksheet covered later.

- The bearing on the top of the pier has a longitudinal stiffness of 315 MN/m. Enter **315** for the **Bearing Springs on Top of each Pier** because the units for the worksheet entry are kN/mm.

- Enter **30** for the **Span Length** of Span 1 of Deck 2.

- Enter **1** for the **Geometric Assignment** for the span of the deck. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. 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.

- The right-hand abutment is modelled as fully restrained. Enter **R** for the **Spring Support for each Abutment/Pier** for the end of Span 2 of Deck 2.

- The bearing at the right-hand abutment for Deck 2 is free so enter **F** for the **Bearing Springs on Top of each Pier** for the right-hand end of Span 2 of Deck 2.

- The bearing at the right-hand abutment is not located at the extreme end of the deck but instead is located 0.25m inboard of the end of the deck. Enter **0.25** for the **Bearing Offset from End of Deck** for the right-hand end of Span 2 of Deck 2.

- Enter **30** for the **Span Length** of Span 2 of Deck 2.

- Enter **1** for the **Geometric Assignment** for the span of the deck. This ID will match a geometric definition in the **Geometric Properties** worksheet covered next.

- Enter **1** for the **Material Assignment** for the span of the deck. 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.

The worksheet should look like this:

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 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 has been discussed further in the *Modelling Discussion* section of the example that replicates the UIC774-3 E1-3 and E4-6 fundamental tests.

The deck geometric properties are now defined in the **Geometric** Properties worksheet. 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 **3** for the **Depth of Section** in m.

- Select **Concrete Deck** from the Component Type list. The deck constructed from concrete and this type will be used later in the Loading worksheet to apply the temperature loadings to the model.

- Enter **10** for the area (**A**) in m^2.

- Enter **10** for the second moment of inertia about the horizontal y-axis (**Iyy**) in m^4.

- Enter **100** for the second moment of inertia about the vertical z-axis (**Izz**) in m^4.

- Enter **100** for the torsional constant (**J**) in m^4.

- Enter **10000** for the shear area for the y-direction (**Asy**) in m^2. The shear deformations have been ignored by setting the shear area to 1000*A in accordance with the *Element Reference Manual*.

- Enter **10000** for the shear area for the z-direction (**Asz**) in m^2.

- Enter **1.25** for the **Eccentricity** in the deck in m. The track is 0.25m above the top surface of the section and the neutral axis is 1.0m from the top of the section. The eccentricity of the deck section neutral axis from the track is therefore 1.25m.

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

The pier geometric properties are now defined in the **Geometric** Properties worksheet. The pier is circular with a diameter of 2.1m. Enter the following values for the deck:

- Enter **2** for the ID in the first column to match the geometric assignment ID for the piers in the **Structure Definition** worksheet.

- Enter **0** for the **Depth of Section** in m. The depth of section is not used for pier assignments, only for deck assignments.

- Select **Pier** from the Component Type list. Pier geometric components are not assigned temperature loadings from the Loading worksheet.

- Enter **3.4636059** for the area (**A**) in m^2.

- Enter **0.9546564** for the second moment of inertia about the horizontal y-axis (**Iyy**) in m^4.

- Enter **0.9546564** for the second moment of inertia about the vertical z-axis (**Izz**) in m^4.

- Enter **1.9006014** for the torsional constant (**J**) in m^4.

- Enter **3463.6059** for the shear area for the y-direction (**Asy**) in m^2 to exclude shear deformations in accordance with the *Element Reference Manual*.

- Enter **3463.6059** for the shear area for the z-direction (**Asz**) in m^2 to exclude shear deformations in accordance with the *Element Reference Manual*.

- Enter **0** for the **Eccentricity** in the pier in m.

- Enter **Pier Cross-Section** in the **Description** for the pier.

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 (**v**).

- 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).

- 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 **36000** for the Young's modulus (**E**) in N/mm^2.

- Enter **0.2** 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 - Concrete** in the **Description** for the material properties.

Enter the following values for the pier:

- Enter **2** for the ID in the first column to match the material assignment ID for the deck in the **Structure Definition** worksheet.

- Enter **36000** for the Young's modulus (**E**) in N/mm^2.

- Enter **0.2** 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 **Pier - Concrete** in the **Description** for the material properties.

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

- Pick the **Interaction and Expansion Joint** worksheet.

- Enter **0.25** for the eccentricity between the rail and slab as the track is 0.25m above the top of the deck.

- Enter **0.5** for the Parametric Distance of Interaction Joint from Rail. For the modelling of the eccentricity between the rail and the slab this will place the interaction joints halfway between the track and slab.

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 u_0 in the bilinear interaction behaviour is equal to 2mm which is the representative value for the resistance of a sleeper in ballast. The resistance k in the

plastic zone for the track is taken as k = 20kN/m which represents the unloaded resistance of sleepers in ballast with good maintenance (from UIC774-3). This gives a stiffness of 20kN/m / 2mm = 10kN/m/mm.

- Enter **20** for the **Unloaded Yield Force** in the longitudinal direction in kN/m. This parameter is equivalent to the resistance in the plastic zone, k.

- Enter **1.0E-6** for the **Unloaded Hardening Stiffness** in the longitudinal direction in kN/m/mm. Zero cannot be entered but a very small hardening stiffness will maintain the force in the interaction joints at the unloaded yield force.

- Enter **30** for the **Loaded Elastic Spring Stiffness** in the longitudinal direction in kN/m/mm. The u_0 in the bilinear interaction behaviour is again equal to 2mm which is the representative value for the resistance of a sleeper in ballast. The resistance k in the plastic zone for the track is taken as k = 60kN/m which represents the resistance of loaded track (from UIC774-3). This gives a stiffness of 60kN/m / 2mm = 30 kN/m/mm.

- 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. Again, zero cannot be entered but a very small hardening stiffness will maintain the force in the interaction joints at the loaded yield force.

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 hardening stiffness should always be set to a very small value to avoid numerical instabilities.

The track includes expansion devices (joints) at each of the abutments, each with an initial gap of 10mm. The details of these are also defined in the **Interaction and Expansion Joint** worksheet.

Enter the following values for the rail expansion joints:

- Enter **1** for the track ID in the first column for the expansion joint in the single track at the left-hand abutment.

- Enter **100** for the **Position** of the expansion joint in Track 1 at the left-hand abutment. All expansion joint positions are defined from the left-hand extent of the model including the embankment. The left-hand approach embankment is 100m in length and therefore the position at the left-hand abutment is equal to 100m.

- Enter **10** for the **Initial Gap** of the expansion joint in Track 1 at the left-hand abutment. This means that it takes 10mm of relative movement of the track ends in the longitudinal direction either side of the expansion joint to close the gap.

- Enter **1** for the track ID in the first column for the expansion joint in the single track at the right-hand abutment.

- Enter **220** for the **Position** of the expansion joint in Track 1 at the right-hand abutment. All expansion joint positions are defined from the left-hand extent of the model including the embankment. The left-hand approach embankment is 100m in length and the structure is 120m in length, therefore the position is equal to 220m.

- Enter **10** for the **Initial Gap** of the expansion joint in Track 1 at the right-hand abutment. This means that it takes 10mm of relative movement of the track ends in the longitudinal direction either side of the expansion joint to close the gap.

Defining the Trainset Loading for the Structure

The analysis includes the effects of three different trainset configurations passing over the structure. Each of these trainset configurations will be defined in a separate Train Loading Group within the **Loading** worksheet. The temperature loading to the tracks and decks is also defined within the **Loading** worksheet.

- Pick the **Loading** worksheet.

The temperature loading will be defined first. Enter the following values for the temperature loading:

- Enter **30** for the **Temperature** variation of the **Concrete Deck** in $^{\circ}$C.

- Enter **50** for the **Temperature** variation of the **Rails** in $^{\circ}$C.

The number of Train Loading Groups to be analysed should be specified. Sometimes this number may not be known until all of the trainsets (combinations of trainsets if there is loading to more than one track) have all been input for a structure but for this example we know that there are three independent trainsets being passed along the single track. There is one in each Train Loading Group, so they are analysed with only one trainset configuration on the structure at any one time but with all trainsets / positions considered from the analysis when we eventually post-process the results of the analysis.

- Enter **3** for the **Number of Train Loading Groups to Analyse** in the train loads section of the worksheet.

Note. If more Train Loading Groups are defined in the worksheet than is specified in the **Number of Train Loading Groups to Analyse** entry of the worksheet the additional definitions above the number will be excluded from the analysis.

For the analysis all three of the trainsets travel from arrival at the left-hand abutment of the structure through to departure at the right-hand abutment of the structure. The configurations / lengths of the trainset loadings for each of the Train Loading Groups is different and therefore separate movement definitions will be required for each of these. The trainset definitions will be entered in the following order: SW/0, SW/2 and HSLM-A1.

SW/0 trainset loading

The SW/0 loading consists of UDLs representing the vertical and braking loads. These will be defined in the worksheet with meaningful names with the origin of the load defined at the centre.

Enter the following values for Train Loading Group 1, the SW/0 loading:

- Enter **5** for the **Number of Track Loading Locations** for the passage of the SW/0 trainset from the left-hand abutment to the right-hand abutment. This is a low value for example purposes and a true analysis would require more locations to fully describe the passage of the trainset loading across the structure.

- Enter **Vertical SW/0 (Left UDL)** for the **Loading Type** in the first row of loading. The type of loading is defined by the first character of the description, thus allowing more detailed descriptions for more complex loading configurations.

- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.

- Enter **-17.65** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the left UDL vertical loading.

- Enter **-2.65** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the left UDL vertical loading.

- Enter **133** for the **Amount (per unit length)** to apply 133kN/m vertically downwards for the left UDL vertical loading.

- Enter **82.35** 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 (locations are defined from the left-hand extent of the model including the embankment). The SW/0 loading is symmetrical about the origin meaning that, with a 100m left-hand embankment, the starting location for the origin of the loading is equal to (100 - 17.65) = 82.35m.

- Enter **237.65** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis (locations are defined from the left-hand extent of the model including the embankment). The SW/0 loading is symmetrical about the origin meaning that, with a 100m left-hand embankment and 120m structure, the finishing location for the origin of the loading is equal to (100 + 120 + 17.65) = 237.65m.

This completes the definition for the left UDL representing the vertical loading of the SW/0 trainset. The braking load for the left-hand loading and vertical plus braking loading for the right-hand part of the SW/0 trainset still needs to be defined.

Enter the following values for Train Loading Group 1, the SW/0 loading:

- Enter **Braking SW/0 (Left UDL)** for the **Loading Type** in the next row of loading.

- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.

- Enter **-17.65** again for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the left UDL braking loading (which should be placed over the same extents as the vertical loading).

- Enter **-2.65** again for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the left UDL braking loading (which should be placed over the same extents as the vertical loading).

- Enter **20** for the **Amount (per unit length)** to apply 20kN/m horizontal braking forces acting to the right for the SW/0 trainset moving from left to right.

- Enter **82.35** again 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.

- Enter **237.65** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis.

- Enter **Vertical SW/0 (Right UDL)** for the **Loading Type** in the next row of loading.

- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.

- Enter **2.65** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the right UDL vertical loading.

- Enter **17.65** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the right UDL vertical loading.

- Enter **133** for the **Amount (per unit length)** to apply 133kN/m vertically downwards for the right UDL vertical loading.

- Enter **82.35** again 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.

- Enter **237.65** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis.

- Enter **Braking SW/0 (Right UDL)** for the **Loading Type** in the next row of loading.

- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.

- Enter **2.65** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the right UDL braking loading.

- Enter **17.65** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the right UDL braking loading.

- Enter **20** for the **Amount (per unit length)** to apply 20kN/m horizontal braking forces acting to the right for the SW/0 trainset moving from left to right.

- Enter **82.35** again 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.

- Enter **237.65** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis.

This completes the definition for the SW/0 trainset loading in Train Loading Group 1. The trainset loading definitions of the remaining two Train Loading Groups still needs to be defined and is detailed below.

SW/2 trainset loading

The SW/2 trainset loading has a very similar layout (albeit with different dimensions) to the SW/0 trainset loading defined above and therefore the input for the SW/2 trainset is detailed below without further explanation.

Enter the following values for Train Loading Group 2, the SW/2 loading:

- Enter **5** for the **Number of Track Loading Locations** for the passage of the SW/2 trainset from the left-hand abutment to the right-hand abutment. This is a low value for example purposes and a true analysis would require more locations to fully describe the passage of the trainset loading across the structure.

- Enter **Vertical SW/2 (Left UDL)** 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 **-28.5** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the left UDL vertical loading.

- Enter **-3.5** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the left UDL vertical loading.

- Enter **150** for the **Amount (per unit length)** to apply 150kN/m vertically downwards for the left UDL vertical loading.

- Enter **71.5** 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 (locations are defined from the left-hand extent of the model including the embankment).

- Enter **248.5** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis (locations are defined from the left-hand extent of the model including the embankment).

- Enter **Braking SW/2 (Left UDL)** for the **Loading Type** in the next row of loading.

- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.

- Enter **-28.5** again for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the left UDL braking loading (which should be placed over the same extents as the vertical loading).

- Enter **-3.5** again for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the left UDL braking loading (which should be placed over the same extents as the vertical loading).

- Enter **35** for the **Amount (per unit length)** to apply 35kN/m horizontal braking forces acting to the right for the SW/2 trainset moving from left to right.

- Enter **71.5** again 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.

- Enter **248.5** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis.

- Enter **Vertical SW/2 (Right UDL)** for the **Loading Type** in the next row of loading.

- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.

- Enter **3.5** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the right UDL vertical loading.

- Enter **28.5** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the right UDL vertical loading.

- Enter **150** for the **Amount (per unit length)** to apply 150kN/m vertically downwards for the right UDL vertical loading.

- Enter **71.5** again 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.

- Enter **248.5** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis.

- Enter **Braking SW/2 (Right UDL)** for the **Loading Type** in the next row of loading.

- Enter **1** in the **Track Selection to be Loaded** since there is only a single track in the analysis.

- Enter **3.5** for the **Parametric Starting Position for Loadings** (in m) to indicate the left-hand limit of the right UDL braking loading.

- Enter **28.5** for the **Parametric End Position for Loadings** (in m) to indicate the right-hand limit of the right UDL braking loading.

- Enter **35** for the **Amount (per unit length)** to apply 35kN/m horizontal braking forces acting to the right for the SW/0 trainset moving from left to right.

- Enter **71.5** again 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.

- Enter **248.5** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis.

This completes the definition for the SW/2 trainset loading in Train Loading Group 2

HSLM-A1 trainset loading

The final Train Loading Group is for the HSLM-A1 trainset which is a much more complex trainset configuration involving multiple concentrated loads.

Note. The loading input for the track-structure interaction analysis takes the form of UDLs but a concentrated load can be approximated, especially with the scale of the modelling, by a UDL over a small contact length. This is used to model the concentrated loads which define the HSLM-A1 trainset configuration. For the definition of each of the concentrated loads a contact length of 0.01m is used to convert the concentrated load into an equivalent UDL. This means that the 170kN concentrated load becomes a 17000kN/m UDL applied to this 0.01m contact length.

The HSLM-A1 trainset configuration consists of 50 concentrated loads which each need to be defined in Train Loading Group 3. To define each of these manually would

be a long process and therefore a separate Microsoft Excel spreadsheet is provided which includes the definition of the HSLM-A1 trainset using this equivalent UDL approach with the origin of the loading at the centre of the trainset definition.

Note. For a list of assumptions made in defining HSLM-A1 trainset loading (as used to define values in the supplied spreadsheet for use with this example) please see Appendix B of the Rail Track Analysis User Manual. Assumptions made to derive values in this supplied spreadsheet need to be considered for each project individually, and the supplied spreadsheet should not be used as-is without checking the data within it is suitable for use on your project.

- Load the **HSLM-A1.xlsx** spreadsheet if using Microsoft Excel 2007 and above or the **HSLM-A1.xls** spreadsheet if you are using an older version of Microsoft Excel.

- Select all of the braking load definition for the HSLM-A1 trainset as indicated below and copy it to the clipboard.

A13 · *fx* Vertical (Left power car axle 1)

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

HSLM-A1

A13 · *fx* Vertical (Left power car axle 1)

	A	B	C	D	E
37	Vertical (Int. coach 9 axle 2)	TrackID	-1.005	-0.995	17000
38	Vertical (Int. coach 10 axle 1)	TrackID	0.995	1.005	17000
39	Vertical (Int. coach 10 axle 2)	TrackID	16.995	17.005	17000
40	Vertical (Int. coach 11 axle 1)	TrackID	18.995	19.005	17000
41	Vertical (Int. coach 11 axle 2)	TrackID	34.995	35.005	17000
42	Vertical (Int. coach 12 axle 1)	TrackID	36.995	37.005	17000
43	Vertical (Int. coach 12 axle 2)	TrackID	52.995	53.005	17000
44	Vertical (Int. coach 13 axle 1)	TrackID	54.995	55.005	17000
45	Vertical (Int. coach 13 axle 2)	TrackID	70.995	71.005	17000
46	Vertical (Int. coach 14 axle 1)	TrackID	72.995	73.005	17000
47	Vertical (Int. coach 14 axle 2)	TrackID	88.995	89.005	17000
48	Vertical (Int. coach 15 axle 1)	TrackID	90.995	91.005	17000
49	Vertical (Int. coach 15 axle 2)	TrackID	106.995	107.005	17000
50	Vertical (Int. coach 16 axle 1)	TrackID	108.995	109.005	17000
51	Vertical (Int. coach 16 axle 2)	TrackID	124.995	125.005	17000
52	Vertical (Int. coach 17 axle 1)	TrackID	126.995	127.005	17000
53	Vertical (Int. coach 17 axle 2)	TrackID	142.995	143.005	17000
54	Vertical (Int. coach 18 axle 1)	TrackID	144.995	145.005	17000
55	Vertical (Int. coach 18 axle 2)	TrackID	160.995	161.005	17000
56	Vertical (Right end coach axle 1)	TrackID	162.995	163.005	17000
57	Vertical (Right end coach axle 2)	TrackID	176.2325	176.2425	17000
58	Vertical (Right end coach axle 3)	TrackID	178.2325	178.2425	17000
59	Vertical (Right power car axle 1)	TrackID	181.7575	181.7675	17000
60	Vertical (Right power car axle 2)	TrackID	184.7575	184.7675	17000
61	Vertical (Right power car axle 3)	TrackID	195.7575	195.7675	17000
62	Vertical (Right power car axle 4)	TrackID	198.7575	198.7675	17000
63	Braking	TrackID	-198.7625	198.7625	15.093390352
64					
65	Braking load UDL has been factored as total load over the 397.525 m trainset is 7950.5 kN (> 6000 kN limit for default UDL)				
66	Braking load UDL reduced to = 15.093390352808 kN/m				
67					
68					
69					
70	ACCELERATING HSLM-A1 TRAIN				
71	Vertical (Left power car axle 1)	TrackID	-198.7675	-198.7575	17000
72	Vertical (Left power car axle 2)	TrackID	-195.7675	-195.7575	17000

HSLM-A1

- Select the **Loading Type** cell in the first row of the definition of Train Loading Group 3 and choose **Paste Values** to paste all of the HSLM-A1 concentrated loads and braking loads.

The full definition of the HSLM-A1 trainset has been pasted into Train Loading Group 3 with the **Track Selection to be Loaded** set to **TrackID** to indicate that this should be changed. For other models with more than one track this could be set to a track other than Track 1 but for this example we only have a single track.

- For all of the rows of data change the **TrackID** to **1** to apply the HSLM-A1 trainset to the single track in the model.

Enter the following values for the remaining definition of the HSLM-A1 trainset:

- Enter **5** for the **Number of Track Loading Locations** for the passage of the HSLM-A1 trainset from the left-hand abutment to the right-hand abutment. This is a low value for example purposes and a true analysis would require more locations to fully describe the passage of the trainset loading across the structure.

- Enter **-98.7675** in the first row 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 (locations are defined from the left-hand extent of the model including the embankment). The HSLM-A1 trainset has a total length of 397.535m, 198.7675m either side of the origin, and accounting for the 100m long left-hand approach embankment to the left-hand abutment, a value of (100 - 198.7675) = -98.7675m will place the front of the HSLM-A1 trainset at the left-hand abutment.

- Enter **418.7675** for the **Finishing Location of Loading for Last Analysis** to place the trainset in a location where it has just departed from the deck structure at the right-hand abutment for the last analysis (locations are defined from the left-hand extent of the model including the embankment). As above, the right-hand abutment location is the sum of the length of the left-hand approach embankment (100m) and the length of the structure (120m) and equal to 220m. The original of the HSLM-A1 train needs to be placed 198.7675m further on from the right-hand abutment giving a value of (100 + 120 + 198.7675) = 418.7675m.

- Select and copy the **Starting Location of Loading for First Analysis** and **Finishing Location of Loading for Last Analysis** entered in the first row.

- Select the **Starting Location of Loading for First Analysis** and **Finishing Location of Loading for Last Analysis** cells from rows 16 to 65 in the worksheet and **Paste Values** to paste the locations into all of the rows defining the HSLM-A1 trainset.

- **Save** the spreadsheet and close the Microsoft Excel application.

Note. The loading for the HSLM-A1 trainset (Train Loading Group 3) is a total of 397.535m long which is greater than the approach embankment lengths of 100m and also greater than the overall model length of 320m. As a consequence of this some proportion of the trainset loading will always be outside the extents of the model for any positioning of the trainset. Loading outside the extents of the model will be ignored in the analyses and a warning will be displayed when the trainset loading is being applied to the model. This is illustrated in the images that follow, which show the positioning of the HSLM-A1 trainset for the first three analysis locations.

Scale: 1: 874.174
Zoom: 100.0
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Train Loading Group 3 - Position 1
Loadcase: 22:Train Loading Group 3 - Position 1 - Train Loads, 2:Increment 2 Load Factor = 1.00000
Results file: RTA_Example2~Train Loading Group 3 - Position 1.mys

Left-hand Abutment   Right-hand Abutment

Scale: 1: 874.174
Zoom: 100.0
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Train Loading Group 3 - Position 2
Loadcase: 24:Train Loading Group 3 - Position 2 - Train Loads, 2:Increment 2 Load Factor = 1.00000
Results file: RTA_Example2~Train Loading Group 3 - Position 2.mys
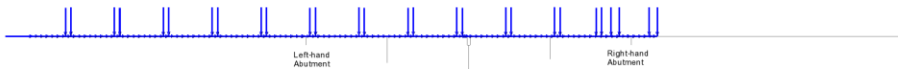
Left-hand Abutment   Right-hand Abutment

Scale: 1: 874.174
Zoom: 100.0
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Train Loading Group 3 - Position 3
Loadcase: 26:Train Loading Group 3 - Position 3 - Train Loads, 2:Increment 2 Load Factor = 1.00000
Results file: RTA_Example2~Train Loading Group 3 - Position 3.mys

Left-hand Abutment   Right-hand Abutment
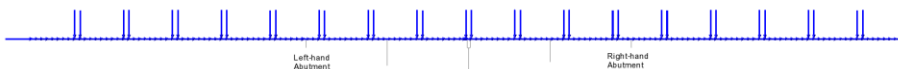
This completes the definition of the Microsoft Excel spreadsheet input for track-structure-interaction problem.

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 the Combined Temperature and Rail Load 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 in different input spreadsheets (see the *Rail Track-Structure Interaction to UIC774-3* worked example). If Train Loading Groups are not used then this could be the approach to follow for the current analysis but since we are including three Train Loading Groups (1 = SW/0 loading, 2 = SW/2 loading and 3 = HSLM-A1 loading) we can generate the combined temperature and rail loading model for this example.

File
New…

- Enter **RTA_BlankModel** for the model name.

- Select an analysis category of **3D** and click **OK**.

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

Bridge
Rail Track Analysis
UIC774-3 >
Build Model…

- Enter a model filename of **RTA_Example2**

- Enter the filename of the Microsoft Excel spreadsheet you created which contains the definition of the track-structure-interaction model and the loading to be applied in the Rail Track Analysis (e.g. **RTA_2DeckBearingOffset_3TLG.xlsx**) or browse for it using the **Browse...** button in the Microsoft Excel spreadsheet. If the full folder information is not entered it will be assumed that the Microsoft Excel spreadsheet is in the current working folder which is reported in the dialog.
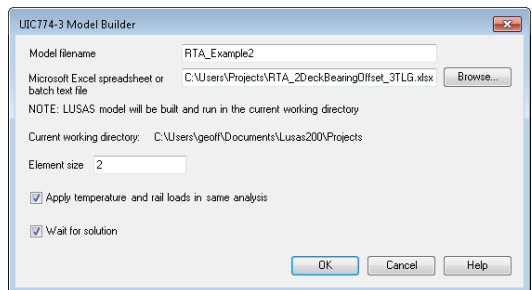
- If wanting to build the model from a supplied spreadsheet, select the file **RTA_2DeckBearingOffset_3TLG.xlsx** that was downloaded and placed in a folder of your choosing.

- Ensure an Element size of **2** is specified which will create elements of a maximum length of 2m in the LUSAS model.

- Ensure that the **Apply temperature and rail loads in same analysis** option is selected.

- Ensure the **Wait for solution option** is selected and click the **OK** button.

- Click **Yes** when the dialog below pops up warning that loading has been defined which is outside the extent of the model. The HSLM-A1 trainset is almost 400m long and therefore an equivalent embankment length would be required to accommodate the whole trainset as it approaches and departs from the structure. In the model embankments of only 100m have been used with an overall model length of 320m including the structure and therefore the load outside the extents of the model will be ignored for HSLM-A1 trainset loading that is not fully within a model.
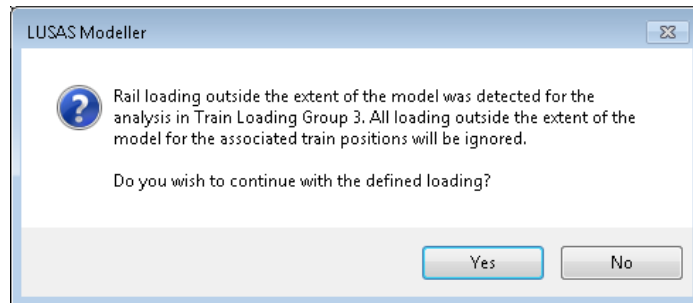
Assuming that there have been no errors in the input for the Microsoft Excel spreadsheet the Rail Track Analysis software option will automatically generate a LUSAS model from the spreadsheet data and run a rail track analysis for the combined temperature and rail loading.

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.

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.

❑ **RTA_2DeckBearingOffset_3TLG.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

When the results are loaded after carrying out the Rail Track Analysis the 🕒 Treeview will be populated with all of the positions for each of the Train Loading Groups with each as a separate analysis as indicated in the following figure.

Automatic Extraction of Results into Microsoft Excel

The Rail Track Analysis option provides a post-processing tool that automatically extracts the results of all of the analyses (all positions of all Train Loading Groups) 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…
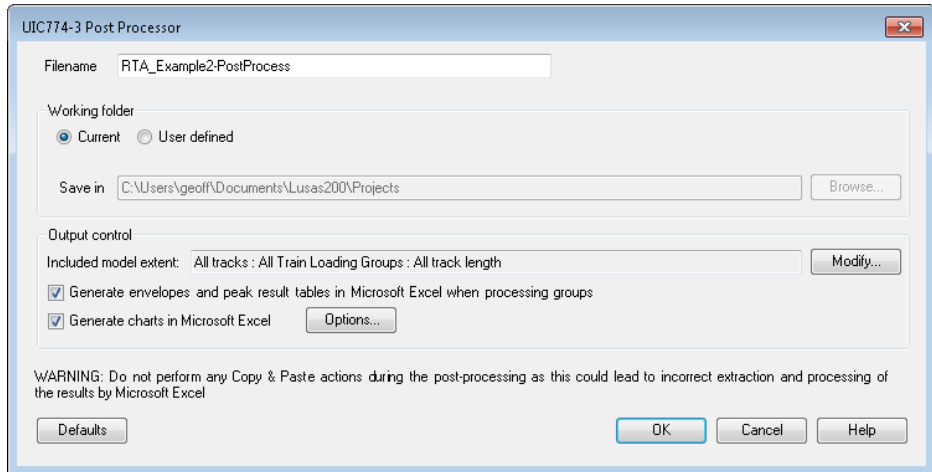
- Enter **RTA_Example2-PostProcess** for the **Filename**. Note that no *.xlsx or *.xls extension is required.

- Ensure the **Working folder** is set to **Current** to place the post-processing Microsoft Excel spreadsheet into the same folder as the analyses.

- 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 in Microsoft Excel when processing groups** option is selected.

- Ensure the **Output Control** is reporting that the **Generate charts in Microsoft Excel** 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.

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.

The automatic Rail Track Analysis post-processor will now extract the results from the loaded analyses 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 **RTA_Example2-PostProcess** in Microsoft Excel.

Since the creation of envelopes was specified earlier the results spreadsheet will contain eleven 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**
❑ **Deck Long. Gap Check-Axial**
❑ **Deck Long. Gap Check-End Rot.**
❑ **Deck Long. Gap Check-Total**
❑ **Deck Vertical Gaps Check**
❑ **Longitudinal Reactions Check**
❑ **Rail Stresses Check**

The enveloping in the **Envelope – Track 1** and **Envelope – Decks** will be over the analyses of all of the Train Loading Groups and their respective positions.

The **Deck Long. Gap Check-Axial**, **Deck Long. Gap Check-End Rot.**, **Deck Long. Gap Check-Total** and **Deck Vertical Gaps Check** are additional tables of peak results required by UIC774-3 which are present because there is more than one deck in the analysis (the example which replicates the UIC774-3 E1-3 and E4-6 fundamental tests only had a single deck and therefore these results were not available). The **Deck Long. Gap Check** worksheets list the peak gap opening and closing in the longitudinal direction between the ends of neighbouring decks or the abutment for axial effects, end rotation effects and total combined effects of the two. Similarly, the **Deck Vertical Gaps Check** worksheet lists the peak vertical movement between the ends of neighbouring decks or the abutment.

Overall Displacement and Stress Behaviour of Railtrack

The overall behaviour of the track-structure model can be inspected through the **Track 1** and **Decks** worksheets which provide the raw data from the analyses along with summary tables and useful charts.

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

For each Train Loading Group and associated position the worksheet will contain the results for the temperature effects alone and also the combined temperature and rail loading as indicated below for position 1 of Train Loading Group 1 (SW/0 loading). The summary table at the top provides key information such as the peak displacements of the track, the peak relative railbed displacements, the forces and moments in the track and the axial stresses in the track for each set of results.
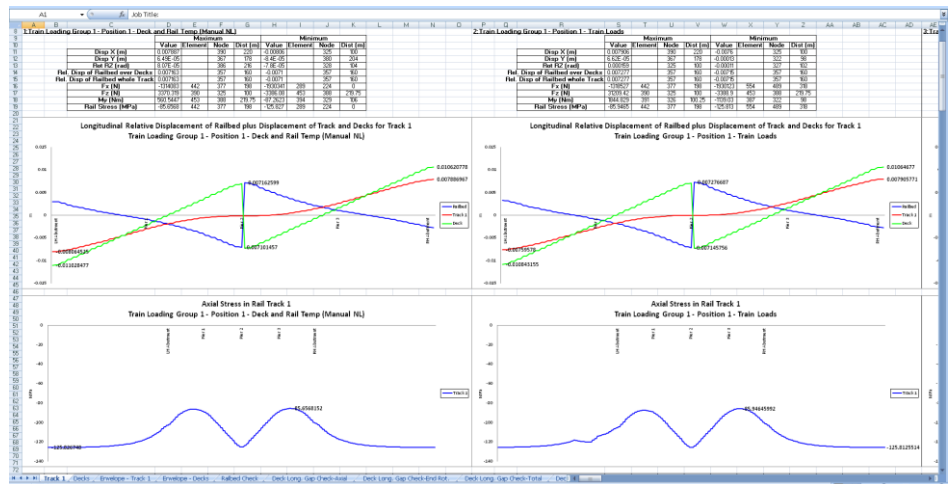
The displacement chart overlays the longitudinal displacement results of the track (in red) and the deck (in green) with the relative railbed displacement occurring from these also displayed (in blue). Large discontinuities (jumps) observed in these deck and relative railbed displacement results correlate with the discontinuities of decks in the structure. Discontinuities may also be seen in the results of the track longitudinal displacements for some analyses if expansion joints are present within the length of the structure (this is not the case for this model, the expansion joints are at the left-hand and right-hand abutments).

The rail axial stress chart shows the rail stresses observed in the railtrack over the full extent of the model. Should the model include more than one track then an additional chart displaying the rail stresses for all tracks may also be shown.

Similar raw results and charts are contained in the **Decks** worksheet which provides displacements, forces and moments for the members of the decks.

In addition to the raw results of the track-structure-interaction analyses, because of the selection to generate envelopes earlier this also makes the post-processor evaluate and report similar enveloped results over all of the Train Loading Groups and positions. 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.

The summaries and charts are displayed for the **Envelope – Temperature and Train (Max)** and **Envelope – Temperature and Train (Min)** results in the following image.

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

Within the summary tables and charts, it indicates that the maximum positive relative railbed displacement observed over all Train Loading Groups is +0.009839m (or 9.839mm) and the minimum negative relative railbed displacement is -0.00762m (or -7.62mm), an absolute maximum value of 0.009839m. Similarly, the most tensile axial rail stress is -73.3446 MPa and the most compressive axial rail stress is -138.207 MPa. These results will be revisited later on through the tables of peak results.

Peak Relative Railbed Displacement

The previous section obtained the peak relative railbed displacements over all Train Loading Groups and positions. The post-processor also provides tabular peak results for each of the Train Loading Groups and positions in the **Railbed Check** worksheet.

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

The table indicates from the highlighted row that the absolute maximum value of relative railbed displacement occurs in Train Loading Group 2 when the SW/2 loading is at the second position. The value of the relative railbed displacement is +0.009839m (+9.839mm) which occurs 60m from the left end of the structure, which is at Pier 2, the pier that supports both deck 1 and 2. This value agrees with the value reported in the summary table previously but also tells us the precise trainset loading configuration and positioning of that trainset which causes the worst case along with a better description of where the peak is occurring.

Peak Longitudinal Displacements Between Deck Ends / Abutments

The movement / opening and closing of gaps between the ends of decks / abutments needs to be considered within UIC774-3 and to assist with this the post-processor automatically calculates these quantities if enveloping has been selected in the post-processing.

Results are provided for axial effects alone in the **Deck Long. Gap Check-Axial** worksheet, end rotation effects alone in the **Deck Long. Gap Check-End Rot.** worksheet and total (combined) effects of both axial and end rotation in the **Deck Long. Gap Check-Total** worksheet. For this example, we are only looking at the total (combined) effects.

- Click on the **Deck Long. Gap Check-Total** worksheet tab.

The table indicates from the highlighted row that the absolute maximum value of deck end gap movement is -0.0175m (-17.5mm) closure of the gap between decks 1 and 2 at Pier 2 in Train Loading Group 2 when the SW/2 loading is at the second position.

Peak Longitudinal Reactions at the Piers and Abutments

The intermediate piers for each deck provide all of the longitudinal restraint to each of the decks of the structure and the peak longitudinal reactions at these piers 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 table indicates from the highlighted row that the absolute maximum value of longitudinal reaction is -1078553.346N (or -1.07855MN) at Pier 3 (the intermediate pier in Deck 2) in Train Loading Group 2 when the SW/2 loading is at the third position.

> 📝 **Note.** Should the reactions at any other support / Train Loading Group / position be required from the analysis rather than just the peak values shown in the table then these can simply be obtained through normal post-processing methods in Modeller. This is illustrated below for "Train Loading Group 2 – Position 3" which shows an identical result of -1.07855E6 N for Pier 3 along with the reactions for the remaining piers and the abutments.
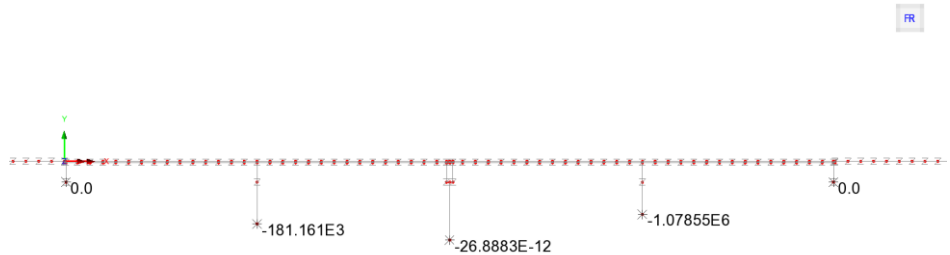
Peak Axial Rail Stresses

The peak axial rail stresses were previously obtained from the raw results in the **Envelope - Track 1** worksheet tab which gave the most tensile axial rail stress is -73.3446 MPa and the most compressive axial rail stress is -138.207 MPa. In addition to the raw envelope results in this worksheet tab the post-processor also generates tables of the peak axial rail stresses for each of the Train Loading Groups and positions.

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

The table indicates from the highlighted row that the most tensile and most compressive axial rail stresses both occur for Train Loading Group 2 when the SW/2 loading is at the second position.

Zooming into the results columns (for clarity) it shows that the most tensile axial rail stress is -73.3446MPa which occurs at the left-hand abutment and the most compressive axial rail stress is -138.207MPa which occurs within Deck 1. These results were observed previously in the summary tables and charts for the **Envelope - Track 1** worksheet tab.

These values agree with the values reported previously in the enveloping summary table for Track 1 and also provide the precise trainset loading configuration and positioning that caused the worst tensile and worst compressive axial stress in the rails along with a description of the locations of where these peaks occurred.

- Close the Microsoft Excel application.

Viewing Results for a Single Train Loading Group

The post-processing that was carried out looked at the behaviour of the model for all three Train Loading Groups that were analysed. If we wished to only generate the output Microsoft Excel spreadsheet for a limited set of Train Loading Groups (or possibly limited tracks / track length for another model) the extent of the model to be post-processed can be adjusted using the additional output controls available on the post-processor dialog – for full details of how to use all of the facilities within the post-processor, please see the Rail Track User Manual.

For this example, we will demonstrate the basic use of these facilities to post-process the Train Loading Group which gave the worst effects, Train Loading Group 2 which represented the SW/2 loading.

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

UIC774-3 Post Processor

Filename   RTA_Example2-PostProcessTLG2

Working folder
◉ Current   ○ User defined

Save in   C:\Users\geoff\Documents\Lusas200\Projects   Browse...

Output control

Included model extent: All tracks : Train Loading Groups [2] : All track length   Modify...

☑ Generate envelopes and peak result tables in Microsoft Excel when processing groups

☑ Generate charts in Microsoft Excel   Options...

WARNING: Do not perform any Copy & Paste actions during the post-processing as this could lead to incorrect extraction and processing of the results by Microsoft Excel

Defaults   OK   Cancel   Help

- Enter **RTA_Example2-PostProcessTLG2** 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.

- Click the **Modify…** button in the **Output control** to change the **Included model extent** from the current selection.

- In the **Modify Included Output** dialog, deselect the **All Train Loading Groups** option.

- Ensure that only **Train Loading Group 2** is selected in the list as shown in the image below.

- Click **OK** button on the **Modify Included Output** dialog to update the included model extent.

- Click the **OK** button on the **UIC774-3 Post Processor** dialog.
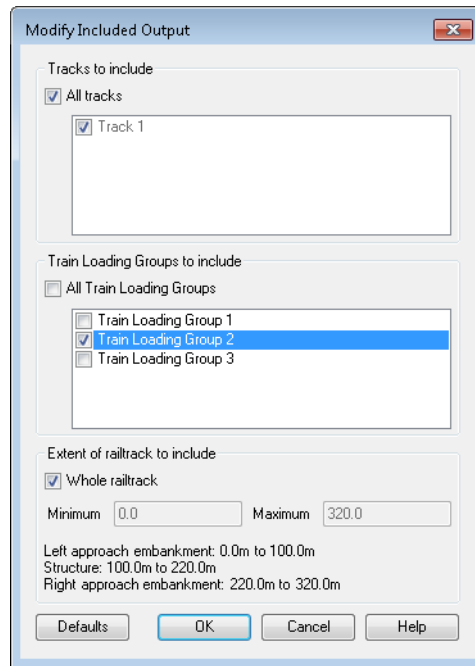
The automatic Rail Track Analysis post-processor will now extract the results from just Train Loading Group 2 (the SW/2 loading) into the output Microsoft Excel spreadsheet.

Identical results worksheets (Tracks, Decks, Envelopes of Tracks/Decks, Railbed Check, etc) will be generated in the Microsoft Excel spreadsheet that is created from the post-processor when the output extent is modified but the restriction of the post-processing could mean that peak results / the most onerous behaviours of output quantities are missed in the post-processing as a result of the restricted post-processing. As a result, warning messages will be issued in the Microsoft Excel spreadsheet when post-processing of the whole model is not carried out.

In the worksheet for the track results shown in the next image the following warning has been placed at the top of the results:

"Warning: Only selected Train Loading Groups were included in the results. Exclusion of results could lead to peak behaviours being missed and more critical conditions being excluded from the design process"

An identical warning is also placed at the top of the worksheet for the deck results and also at the top of the worksheets for the enveloped track and deck results.
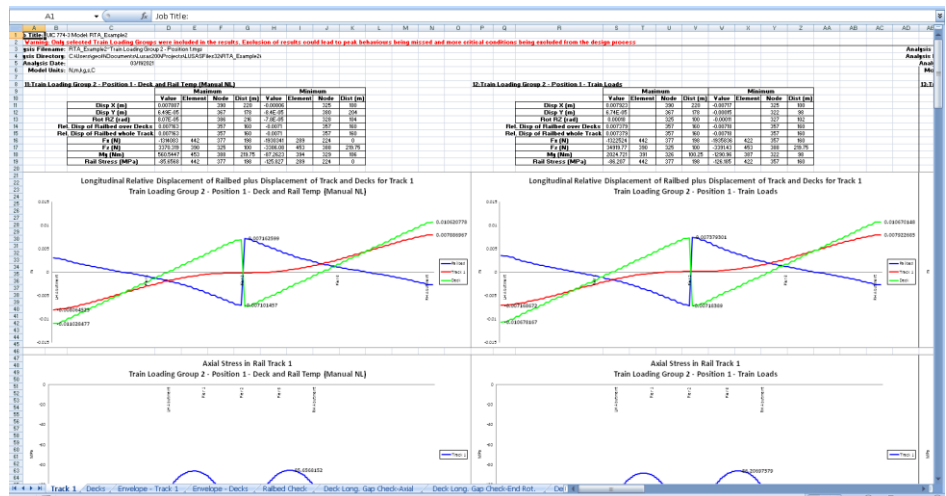
The table of longitudinal relative displacement of the railbed that is created as part of the enveloping is shown in the following image. The restriction of the Train Loading Groups to just the second Train Loading Group is shown from the list of result filenames included (RTA_Example2~Train Loading Group 2 - Position 1.mys to RTA_Example2~Train Loading Group 2 - Position 6.mys). A warning message has also been added to the bottom of the table as follows due to the restricted post-processing of the track-structure-interaction analysis:

"Warning: Only selected Train Loading Groups were included in the main results, enveloping and the table above. Exclusion of Train Loading Groups could result in peak behaviours from excluded results being missed and more critical conditions being excluded from the design process"

For these longitudinal relative displacement of the railbed results we have previously carried out a "whole model" post-processing and we can therefore ignore this warning. Comparison of the railbed displacement result of +0.009839m (+9.839mm) from the post-processing of Train Loading Group 2 alone shows that this exactly matches the value of +0.009839m (+9.839mm) obtained when the whole model was post-processed, as expected.

Inspection of the remaining worksheets of the post-processing will show similar warning messages and result comparisons. Choosing alternative forms of output restriction using the **Modify Included Output** dialog will allow different parts of the track-structure-interaction analysis to be post-processed and will also lead to different warning messages being issued to the Microsoft Excel result spreadsheets.

Note. Ultimately it is the responsibility of the analyst to ensure that peak / most onerous behaviours are not missed when restricting the post-processing of a track-structure-interaction analysis.

- Close the Microsoft Excel application.

File
Close

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

This completes the example.

A brief discussion follows on the effect of the length of the approach embankments on the accuracy of the modelling.

Effect of Approach Embankment Length on Peak Axial Rail Stresses

Within UIC774-3 it recommends that the minimum approach embankment length for modelling of track-structure-interaction analyses is 100m. This minimum has been used in this example and from inspection of the axial rail stresses at the extremes of the model the axial stresses are equal to -125.826748MPa.

From the temperature behaviour of a restrained bar, it can be calculated that, with a coefficient of thermal expansion for the track of 1.2E-5, the target compressive stress in the track alone under thermal loading would be -126 MPa.

The axial stress achieved away from the structure is marginally lower than this target value but still within an acceptable tolerance of this target value. If, however, the approach embankments were extended to be 300m the axial rail stresses at the extremes of the model become -125.9999975MPa or -126MPa which is exactly equal to the target of -126MPa calculated above. This is shown in the image below.

The Railtrack Analysis Tool will allow approach embankments to be defined which are shorter than the 100m recommended but it is up to the user to establish whether these shorter approach embankments are sufficient for accurate modelling of the track-structure-interaction analysis. Generally, the 100m limit should be observed as indicated in the following image where the analysis has been performed with only a 50m approach embankment. In this the axial rail stresses at the extremes of the model are only -123.19862MPa which is not sufficiently close to the target of -126MPa.