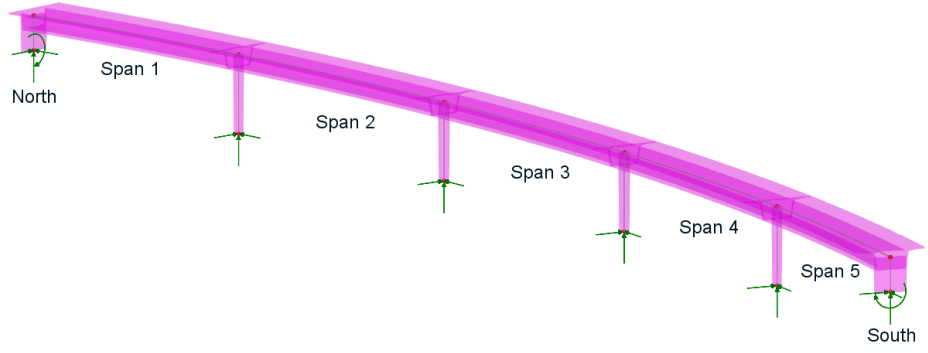
Vehicle Load Optimisation of a Box Beam Bridge

For LUSAS version:	24.0
For software product(s):	Bridge and Bridge Plus
With product option(s):	LUSAS Vehicle Load Optimisation

Description

A 5-span concrete box curved bridge with end spans of 45m and three internal spans of 50m is modelled with beams to illustrate the use of the Direct Method Influence (DMI) attributes and Vehicle Load Optimisation (VLO) facilities in LUSAS.



A script is supplied to build a base model with assigned mesh, material and support attributes is supplied for use with this example.

Units used are kN, m, kg, s, C throughout.

Objectives

The required steps in the analysis consist of:

- ❑ Run a Direct Influence Method Analysis to calculate the effects of a unit load
- ❑ Define influence attributes and assign them onto the model
- ❑ Create influence surfaces
- ❑ Create optimised vehicle loading results with VLO

Keywords

3D, Beam, Bridge, Concrete, Box Girder, Direct Method Influence, Vehicle Load Optimisation

Associated Files

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

Modelling

- ❑ **curved_bridge.lvb** creates an initial basic beam model of the bridge.

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

File
New…

- Enter a file name of **curved_bridge**.
- 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.

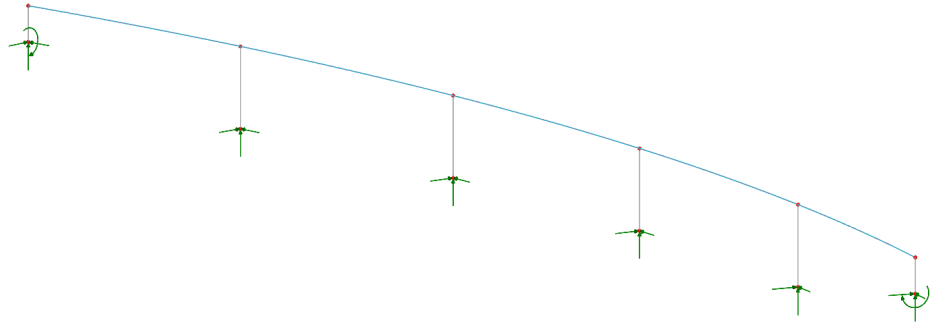
File
Script >
Run Script…

-  To create the model, open the read-only file **curved_bridge.lvb** that was downloaded and placed in a folder of your choosing.

Model Description

The 5-span, box girder bridge has spans of 45m, 50m, 50m, 50m and 45m, all set-out to a horizontal curvature of 510m radius. For simplicity the cross-section of the bridge is considered constant across its length, and the deck is supported on 5.5m high abutments and 12.5m high circular pier columns, which are considered fully integral with it. The box girder of the deck, including cantilever outstands, is 11.5 m wide. The carriageway itself is 7.7m wide, with space for a footway on the inside and hard standing margin on the outside.

The deck is modelled as a series of beams along the centreline of the carriageway at a radius of 510m. The lines representing the centroid of the box girder are used to define a search area for loading purposes, and to define a reference path which is used to define a loading grid, and for defining the 7.7m width of the carriageway.



For the purposes of this example the geometric lines of this model have been assigned a line mesh of thick beam elements with a specified element length of 5m.

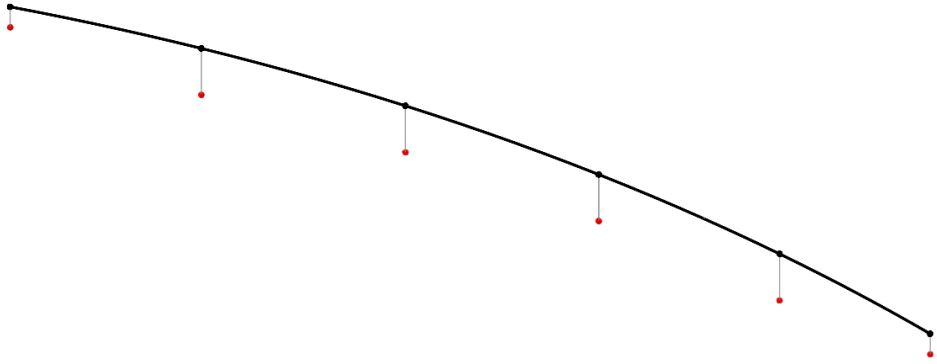
A cylindrical coordinate system has been used to orientate the abutments and piers supports. Concrete EU f_{ck}=50MPa has been assigned to all members.

Pin supports restrain the base of the piers and other pin supports, having the additional fixity, THY, are used at the abutments. A local cylindrical coordinate system has been assigned to the end points to orientate the supports as needed.

Defining a reference path

A reference path is to be created for use as a centreline for the bridge and for use in Vehicle Load Optimisation.

- In the Treeview right-click on **Deck** and click **Select Members** to select the lines representing the bridge centreline.



Utilities
Reference Path…

- Change the name to be **Bridge Centreline** and click **OK**. A corresponding path definition entry will be created in the Treeview.

Note. The direction of the reference path will control the order of any created influence entries in the Treeview.

Defining a search area

A search area is to be used to limit the area or features over which loads are applied, so that the effect of the load on certain features may be removed from the analysis. It is strongly recommended to define a search area for VLO analyses.

Attributes
Search Area…

- Change the name to **Deck** and click **OK**.
- In the Treeview, and with the lines defining the deck still selected, drag and drop the newly defined **Deck** search area onto the model to assign the attribute.

Direct Method influence analysis

Direct Method influence analysis is a means of creating an influence where the effect of a specified point load is assessed at each node or grid location on a loadable area of a structure. The value of the load effect of interest at each specified location is then used to construct an influence line or surface for that location. The direct method influence enables the construction of influence surfaces for any results component at any node in the structure. Note that for a line beam analysis, as used in this worked example, Direct Method influence attributes must be used; Reciprocal theorem attributes are not available.

Defining a Direct Method influence analysis

Analyses
Direct Method Influence Analysis
General…

- Choose **Deck** as the **Search area** to apply a prescribed unit load only on the deck beams.

For a line beam model, where the geometric section represents a beam with a loadable top slab, a loading grid of points should be defined to represent the slab. This virtual grid is equivalent to the nodes or points present in a shell or plate model and is used to create an influence surface for each location of interest.

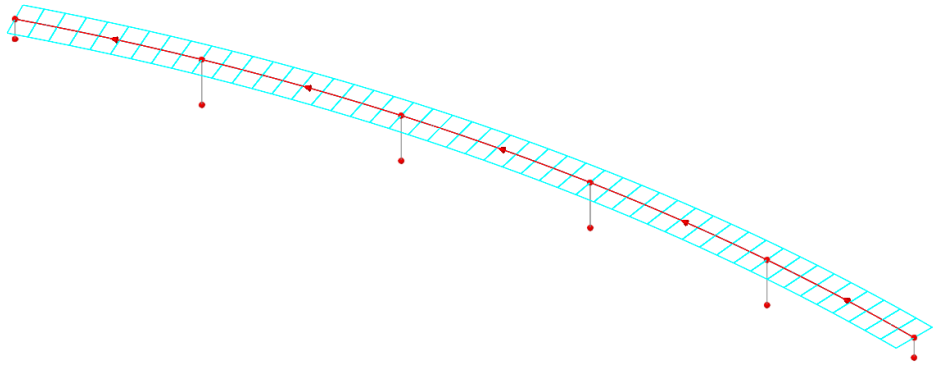
- Ensure that **Grid** is selected.
- Ensure that the chosen Centreline is the previously defined **Bridge Centreline** reference path.
- Set a Transverse width of **11.5**. This is the width of the grid to be loaded for influence analysis.
- Press the **Grid Settings** button and make sure that **Match nodes in search area (line beams only)** is selected. Click **OK** to return to the previous dialog.
- Change the name to **DMI My** and click **OK** to exit the dialog.

Note. The Grid Settings advanced dialog controls the spacing and number of load locations within the defined width and search area length. For line beam models the most accurate results are obtained when the grid spacing along the centreline of the loading grid is set to match the longitudinal spacing (and hence number of nodes) of the underlying beam mesh.

Note. When the 'Match nodes in search area option' is used for line beam models, only one transverse point is used to define the extent of the loading grid to each side of the line beam. Using a larger number of transverse points across a single beam will not make the analysis more accurate and is not required because results are only calculated for the two extreme fibres. If a very fine grid was defined the solution stage may take some time, as the solution time is proportional to the mesh and grid density.

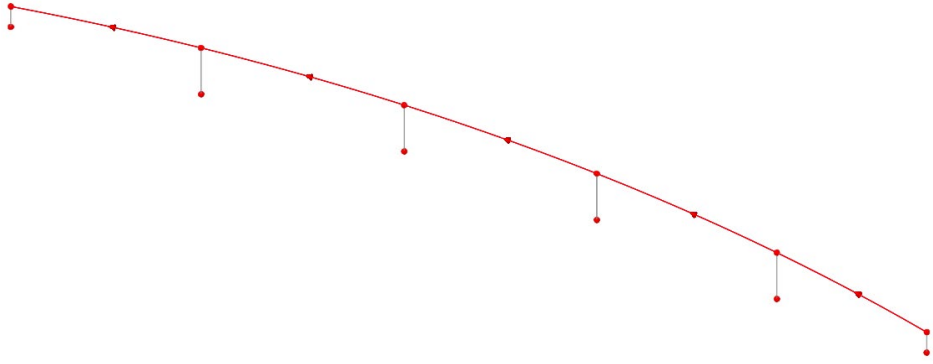
Note. In this example the loading grid is defined using the lines representing the centroid of the box girder sections and not at the level of the top of the section. This will not give a true visual representation if fleshing of the box girder is turned on but will not affect the engineering results obtained.

The defined grid that is now shown on the model will be used by an influence analysis to apply a unit load at each grid point.



The grid can be displayed or hidden on the screen.

- In the Treeview right-click on **DMI My** and select **Show Grid** to un-tick the entry and make the grid invisible.



Note. A Direct Method Influence analysis can include any number of influence types or can include only particular influence assignments for a particular span or section of the model. Here, an analysis for just one influence type (My) is being used for all spans.

Defining Direct Method influence attributes

Attributes
Influence >
Direct Method…

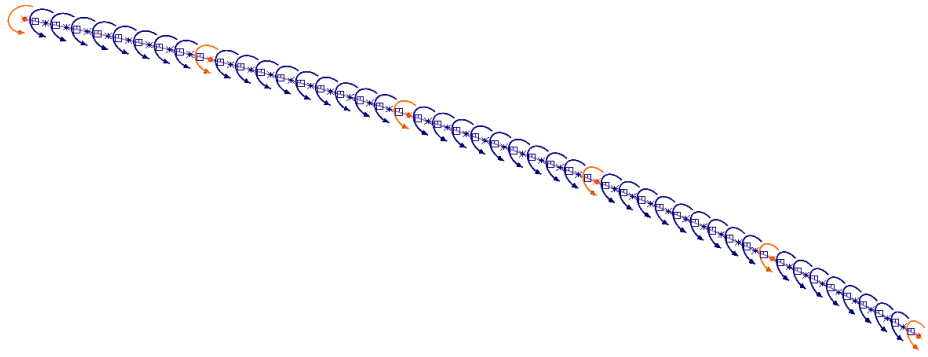
- Select Entity as **Force/Moment – Thick 3D Beam**
- Ensure the Direction is **Element local**
- Select **My** as the Component of interest.
- Enter **My Influence** as the name and press **OK** to close the dialog.

Once created, an influence attribute is held in the Treeview for assignment to selected nodes or points. Note that subsequent assignment of the same attribute to other nodes or points of interest on a model will use the same influence type settings that were initially made.

Assigning Direct Method influence attributes to the deck

Influence assignments will be made to all nodes along lines representing the deck.

- In the Treeview turn off the display of the **Utilities** layer. This turns off the display of the reference path.
- In the Treeview right-click on **Deck** and click **Set as Only Visible** to display only the lines representing the bridge centreline.
- **Hold-down the N key** (to select just the Nodes) and make a box-selection with the cursor to enclose the five lines representing the deck. 49 nodes will be selected.
- From the Treeview, drag and drop the **My Influence** attribute onto the selection in the view window to assign it to the selected nodes.



Influence loadcases (as yet unsolved) will be added to the **DMI My** analysis in the Treeview, indicating the name and position of the influence attribute assigned. Note that where a node coincides with its parent geometry the geometry name will appear as part of the influence assignment name.

Make all geometry visible again

- With no features selected right-click the view window and select **All visible**.

Finding assigned influence locations

In models with lots of elements, nodes and attributes you can quickly locate an assigned influence location in the view window by selecting the 'Find' context menu item for an influence attribute:

- In the Treeview, right-click on **My Influence (My) – (495.947, 118.896, 0.0)** and choose **Find.**

A temporary indicator will appear, highlighting the node with the assigned influence attribute, and showing it to be in the middle of span 3.

Solving the analyses

- Press the **Solve Now** button. On the Solve Now dialog ensure that both **Analysis 1** (which includes the self-weight loadcase that assumes the bridge is wished-in-place for the purposes of this example) and **DMI My** are checked and press **OK** to run the analysis.

This applies a unit load to each loading point on the grid and caches the results for each influence assignment.

If the analysis is successful...

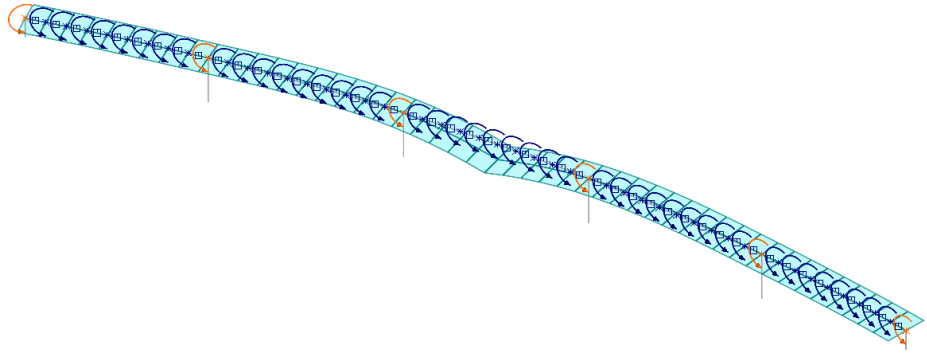
A results loadcase for Analysis 1 and a DMI My analysis entry are added to the Treeview.

Visualising influence shapes

- In the Treeview, right-click **My Influence (My) – (495.947, 118.696, 0.0)** and now choose **Set Active** to view the influence shape for My at the centre of span 3.

Note. Note that the results loadcase must be set active, and the next step must be completed before the influence shape will be drawn.

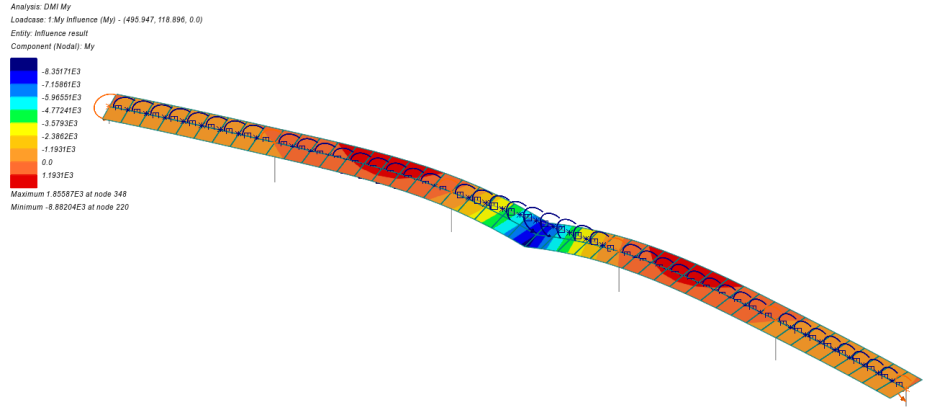
- With no features selected right-click in a blank part of the view window and select the **Influence shape** option.
- In the Treeview turn the **Geometry** off, to leave a view of the chosen influence shape.



Contouring influence results

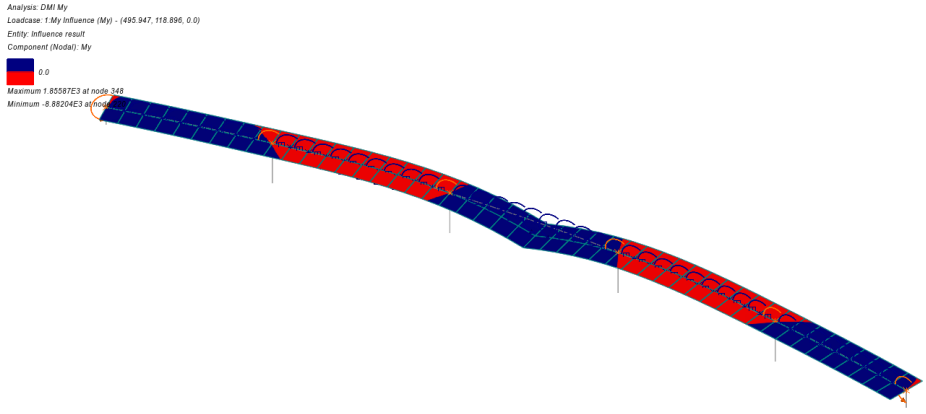
After the influence attributes have been defined and assigned, contours can be added to the view to indicate just what effect the degree and direction of influence loading applied along the surface will have on the assigned node.

- With no features selected right-click in a blank part of the view window and select the **Contours** option to add the Contours layer to the Treeview.
- Select the Entity **Influence result**. Note that the Component **Inf** and Display of **Nodal** will be automatically selected.
- To plot the contour on the influence shape, click the **Appearance** tab, and tick **Deform.**
- Press **OK** to exit the dialog.



The contours can be simplified to indicate which areas of the structure, when loaded, will have a positive, or negative influence for the selected influence assignment.

- Double-click the **Contours** layer to the Treeview to open the properties dialog.
- Select the **Appearance** tab, press the radio button for the **Red/blue** option, and click **OK**.



Note. For this influence analysis, carried out using Direct Method Influence attributes, vehicle loading placed onto the negative areas (blue) will create a negative moment for the influence shape for this chosen influence location. Vehicle loading placed onto the positive areas (red) will create a positive moment for the influence shape for this chosen influence location. The Vehicle Load Optimisation facility will make use of these areas in its positioning of traffic loading patterns.

Vehicle Load Optimisation (VLO)

Now that influence attributes have been defined and assigned, the VLO facility can be used to define optimised traffic loading for the bridge for these influence assignments, based on a chosen code of practice. In this example EN1991-2 UK will be used.

- In the Treeview, turn off **Contours** and **Influence shape** and **Annotation**
- In the Treeview, turn on **Geometry**
- In the Treeview, turn off **Visualise Assignments** for the **My Influence (My)**

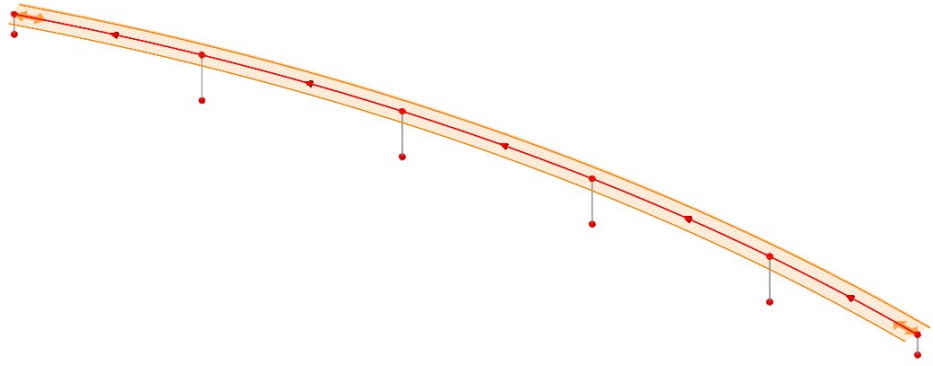
Defining VLO Highway

Bridge
Vehicle Load Optimisation >
Highway Definition…

A highway consists of one or more loadable areas. For this example, we will have a single carriageway as the only loadable area.

- Click **New…** under the Available loadable areas

- VLO can either calculate lane widths automatically to the design code in use, or you can specify the lanes manually. Choose **Carriageway (automatic lanes)** and click **Next**.
- Ensure the reference line is the previously defined Bridge Centreline, enter a distance to the centreline of carriageway of **0** and enter the carriageway width to be **7.7**. Leave the Vehicle direction as **Both** and click **Finish**.
- Click on **Carriageway1** and then click the 'Add to' button  to move it to the **Loadable areas to use**.
- Click **OK** to create the Highway utility.
- In the  Treeview turn on the display of the **Utilities** layer. This turns on the display of the carriageway.



- In the  Treeview turn the display of the **Utilities** layer back off.

Creating the VLO run

Bridge
Vehicle Load Optimisation
VLO Run…

- Select **United Kingdom** from the Country drop list and choose **EN1991-2 UK 2009** as the Design code.

For simplicity only the effects of a characteristic LM1 load and an LM2 load will be considered in this example.

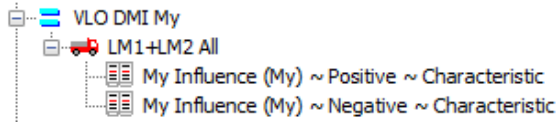
- Press **Optional Code settings** and ensure that **Characteristic** is the only one of the representative values required, and **Group 1a – LM1** and **Group 1b – LM2** are the only load groups to be included.
- Turn off the **Output for each load group** option to not create influence design loadcases 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. Press **OK** to exit the dialog

- On the main VLO dialog, press **Set influence surfaces** and on the next dialog select **Include all influence surfaces**.
- Ensure that the **Positive** and **Negative** checkboxes are selected for all the My Influences included (see note below). This means that the VLO analysis will produce loading patterns for positive and negative effects of My.

Note. Clicking in the header cell of a column will select the whole column so that checking (ticking) one entry will check (tick) all in that column.

- Press **OK** to return to the main VLO dialog.
- On the main VLO dialog, ensure that the selected highway is the previously defined **Highway1**.
- Ensure the option to **View onerous effects table** is selected.
- Ensure the option to **Create loading patterns** is not selected.
- To specify a non-default analysis name, choose **New** from the drop-down list, and enter the analysis name to be **VLO DMI My**
- Change the VLO run Name to be **LM1+LM2 All**
- Press **OK** to exit the dialog.
- After a short time, the VLO will be completed. Click **OK** to acknowledge that results can be filtered by making selections on the model and generate optimised loading.

At the bottom of the Treeview, the new **VLO DMI My** analysis will be created. This contains the **LM1+LM2 All** VLO run, as denoted by this icon , which includes Characteristic results table entries for the negative and positive My Influence assignments as shown in the following image.



VLO results tables will also appear on tabbed results pages for the negative and positive influence assignments that have been made, and with the most onerous influence assignment in each set of tabbed results shown highlighted in red.

Note. Because the option to 'Create loading patterns' was not chosen on the main VLO dialog, no loading folders will initially appear for an influence in the Treeview, but the VLO results table will show 'Create Loading' alongside all influence assignment entries, loading patterns to be created, as necessary, one at a time.

Filtering influence results

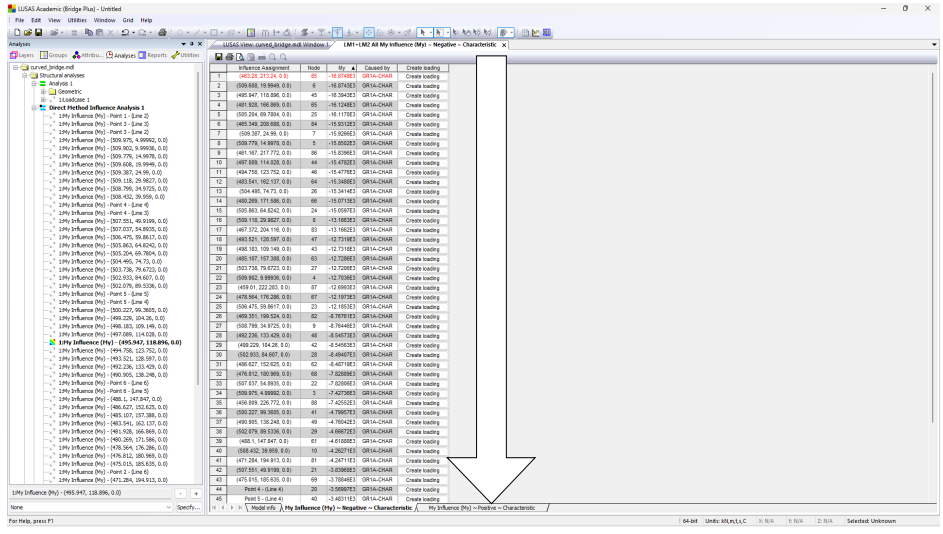
- In the VLO results table, ensure that the **My Influence (My) – Negative – Characteristic** tab is selected.

By default, results in tables are listed for all visible nodes in order of descending effect showing the most onerous value at the top of the listing in red. If desired, and by selecting a feature on the model, only those results applicable for a particular feature may be shown. One way of seeing this is to arrange the View and Results Table windows side-by-side and to select the individual lines representing each span of the model in turn as follows:

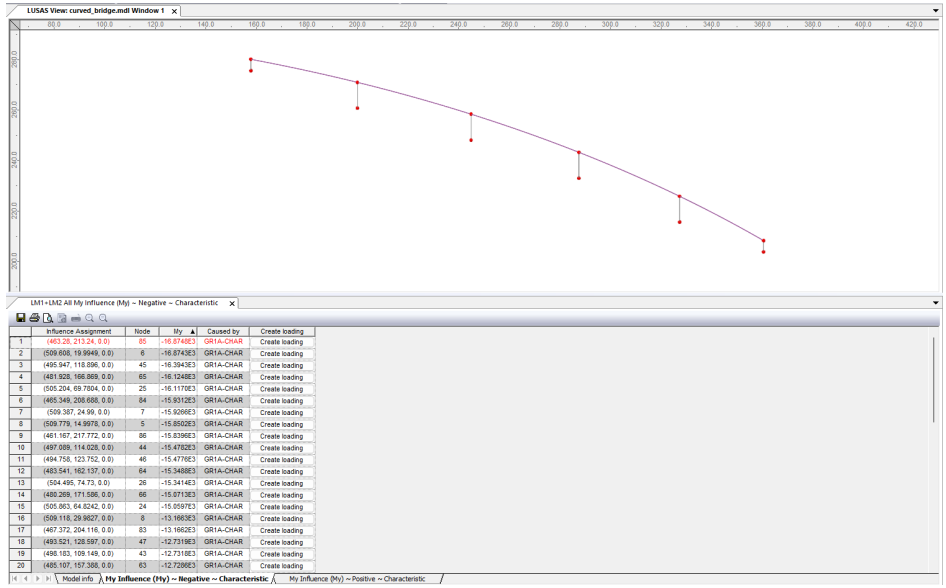
Window
Layout
Tabbed documents

If necessary, ensure that tabbed documents are being viewed.

- **Click, hold-down and slowly drag** the tab named **LM1 + LM2 All My Influence…** to the bottom of the view window until a highlighted region, that represents the new position of the view window, appears, and then release.

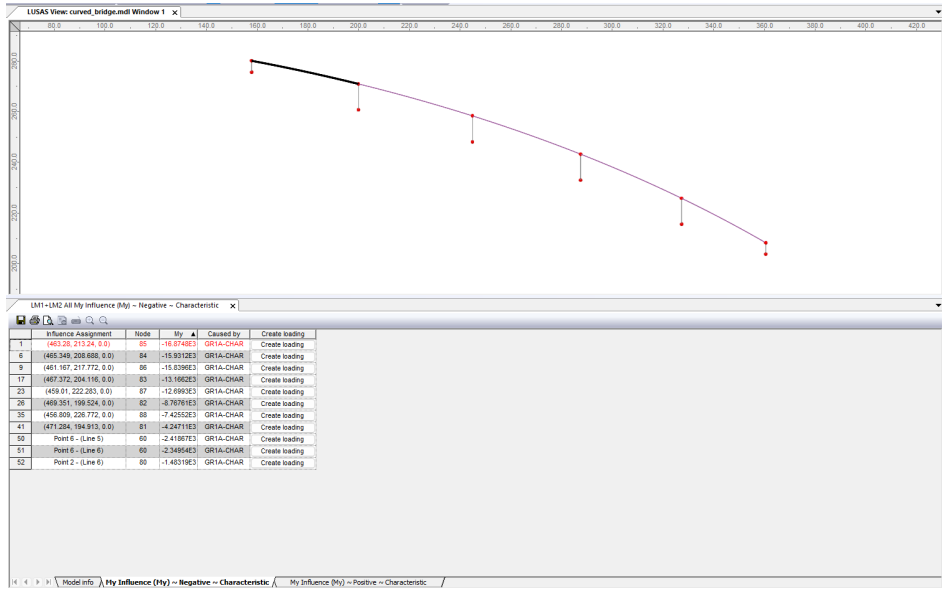


- Then click on the tab '**LUSAS view: curved_bridge.mdl Window 1**' to make this view window active. It should be sitting above the results table, as shown in the following image, where unfiltered influence results show results for all features (all spans).



	Influence Assignment	Node	My	Caused by	Create loading
1	(463.28, 213.24, 0.0)	85	-16.8748E3	GR1A-CHAR	Create loading
2	(509.608, 19.9949, 0.0)	6	-16.8743E3	GR1A-CHAR	Create loading
3	(495.947, 118.896, 0.0)	45	-16.3943E3	GR1A-CHAR	Create loading
4	(481.928, 166.869, 0.0)	65	-16.1248E3	GR1A-CHAR	Create loading
5	(505.204, 69.7804, 0.0)	25	-16.1170E3	GR1A-CHAR	Create loading
6	(465.349, 208.688, 0.0)	84	-15.9312E3	GR1A-CHAR	Create loading
7	(509.387, 24.99, 0.0)	7	-15.9266E3	GR1A-CHAR	Create loading
8	(509.779, 14.9978, 0.0)	5	-15.8502E3	GR1A-CHAR	Create loading
9	(461.167, 217.772, 0.0)	86	-15.8396E3	GR1A-CHAR	Create loading
10	(497.089, 114.028, 0.0)	44	-15.4782E3	GR1A-CHAR	Create loading
11	(494.758, 123.752, 0.0)	46	-15.4776E3	GR1A-CHAR	Create loading
12	(483.541, 162.137, 0.0)	64	-15.3488E3	GR1A-CHAR	Create loading
13	(504.495, 74.73, 0.0)	26	-15.3414E3	GR1A-CHAR	Create loading
14	(480.269, 171.586, 0.0)	66	-15.0713E3	GR1A-CHAR	Create loading
15	(505.863, 64.8242, 0.0)	24	-15.0597E3	GR1A-CHAR	Create loading
16	(509.118, 29.9827, 0.0)	8	-13.1663E3	GR1A-CHAR	Create loading
17	(467.372, 204.116, 0.0)	83	-13.1662E3	GR1A-CHAR	Create loading
18	(493.521, 128.597, 0.0)	47	-12.7319E3	GR1A-CHAR	Create loading
19	(498.183, 109.149, 0.0)	43	-12.7318E3	GR1A-CHAR	Create loading
20	(485.107, 157.388, 0.0)	63	-12.7286E3	GR1A-CHAR	Create loading

- In the model view window, select each of the lines representing the spans in turn to filter the results in the table and see that the most onerous effect (denoted by the red text) occurs in span 5, and shown selected in the following image



	Influence Assignment	Node	My	Caused by	Create loading
1	(463.28, 213.24, 0.0)	85	-16.8748E3	GR1A-CHAR	Create loading
6	(465.349, 208.688, 0.0)	84	-15.9312E3	GR1A-CHAR	Create loading
9	(461.167, 217.772, 0.0)	86	-15.8396E3	GR1A-CHAR	Create loading
17	(467.372, 204.116, 0.0)	83	-13.1662E3	GR1A-CHAR	Create loading
23	(459.01, 222.283, 0.0)	87	-12.6993E3	GR1A-CHAR	Create loading
26	(469.351, 199.524, 0.0)	82	-8.7676E3	GR1A-CHAR	Create loading
35	(456.809, 226.772, 0.0)	88	-7.42552E3	GR1A-CHAR	Create loading
41	(471.284, 194.913, 0.0)	81	-4.24711E3	GR1A-CHAR	Create loading
50	Point 6 - (Line 5)	60	-2.41867E3	GR1A-CHAR	Create loading
51	Point 6 - (Line 6)	60	-2.34954E3	GR1A-CHAR	Create loading
52	Point 2 - (Line 6)	80	-1.48319E3	GR1A-CHAR	Create loading

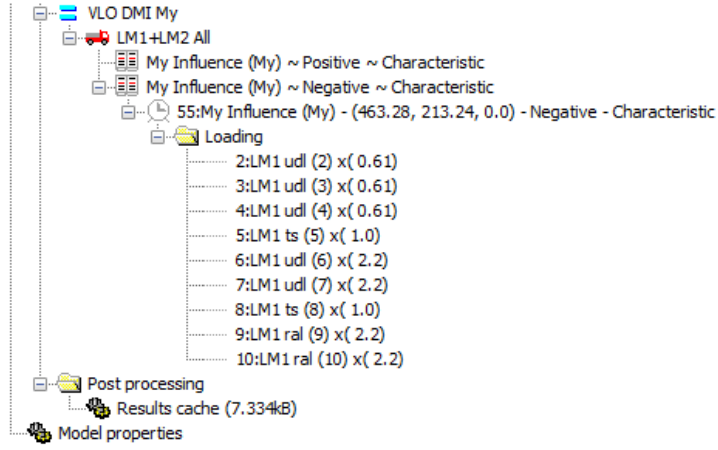
Creating loading patterns

For this worked example, the most onerous loading effect for the influence assignment of interest will be created individually by pressing the 'Create Loading' button alongside the appropriate entry in the onerous results table.

With the line representing span 5 still selected:

- In the VLO results table ensure that the **My Influence (My) – Negative – Characteristic** tab is selected and press the **Create loading** button for the most onerous negative result entry (shown in red at the top of the table in the preceding images).

A loadcase entry and a Loading folder will appear for the VLO results table entry in the Analyses Treeview for that influence. When expanded, it will appear as shown in the following image.



- Leave the results table open to create additional loading patterns.

Check the loading visualisation settings

Before visualising the loading, it is prudent to check or correct the settings required.

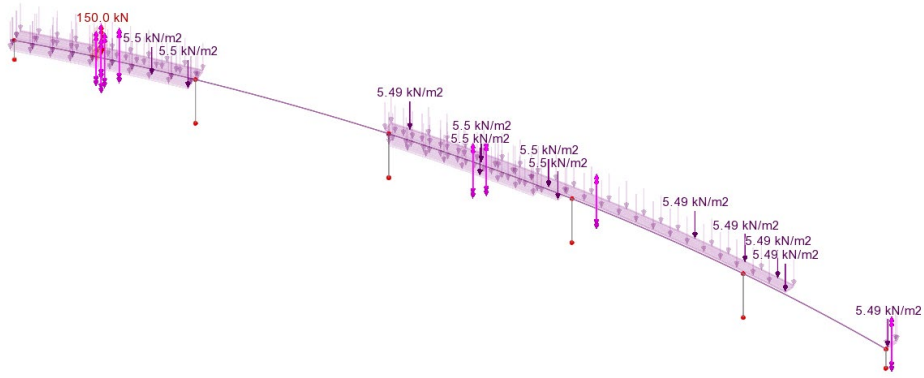
- Click in the Model view window to make that view active (instead of the table of results view) and if necessary, use the zoom facilities to enlarge the view of the model.
- In the Treeview double-click **Attributes**
- Select the **Loading** tab and press **Settings...** button.
- For the visualisation style select **Visualise loading by definition** from the droplist supplied and press **OK** to exit the dialog.

- Press **OK** to return to the model.

Negative effects

- In the Treeview, and from within the VLO DMI My, LM1 All section, select the **My Influence (My) – (463.28, 213.24, 0.0) – Negative - Characteristic** loadcase and choose **Set Active**.
- Press to visualise loading.

The optimised loading for the characteristic case of EN1991-2 UK that gives the maximum My effect in the mid-span of span 5 for negative influence will be displayed.



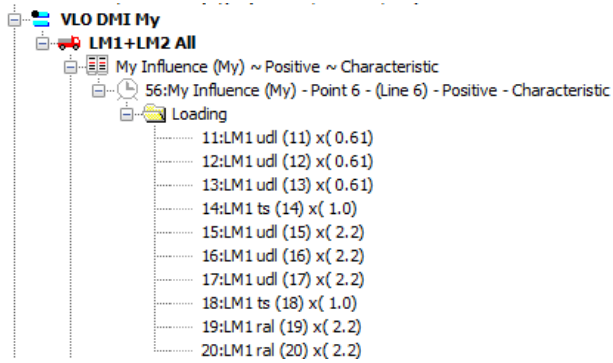
Positive effects

With the line representing span 5 still selected:

- Go back to the VLO results table and select the **My Influence (My) – Positive – Characteristic** tab and press the **Create loading** button for the most onerous positive result entry for the line still selected.

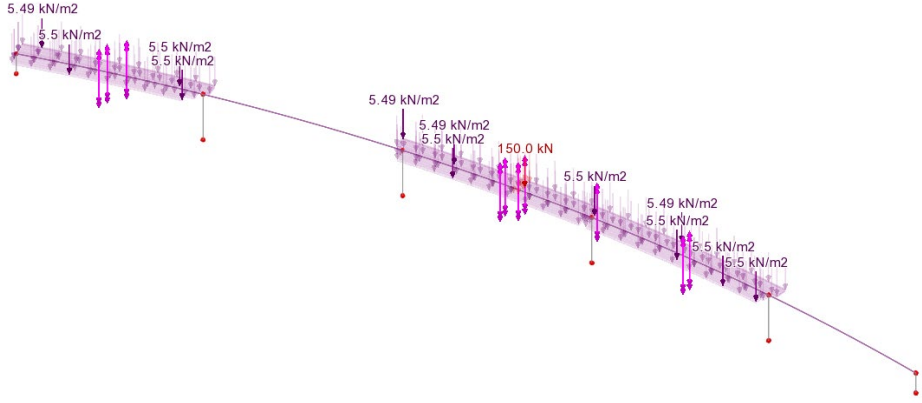
Note. This entry is not the most onerous positive characteristic value for the whole bridge because it is not shown in red.

A loadcase entry and a Loading folder will appear for the VLO results table entry in the Treeview for that influence.

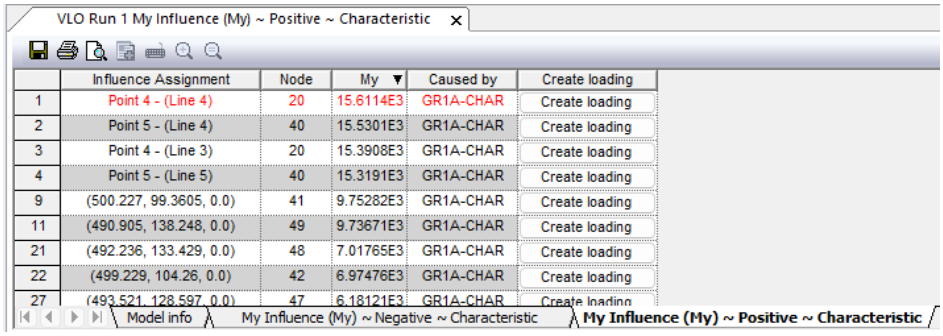


- In the Treeview, and from within the VLO DMI My section, select the **My Influence (My) – Point 6 - (Line 6) – Positive - Characteristic** and choose **Set Active**.

The optimised loading for the characteristic case of EN1991-2 UK that gives the maximum My effect positive influence for span 5 will be displayed.



- Now select the line representing each span and by looking at the filtered results in the onerous results table) it will be seen that the most onerous result for hogging is obtained for span 3 at pier 2 (which is Point 4 in the model).



This loading pattern is not generated at this point in the example.

- Turn-off the display of the loading patterns.

Solving optimised loading arrangements

So, as seen, the VLO run includes loading arrangements that can be optionally visualised but produces no structural results. Results are available only after the VLO analysis has been solved. So:

- With the model view window active, press the Solve Now button.

Only the VLO analysis needs to be solved to produce the results for the optimised loading arrangements for each influence assignment. The Solve Now dialog indicates that the VLO DMI My analysis results are not up to date and that they need to be solved. The other two analyses are unselected by default, as their results are up to date.

- Press **OK** to solve the VLO run.

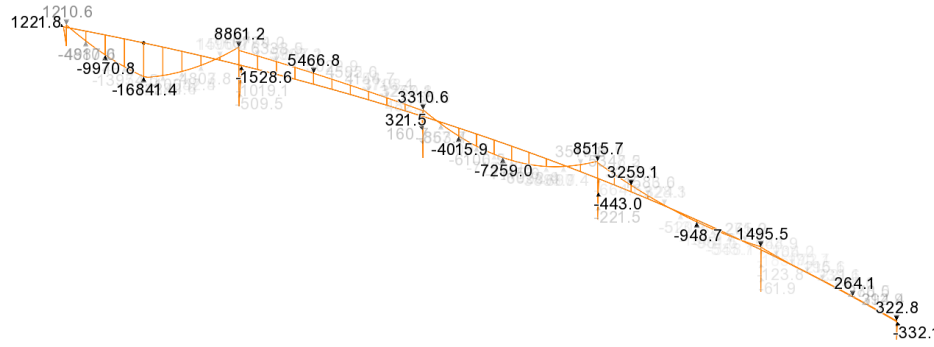
The results will be loaded on top of the current model, with the last viewed 'VLO DMI My' analysis loadcase set active by default.

Viewing results

Plotting bending moments

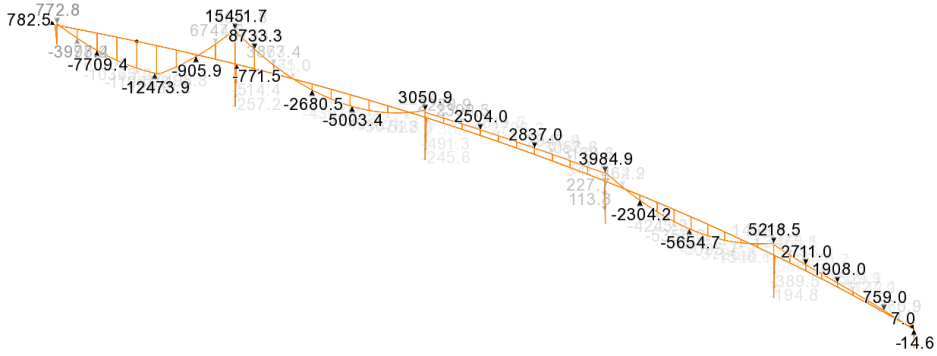
- In the Treeview, and from within the VLO DMI My, LM1 All section, select the **My Influence (My) – (463.28, 213.24, 0.0) – Negative - Characteristic** results loadcase and choose **Set Active**.
- In the Treeview turn off the **Geometry** and **Attributes** layers.
- With no features selected right-click in a blank part of the Graphics window and select the **Diagrams** option to add the **Diagrams** layer to the Treeview

- In the diagram properties drop-down menu, pick **Force/Moment – Thick 3D Beam** from the entity and **My** from the component drop down list.
- From the **Diagram Display** tab deselect the **Use for labels too** option (to draw labels in black by default), select **Decimal places** and change the value to **1**
- Press **OK** to exit.



The preceding diagram shows the worst-case sagging moment, My, for span 5, due to characteristic LM1 + LM2 loading.

- In the Treeview, and from within the VLO DMI My, LM1 All section, select the **My Influence (My) – Point 6 - (Line 6) – Positive - Characteristic** and choose **Set Active**.

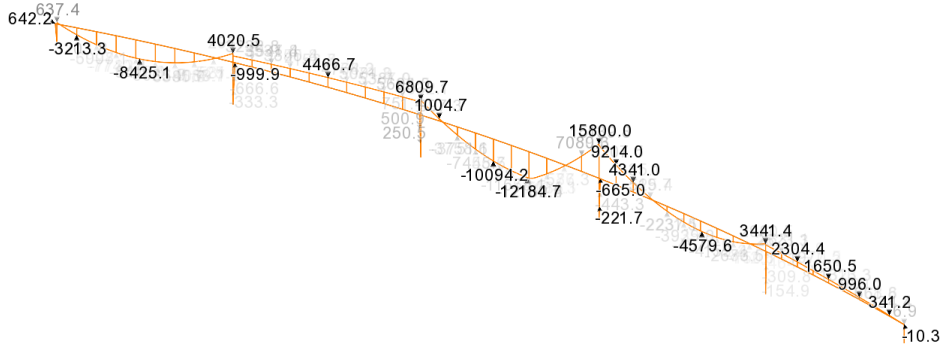


The preceding diagram shows the hogging moment, My, which occurs at pier 4, due to characteristic LM1 + LM2 loading.

Using the procedures described in this example, lines representing each span can be selected, onerous loading patterns can be created, loadcases solved, and the corresponding results for each span can be inspected.

As an example, creating the loading pattern for the most onerous positive characteristic value for the bridge (which as previously stated occurs in span 3 at pier 2 at Point 4 in

the model), setting active the loadcase created, and solving the model to generate results, would result in the following diagram of My being obtained.



This completes the example.

Discussion

This example just shows how a single influence component (My) can be defined and assigned as an attribute to nodes within the lines representing the deck. Other influence attributes such Mx, for investigating torsional effects, could be assigned to nodes in the deck also, with loading and results effects being obtained in the same way. Investigation of axial forces at pier heads can also achieved in a similar fashion, but by making assignments only to the points at those locations.

VLO analysis naming conventions

One Direct Method Analysis entry could contain a single Vehicle Load Optimisation run, for all assigned influence components of interest, but for large models this could result in a great deal of unstructured data within the Analyses treeview that is not easily viewable.

It is often better to have a single Direct Method Analysis entry containing multiple VLO run entries of suitable names such as Deck, or Pier, even including additional references to load types, since this will simplify the viewing and provide a 'structure' to the data in the Analyses treeview and also make the identification of results loadcases easier when results processing.

Appending an influence component name to a Direct Method Analysis entry or a VLO Run name (if they only contain assignments for a single influence type) may also be useful if many entries are present in the Analyses treeview, and some of these entries are contracted when other entries are being viewed.

Influence analysis options

For Vehicle Load Optimisation either Direct Method attributes (as used in this example), Direct Method Influence Envelope attributes, or Reciprocal Method influence attributes may be used.

- For the **Direct Method**, the influence type may be set by defining any Entity of interest (such as a Reaction, or a Force/Moment, or a Stress), an influence direction (such as an axis of a member, or a path along a structure, or a material direction) and a Component of interest (such as My), then assigning it to nodes and elements.

- **Direct Method Influence Envelope** attributes differ from Direct Method Influence attributes in that they allow selection of all the components that are to be optimised (as opposed to only being allowed to only select one in the Direct Method). They also differ in that they are assigned to point, line or surface features in a model (as opposed to just nodes or points) and they provide the optimised load effect of interest (e.g. My) at all nodal locations in the assignment. If an option to include the coincident effects is also chosen, all the coincident effects (e.g. Fx, Fy, Fz, Mx, Mz) at all assigned locations will also be provided for each selected component (as opposed to having to select which ones to include individually).

- For the **Reciprocal Method**, the influence type may be a Shear force, a Reaction, a Moment or a Displacement only. For each influence type the influence direction and either a positive or negative displacement direction needs to be specified.

The Direct method is often more convenient when a limited number of influences are required. The Direct Method Influence Envelope method can provide “whole structure” results, but at an increased computational cost.

The Reciprocal method is no longer the recommended method for carrying out vehicle load optimisation within LUSAS. It is retained for backwards compatibility, or for calculating influence when the load direction is unknown.

Different worked examples are available which show the Direct Method Envelope method.