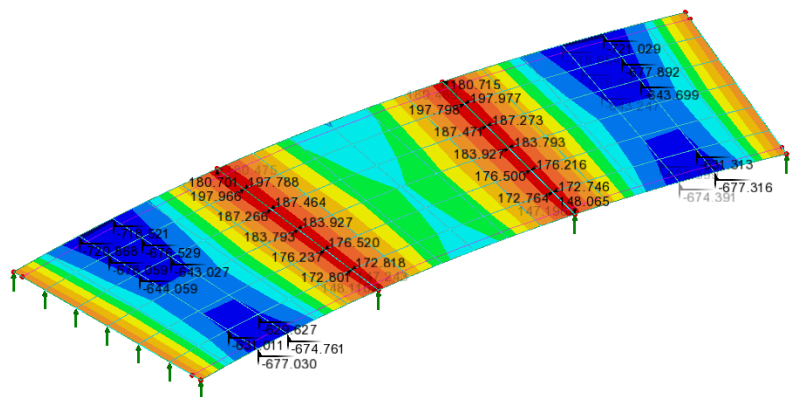# Bridge Slab Traffic Load Optimisation (DMI Envelope Method)

For LUSAS version:	23.0
For software product(s):	LUSAS *Bridge* and LUSAS *Bridge Plus*
With product option(s):	Vehicle Load Optimisation.

Description

This example uses the LUSAS Vehicle Load Optimisation (VLO) software option and the Direct Method Influence Envelope method to aid in the linear static analysis of a 3-span curved concrete bridge deck subject to Eurocode traffic loading.

The structure is modelled using thick plate elements, representing a deck of inner radius 75m, outer radius 86m and thickness 0.7m. The deck has a width of 11m consisting of a 10m wide carriageway region and two 0.5m wide verges. The live loading is to be calculated for three defined influence surfaces using the LUSAS VLO software option.

Units used ar**e** kN, m, t, s, C throughout.

Note. LUSAS VLO is a software option for LUSAS *Bridge*. It extends the vehicle loading capabilities in LUSAS *Bridge* and produces worst-case traffic load effects more easily and much faster than by manual methods. LUSAS VLO generates the most onerous traffic load patterns according to a selected code of practice, based upon influence surfaces for specified load effects (moments, shears, reactions, stresses etc) at selected locations in the structure. A number of Eurocode National Annexes and other codes are supported. This example analyses a bridge deck using EN1991-2 Recommended Values. Subsequent analysis for comparison purposes is carried out using the UK and Swedish National Annex options.

Note. The Direct Method Influence Envelope mode as used in this example provides an optimised load effect of interest (e.g. My) at all locations in a feature (a line or surface) for which the Influence Envelope attribute has been assigned, and optionally for coexistent load effects (e.g. Fx, Fy, Fz, Mx, Mz) at those assigned locations.

Note. A separate example titled "Bridge Slab Traffic Load Optimisation (Reciprocal Method) method provides less functionality than the Direct Method, but it is faster when only a limited number of influences are required at strategic locations on a bridge deck.

Keywords

2D, Plate, Slab, Modelling, Eurocode, Element Axes, Influence Surface, Direct Method, DMI, Envelope, VLO, Vehicle Load Optimisation, Load Combination, Bending Moments, Reactions, Transformed Results, Peak Values

Associated Files

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

❑ **vlo_deck_dmi_env.lvb** carries out the modelling of the slab deck for use by this example.

Vehicle load optimisation in LUSAS

Vehicle load optimisation (VLO) makes use of influence surfaces and influence analysis to identify the most onerous vehicle loading patterns on bridges for a chosen design code and to apply these loading patterns to LUSAS models. A vehicle load optimisation wizard provides the means of defining parameters, for a particular design code, to generate the most critical traffic loading pattern for each influence shape under

consideration. In this example, the bridge deck is loaded according to EN1991-2 Recommended Values.
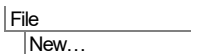
Modelling

Running LUSAS Modeller

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

Creating a Model

Units used ar**e** kN, m, t, s, C throughout.

| File |
| New… |

- Enter a file name of **vlo_deck_dmi_env**

- Use the default **User-defined** working folder.

- Ensure an Analysis type of **3D** is set.

- Click the **OK** button.

Note. There is no need to enter any other new model details when the intention is to run a script to build an initial model, since the contents of the script will overwrite any other settings made.
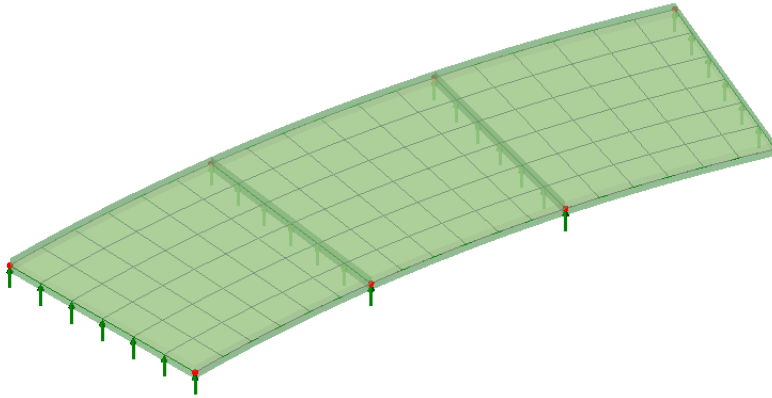
| File |
| Script > |
| Run Script… |
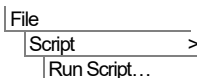
- To create the model, open the read-only file **vlo_deck_dmi_env.lvb** that was downloaded and placed in a folder of your choosing.

The full 3-span model of the bridge deck will be created.

Turn on the isometric view to see the model as shown.

The structure is modelled using thick plate elements, representing a deck of inner radius 75m, outer radius 86m and thickness 0.7m. The deck has a width of 11m consisting of a 10m wide carriageway region and two 0.5m wide verges. The live loading is to be calculated for whole structure the LUSAS VLO software option.

Self-Weight

- With the whole model selected, drag and drop the loading dataset **BFP1 (Gravity – vertical)** from the 🔵 Treeview onto the selected features. Ensure the **Assign to surfaces** option is selected and click **OK** to assign to **Analysis 1**, **Loadcase 1**.

The gravity loading will be visualised on the model.
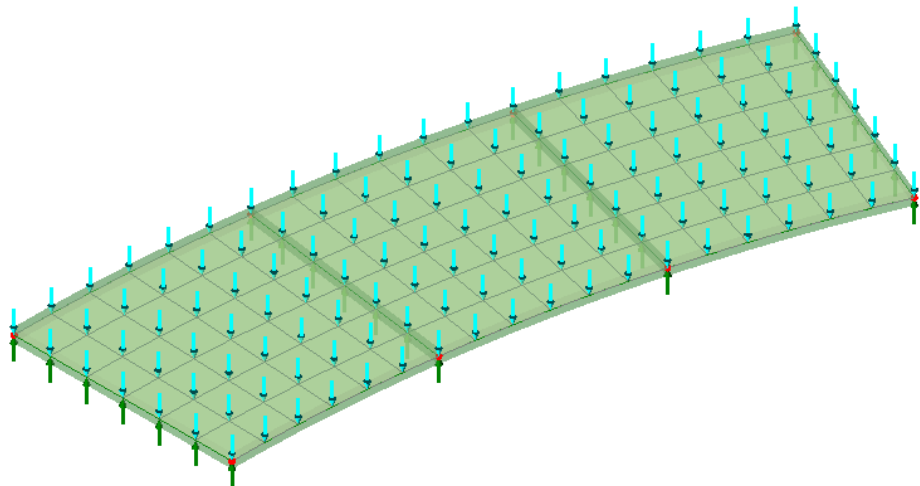
- In the 🕑 Treeview, using the right-hand mouse button, select **Loadcase 1** and select the **Rename** option. Change the loadcase name to **Self Weight**

Local coordinate system

Since this model is a curved deck a cylindrical local coordinate system is used for the direction definition. Specifying a direction definition sets the vertical, longitudinal and transverse axes for a model to assist with model orientation and the calculation of particular effects. A local direction definition is used for aligning influence attributes along a singly curved bridge deck.

Attributes
Local Coordinate…

- Select the **Cylindrical** option and ensure that the **Z-axis** option is set. Enter a dataset name of **Cylindrical about Z-axis** and click **OK**

To use this local coordinate system:

Tools
Direction definition…

- In the Longitudinal section of the dialog set the **Local axis** to be **Cylindrical about Z-axis** for **Theta** and click **OK**.

Influence Attributes

In order to use the vehicle load optimisation facility, it is necessary to define and assign influence attributes to the model. LUSAS generates influence surfaces for each of the chosen locations and load effects. In this example the Direct Method Influence Envelope attribute method is used. A separate example shows the use of Reciprocal method influence attributes that are also available and provide different capabilities.

To make it easier to select the nodes required to define the influence parameters the geometric and load visualisation will be removed from the display.

Select the fleshing on/off button to turn-off the geometric visualisation.

Select the loading on/off button to turn-off the loading visualisation.

For this example, two influence attributes will be defined.

Influence Definition

For the spans

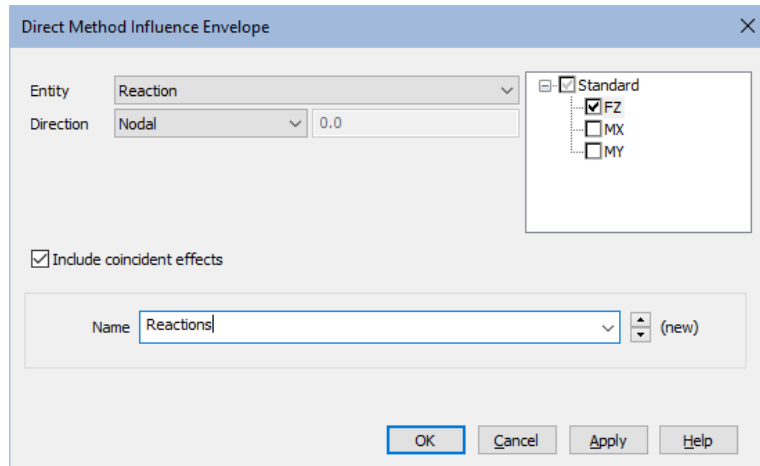| Attributes	
Influence	>
Envelope...	

- Select an entity of **Force/Moment – Thick Plate** and because we wish to obtain results appropriate for the curved deck, set an influence direction of **Local Coords**, **Cylindrical about Z-axis**, **r/theta**. Then, in the adjacent panel, select **Standard** to select all the results components listed. Change the name to be **Forces** and click **Apply**.
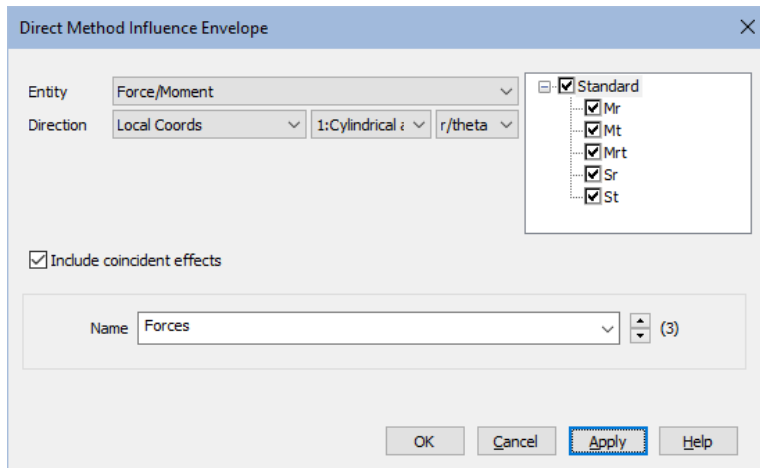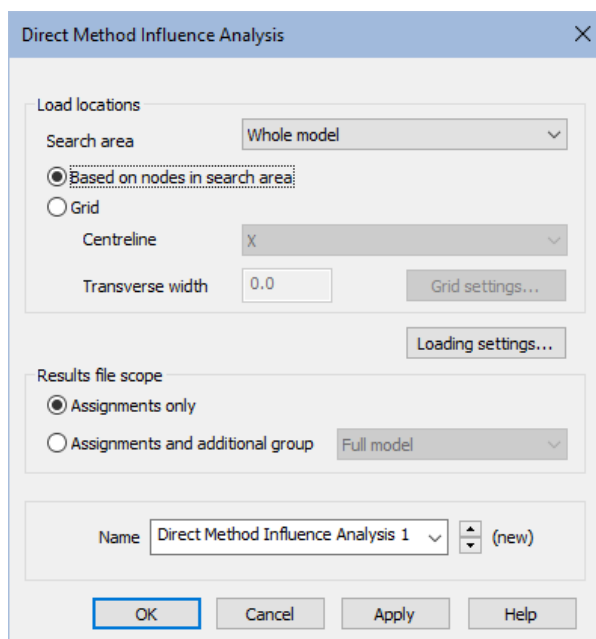
For the supports

- Then select an entity of **Reaction** for an influence direction of **Nodal**, then in the adjacent panel select just **Fz**. Change the name to be **Reactions** and click **OK**.

Create a DMI Analysis

- Select **Based on nodes in search area** and click **OK**.

Analyses
  Direct Method
  Influence Analysis >
   General...

Select features for assignment

Note that DMI Envelope attributes are assigned to features (lines and surfaces) and not directly to nodes.

- Select the **three surfaces** representing the bridge deck.

- Drag and drop the influence attribute **Forces** from the Treeview onto the selected features.
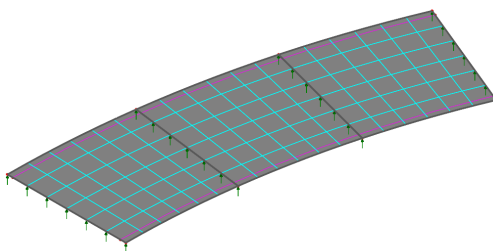
> **Note.** Unlike the assignment of reciprocal or DMI attributes no visualisation of DMI Envelope attributes takes place on the model, but the assignment does add an influence attribute entry 'Forces' to the Analyses Treeview.

- Now select only the **four lines** representing the supports.

- Drag and drop the influence attribute **Reactions** from the ⚛ Treeview onto the selected features.
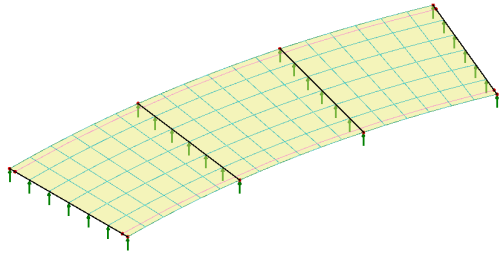
An influence attribute entry 'Reactions' is added to the Analyses 🔍 Treeview.

Using the Vehicle Load Optimisation facility to calculate the most critical loading patterns

The vehicle load optimisation software option automates the creation of traffic load patterns in accordance with a selected design code for locations specified on the model. The example as written uses EN1991-2 Recommended Values, which is supported by the LUSAS VLO software option. Other EN1991-2 National Annexes may be chosen, but different results from those stated here may be obtained..

Select the kerb lines

Prior to running the vehicle load optimisation, the kerb positions defining the extent of the loadable area of carriageway must be selected.

- Select only the **two lines** representing the kerb positions / extent of the traffic lane.
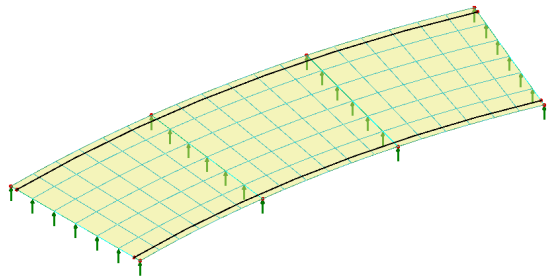
Define Vehicle Load Optimisation parameters

Bridge
  Vehicle Load
 Optimisation…
    VLO Envelope
    Run…

- Select **Europe** from the Country drop down list.

- Select **EN1991-2 Recommended Values 2009** from the Design code drop down list.

- **VLO Envelope Run 1** will be automatically entered for the Analysis name.
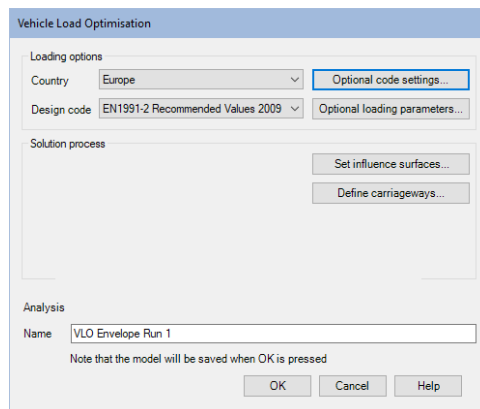
Browse the optional code settings

- Select the **Optional code settings** button and the optional loading parameters dialog will appear for the design code selected.

On this dialog any representative values that are required and load groups that are to be included can be specified. Special vehicle types can be specified, and advanced settings can be defined.
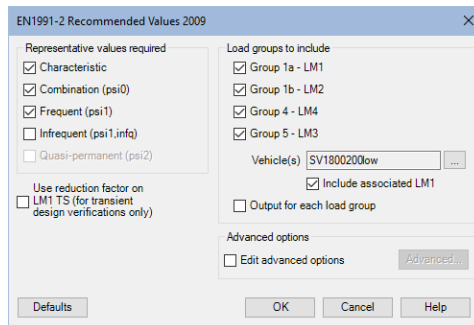
Note that a single special vehicle (**SV1800200low**) is specified as a default in these recommended values and that a vehicle(s) appropriate to the structure being designed should be specified in practice.

- Turn off the **Output for each load group** option to not create influence design loadcases for each load group that is ticked. This provides an overview of the combined effects of all the load groups selected, as opposed to a breakdown of effects group by group. It also helps to simplify the creation of envelopes for this example.

- For this example, un-check the **Infrequent** option, then click the **OK** button to accept the remaining default values and return to the main VLO dialog.

Browse the optional loading parameters

- On the main VLO dialog, select the **Optional loading parameters** button.

- On this Options dialog ensure the **Longitudinal increment** is set to **0.25**, the **Transverse increment** is set to **0.25** and the Vehicle direction is set to **Both.**

- The option **Use rationalised placement method** should be set.

- Click **OK** to return to the main Vehicle Load Optimisation dialog.

Define the carriageways

- On the main VLO dialog, select the **Define carriageways…** button.

Because the kerb lines have been selected the carriageway shape and angle of carriageway are known. **Kerbs from selection** will be automatically selected.

- Click **Apply** to return to the main Vehicle Load Optimisation dialog.
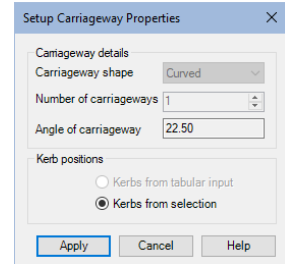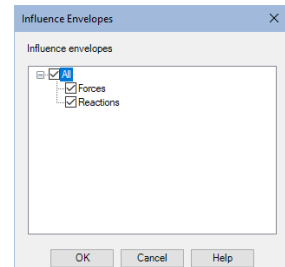
Define the influence surfaces

- On the main Vehicle Load Optimisation dialog, select the **Set influence surfaces** button.

Influence envelopes will be created for the Forces and Reactions influence attributes listed.

- Click **OK** to return to the main load optimisation dialog.

- Press the **OK** button on the main VLO dialog to run the vehicle load optimisation analysis.

This analysis will provide an optimised load effect of interest at all nodal locations in a feature for which each DMI Envelope attribute has been assigned, and also for the coexistent load effects requested at those locations. A progress bar shows the status of the analysis.

On completion, a Max and Min VLO envelope is generated in the Analyses 🕐 treeview for each Representative Value (Characteristic, Combination, Frequent) requested.

These VLO Envelopes allow for results to be combined with results from other loadcases such as those for dead load or temperature load.
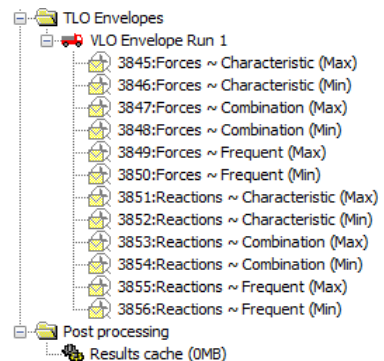
Note. The VLO Envelope Run will use the results from a previously solved DMI envelope analysis to generate the worst traffic load effects. The wizard does not by default output any traffic load patterns, nor does it require the static solution of any traffic load patterns.

Plotting Contours of Moment and Peak Values

- In the ⏱ Treeview right-click on the **<number>:Forces ~ Characteristic (Min)** entry and pick the **Set Active** option. Ensure that entity **Force/Moment – Thick Plate** and then component **Mt** are selected along with a transformation of **Cylindrical about Z-axis** and click **OK**.

Note that by default, and in accordance with established theory, thick plate element results are given along a chosen <u>global</u> axis. Because we wish to look at radial results along the deck the cylindrical local coordinate system must be selected in order to make the appropriate results components available for selection.

- With no features selected click the right-hand mouse button in a blank part of the graphics window and select the **Contours** option to add the contours layer to the 🔲 Treeview.

- Ensure that entity **Force/Moment – Thick Plate** and then component **Mt** are selected along with **Averaged nodal** and a transformation of **Cylindrical about Z-axis.** For envelopes and combinations ensure **Show minimum only** is selected, then click **OK** to display contours of moments in the longitudinal direction.
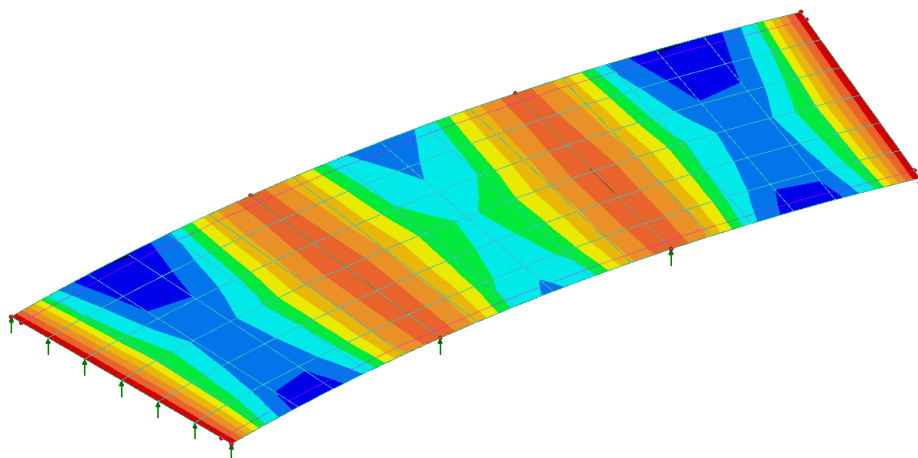

- With no features selected click the right-hand mouse button in a blank part of the graphics window and select the **Values** option to add the values layer to the 🔲 Treeview.

The values properties dialog will be displayed.

- Ensure that entity **Force/Moment – Thick Plate** and then component **Mt** are selected along with **Averaged nodal** and a transformation of **Cylindrical about Z-axis** are selected. For envelopes and combinations ensure **Show minimum only** is selected, then select the **Values Display** tab.

- Deselect the **Maxima** option since the sagging moment is negative (Minima will then be automatically selected). Change the percentage of values to display to **10**

- Set the number of significant figures to **4**

- Click the **OK** button to display contours of moments in the longitudinal direction with the bending moment value displayed.
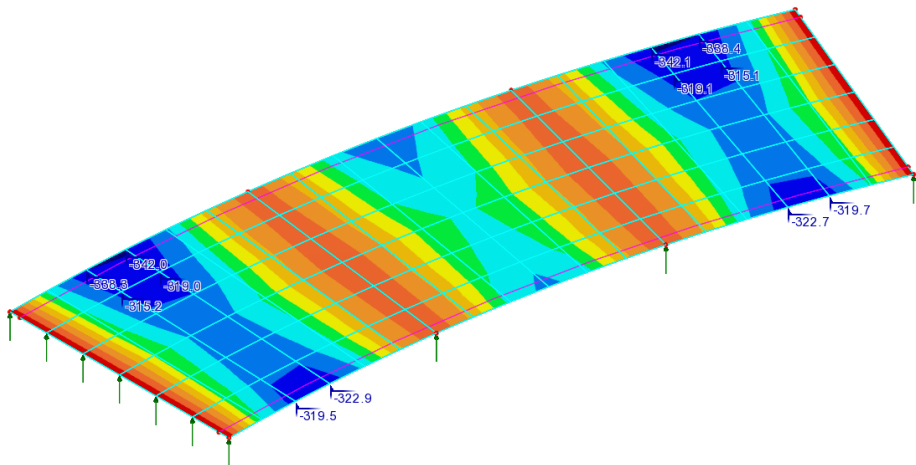
Plotting stress contours and peak values for other VLO envelopes may be done by setting active each in turn.

Viewing a results table

An onerous effects table can be optionally displayed for each VLO envelope present in the Analyses treeview.

- For the **<number>:Forces ~ Characteristic (Min)** entry, right-click on the context menu item **View results table**. The values in the table represent the optimized values calculated by VLO facility, for each result component selected in the Direct Method Interface Envelope attribute.

	Node ▲	Mr[kN.m/m]	Mt[kN.m/m]	Mrt[kN.m/m]	Sr[kN/m]	St[kN/m]
1	1	-54.3672	-5.93532	-28.9705	-2.97407	-13.0303
2	2	-51.8056	-7.4814	-81.201	-42.0385	-11.2276
3	3	-0.991445	-5.04578	-47.8066	-1.50034	-11.5311
4	4	-1.54526	-4.65012	-66.6588	-9.39466	-10.7299
5	5	-2.26575	-5.43313	-78.8987	-12.1968	-10.6605
6	6	-1.38709	-4.53344	-81.7684	-12.6722	-10.6746
7	7	-0.905965	-5.06697	-70.7662	-23.3242	-10.9338
8	8 (A)	-61.5787	-46.4956	-32.8701	-89.7099	-165.908
9	8 (B)	-61.1477	-46.6113	-54.2461	-89.1018	-23.6274
10	9	-2.12987	-240.485	-68.3359	-3.00876	-11.3882
11	10	-5.86123	-338.338	-39.5183	-5.83565	-31.7893

Model info \ **3846:Forces ~ Characteristic (Min)(All)** \ 3846:Forces ~ Characteristic (Min)(All)(Summary)

The summary tab shows the node numbers at which the maximum and minimum values occur:

	Component ▲	Mr[kN.m/m]	Mt[kN.m/m]	Mrt[kN.m/m]	Sr[kN/m]	St[kN/m]
1	Maximum	-0.905965	-4.31273	-9.29359	-1.50032	-3.64179
2	Node	7	102	12	99	111
3	Minimum	-96.4364	-342.127	-81.7684	-89.7099	-173.0
4	Node	121	95	6	8	14

Model info \ 3846:Forces ~ Characteristic (Min)(All) \ **3846:Forces ~ Characteristic (Min)(All)(Summary)**

Note. The same tables of results can be viewed by selecting the Utilities > Print Results Wizard menu item and selecting the VLO Envelope as the reported loadcase.

Visualising Load Definitions

It is not normally necessary to create loadcases representing the most onerous traffic loading patterns for each node and load effect, because the load effects are already available for all the specified nodes and effects - and can be combined and factored together with other loads, such as dead loads and superimposed loads. However, it can be desirable to view the loading pattern for checking purposes.

Select the loading on/off button to **turn-on** the loading visualisation.

If necessary, select the supports on/off button to **turn-on** the support visualisation.

To see the loads and the factors applied the procedure is to set active a VLO Envelope loadset and then select a node of interest on the model. Then select the context menu item 'Visualise loading at node' for the active loadcase. The load pattern causing the effect at that location will be drawn on the model and the loading details displayed in

the Analyses 🔍 treeview. This will be carried out for the worst-case span and support moments.

Loading for worst-case sagging moment

- In the 🔍 Treeview, right-click on the loadcase **<number>:Forces ~ Characteristic (Min)** and pick the **Set Active** option.

From the summary table and contour key it can be seen that worst minimum (sagging) moment in the span occurs at node 95, the location of which is shown below.
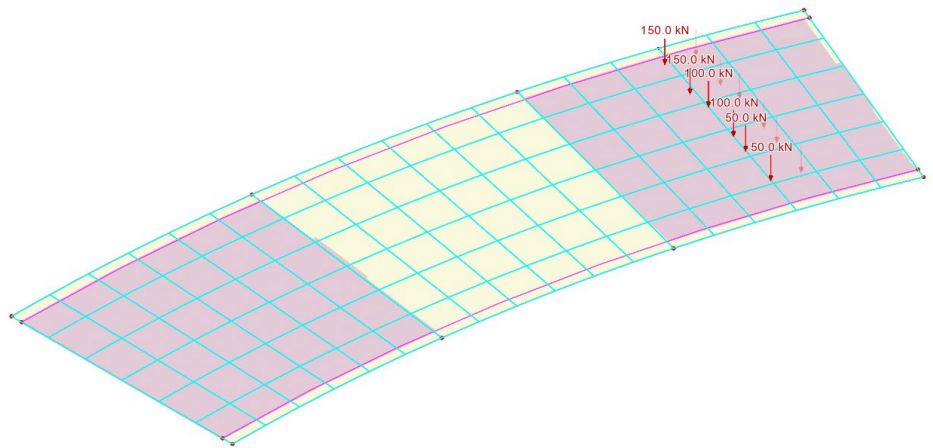
✏️ **Note.** Nodes, elements and features may be located on the model by right-clicking in the view window and selecting the Advanced selection option.
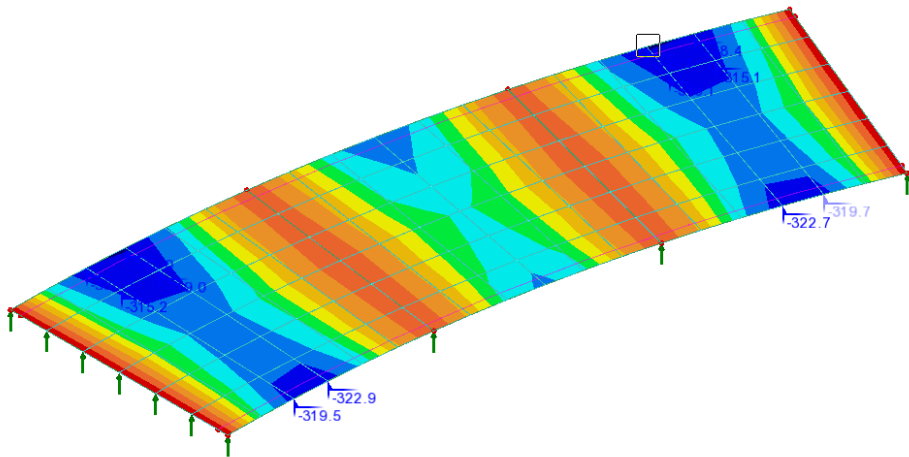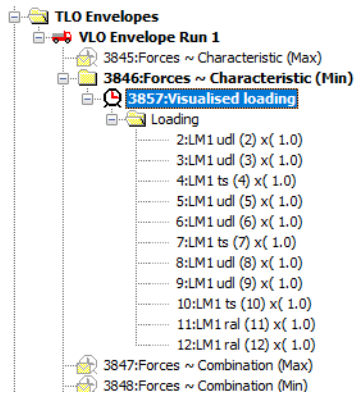

☞ **Tip.** Turning off the display of the contour layer will allow values to be seen more clearly.
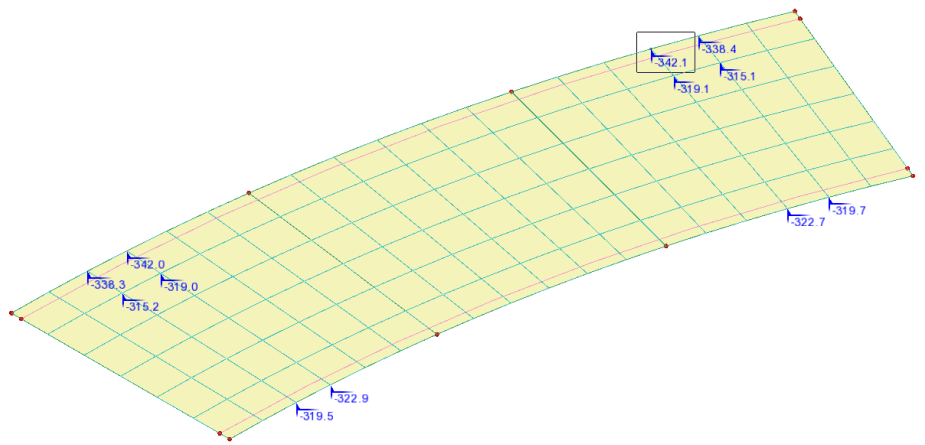
- Box-select node **95**, then, for the active loadcase, select the context menu item **Visualise loading at node**. The load pattern causing the effect at that location will be drawn on the model and the loading details displayed in the Analyses 🔍 treeview.

```
TLO Envelopes
  VLO Envelope Run 1
    3845:Forces ~ Characteristic (Max)
    3846:Forces ~ Characteristic (Min)
      3857:Visualised loading
        Loading
          2:LM1 udl (2) x( 1.0)
          3:LM1 udl (3) x( 1.0)
          4:LM1 ts (4) x( 1.0)
          5:LM1 udl (5) x( 1.0)
          6:LM1 udl (6) x( 1.0)
          7:LM1 ts (7) x( 1.0)
          8:LM1 udl (8) x( 1.0)
          9:LM1 udl (9) x( 1.0)
          10:LM1 ts (10) x( 1.0)
          11:LM1 ral (11) x( 1.0)
          12:LM1 ral (12) x( 1.0)
    3847:Forces ~ Combination (Max)
    3848:Forces ~ Combination (Min)
```

With reference to the loading entries in the Analyses 🔍 treeview, it can be seen that Group 1a dominates and the load pattern is made up of LM1 tandem systems and LM1 UDL patches.

The 10m carriageway width accommodates three 3m wide lanes. With reference to EN1991-2:2003 table 4.2 and clause 4.2.4 (4), Lane Number 1, with the heaviest tandem and udl loads, is positioned adjacent to the influence node of interest on the outer, larger radius side of the deck. Moving away from the location of interest, lanes 2 and 3 appear in order. The remaining area (1m wide) appears on the inner curve side of the bridge deck. Spans 1 and 3 only are loaded (span 2 is not part of the adverse area).

Note. Selecting a loading entry and selecting the 'Visualise Assignments' context menu item to turn off and turn on the loading visualisation will help with interpreting the above statement.

Note. Selecting a new node of interest will remove the visualised loading entry for the previously selected node from the Analyses 🔍 treeview and show the entry for the newly selected node instead.

Loading for worst-case support moment

At supports (a location of a potential discontinuity) a choice must be made between the elements that meet at a node. To see this:

- Turn back on the display of the Contours layer. On the dialog, no results can be selected currently.

- In the 🔍 Treeview, right-click on the loadcase **<number>:Forces ~ Characteristic (Max)** and, accepting the settings present, pick the **Set Active** option and click **OK**.

- In the Layers 🔲 Treeview, double-click on the Values layer, select the Values Display tab and deselect the **Minima** option and select the **Maxima** option since the hogging moment is positive. From the contour key it can be seen that worst hogging moment occurs at node **50**, the location of which is shown below.
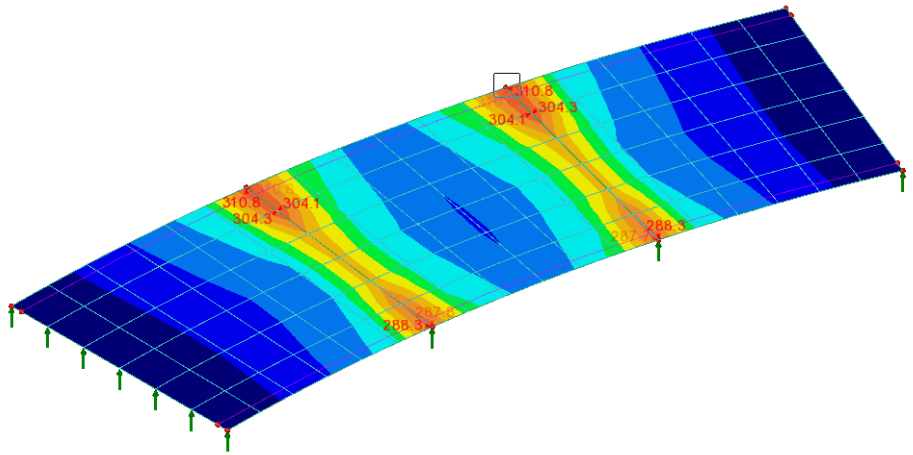
- Using the 'Select nodes' cursor, **select this node**, then, for the active loadcase, select the context menu item **Visualise loading at node**.

There is a choice of results at the selected node, so you will need to select the element for which you wish to see results for.

- Select element **72**.

The load pattern causing the effect at that location will be drawn on the model, the element of interest is highlighted, and the loading details displayed in the Analyses treeview.
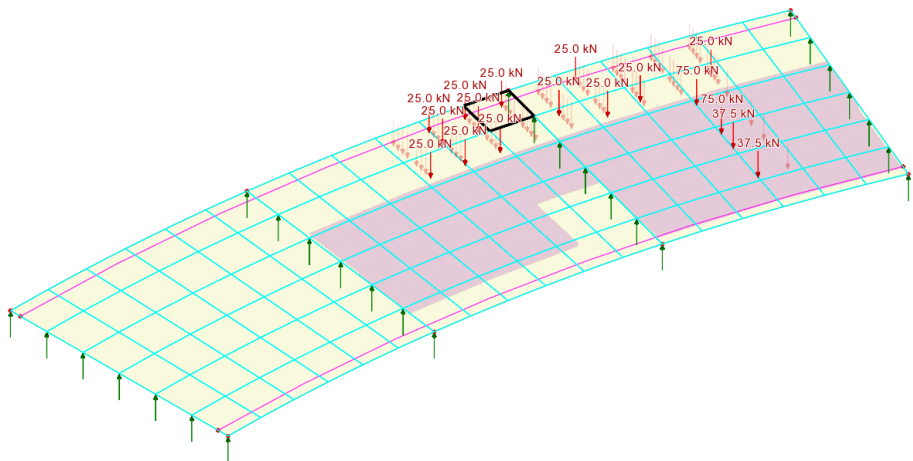
For this example the selection of the adjacent alternative element (78) does not give the same loading pattern.
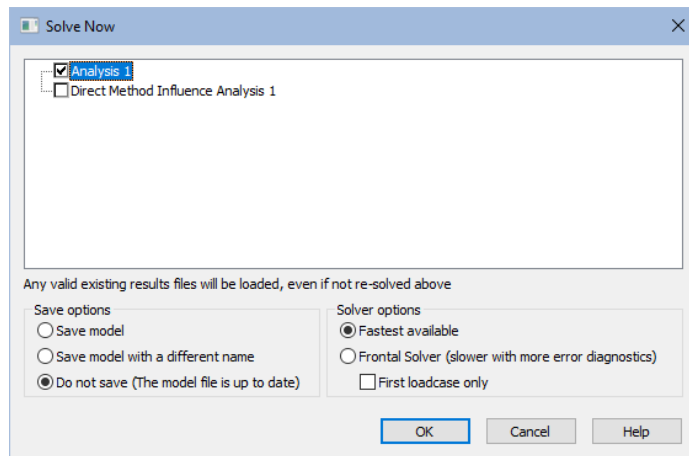
Solving the model

To set-up and view load combinations that involve self-weight, the model must be solved.

Press the Solve now button.

The Direct Method Influence analysis has already taken place but the effect of the self weight loading in Analysis 1 has to be solved.

Creating and Viewing Load Combinations

The LUSAS VLO facility outputs a design value – Characteristic, Combination or Frequent, with the meaning of each given in the VLO Help. In this example the vehicle loading is assumed to be the dominant effect and all other variable actions (wind, snow, temperature etc.) are being ignored. For this case, and in accordance with EN1990 6.4.3.2(3) equation 6.10, the loads can be combined as γ_G*[dead loads] + γ_Q*[traffic loads]. According to clause A2.3.1(4), for the design of structural members not involving geotechnical actions, the γ factors can be found in Table A2.4(B) as γ_G = 1.35 and γ_q = 1.5 for traffic. So, to define a basic combination:

On the Combination Properties dialog:

Analyses
    Basic Combination

- From within the structural analyses listing add **Self Weight** to the included panel.

- From within the TLO Envelopes listing add **<number>:Forces ~ Characteristic (Min)** to the included panel.

- In the grid, enter factors of **1.35** for the Self-weight loadcase and **1.5** for the Forces ~ Characteristic Min loadcase.

- Leave the name as **Combination 1** and click the **OK** button to add the combination to the 🕒 Treeview.

- In the 🕒 Treeview, right-click on **Combination 1** and choose **Set Active** to display the result for component **Mt** and a transformation that is **Cylindrical about Z-axis**.

- In the Layers 🔲 Treeview, double-click on the **Values** layer, select the **Values Display** tab and ensure that **Maxima** option and **Minima** are selected to show the top and bottom **10** percent of the results.
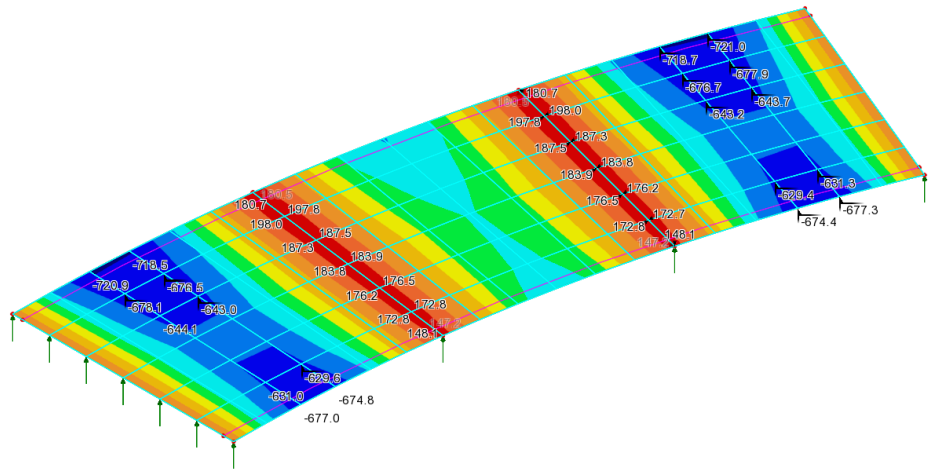
Save the model

File
Save

💾 Save the model file.

✏️ This completes the example.