

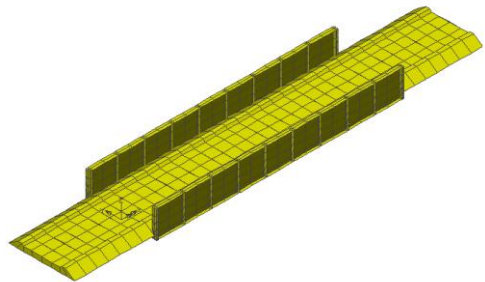
Train Induced Vibration of a Bridge

For LUSAS version:	17.0
For software product(s):	Any Plus version
With product option(s):	IMDPlus
Note: The example exceeds the limits of the LUSAS Teaching and Training Version.	

Description

This example examines the response of a steel rail bridge to the passage of a train.

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



Objectives

The output requirements of the analysis are:

- ☐ Deflections in the X-, Y- and Z-directions for a train speed of 15 m/s
- ☐ Accelerations in the vertical direction for a train speed of 70 m/s
- ☐ Peak deflections and accelerations in the vertical direction for a speed range of 15 m/s to 70 m/s in 5 m/s intervals
- ☐ Stress resultants and peak stress resultants in main girder web.

- ☐ Averaged and peak vertical displacements and resultant dynamic amplification factors from all of the nodes of the bridge structure
- ☐ Total summed reactions and peak reactions from all of the supported nodes of the bridge structure
- ☐ Averaged and peak stresses for a side panel of the bridge structure

Keywords

3D, Moving Load, Time Domain, Response, Interactive, Modal, Dynamics, IMD, IMDPlus, Eigenvalue.

Associated Files



- ☐ **IMDPlus Rail Bridge.mdl** Model of the structure.
- ☐ **ec1-3 Type3.lmd** Attribute library that contains the Eurocode ENV 1991-3 Type 3 moving load train definition for the example.
- ☐ **ec1-3 Type3.xls** Microsoft Excel spreadsheet that contains the axle positions and loads of the Eurocode ENV 1991-3 Type 3 train set.

Modelling

Running LUSAS Modeller

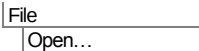
For details of how to run LUSAS Modeller see the heading *Running LUSAS Modeller* in the Examples Manual Introduction.

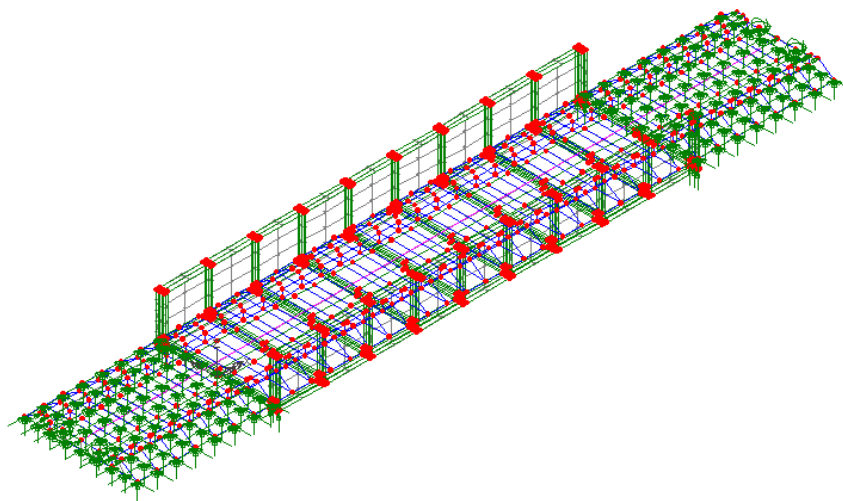
Building and loading the model

To create the model, open the read-only file **IMDPlus Rail Bridge.mdl** located in the **\<LUSAS Installation Folder>\Examples\Modeller** directory.

Depending upon your access rights it may be necessary to copy this file to another folder before it can be opened, and remove the read-only protection before it can be saved to the new folder. Once opened:

After a short while the following view of the model of the bridge will be displayed.

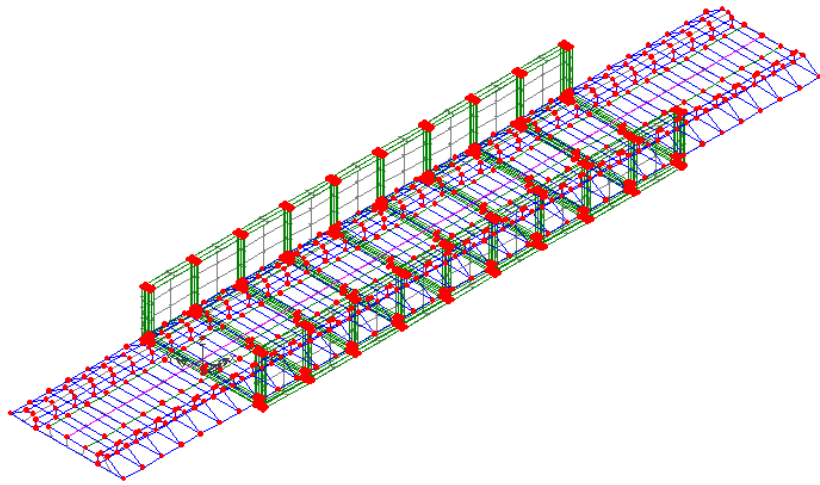




File

Save As...

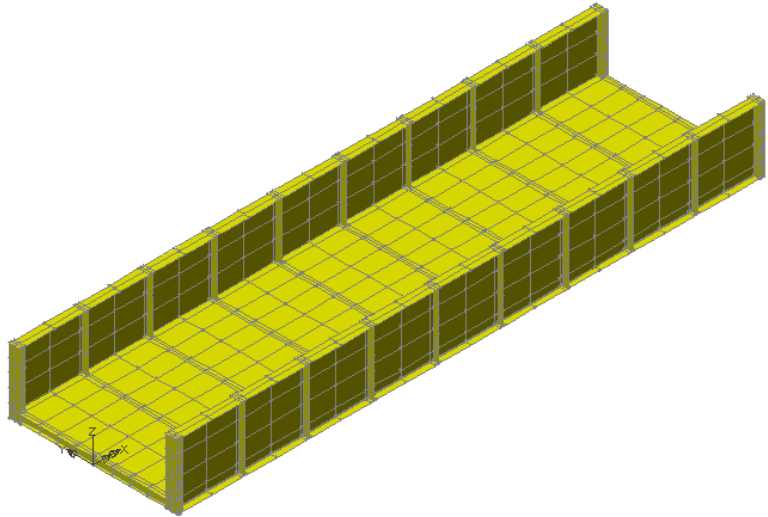
- In the \<LUSAS Installation Folder>\Projects\ folder create a new directory called **IMDPlus Rail Bridge**
- Save the model into this new folder as **IMDPlus Rail Bridge**. This helps keep all relevant IMDPlus created files separate from other analyses and is good practice.
- Turn off the display of the **Attributes** layer in the  Treeview.



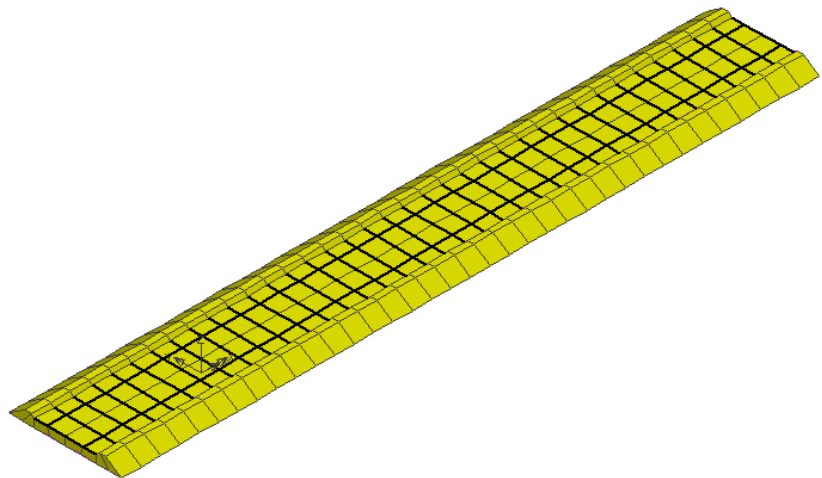
Note. No static structural loading is required for this analysis because only the dynamic loading is considered during the results processing, which is defined later.

Modelling Discussion

The bridge is approximately 16.5m long and 4.75m wide and carries a single track with ballast and concrete sleepers. The primary structure is constructed from steel and is modelled using shell elements. For this analysis, modelling of the ballast/track-bridge interaction has been carried out using a full 3D solid representation of the ballast with the sleepers modelled with thick beam elements laid along the top of the ballast. The rails of the track have been modelled using thick beam elements spanning between the sleepers and the whole ballast/track model is connected to the bridge deck using a sliding-only slideline. For the purposes of this example the bridge and ballast model has been represented with a coarse mesh and therefore the results from this analysis will be inaccurate. For analysing actual structures it is recommended that a finer mesh be used which can capture both the vibration modes of the bridge and the movement of the load across the bridge more accurately.

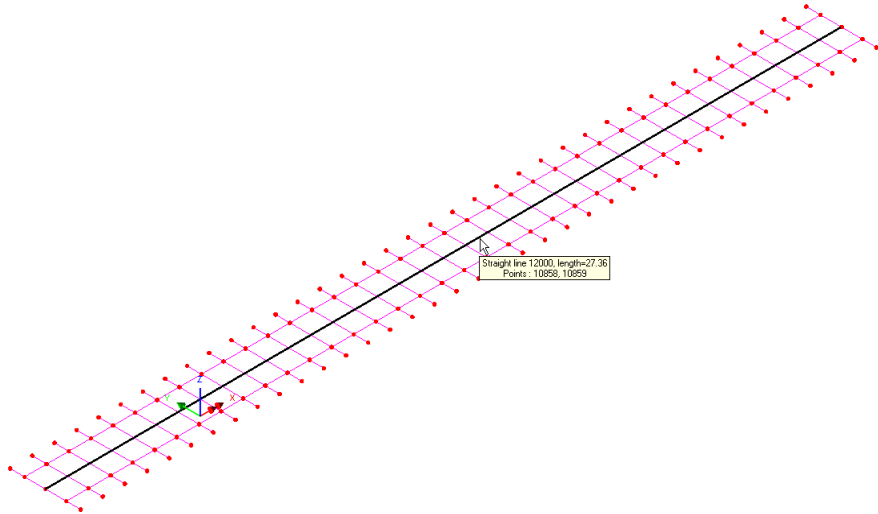


Bridge representation



Ballast representation

To allow the loading of the rails to be distributed to the 3D solid elements using discrete point loads the track modelling uses weak, weightless shell elements which span between the beam elements representing the rails. The track representation is shown in the following figure.



Track (sleepers and rails) representation

Note that the line down the centre of the track (Line 12000) is used to define the path of the train across the bridge and will be used later in this example. In order to avoid any adverse dynamic behaviour of the weak weightless shell elements, only one division is used to span between the two rails thus providing full support to the shells without adding stiffness to the model.

Defining Eigenvalue Controls

Eigenvalue controls are defined as properties of the loadcase.

- In the  Treeview expand **Analysis 1** then right-click on **Loadcase 1** and select **Eigenvalue** from the **Controls** menu.

The Eigenvalue dialog will appear.

The following parameters need to be specified:

- Set the **Eigenvalues required** to **Range**
- Ensure the **Range** is set to **Frequency**
- Set the **Minimum frequency** as **0**

- Set the **Maximum frequency** as 35
- Set the **Number of eigenvalues** to 0 (this solves for ALL frequencies in the range)
- Ensure the **Type of eigensolver** is set as **Default**



Note. Eigenvalue normalisation is set to **Mass** by default. This is essential if the eigenvectors are to be used for subsequent IMD analysis.

- Click the **OK** button to finish.

File
Save



Save the model file.

Running the Analysis

- With the model loaded click the **Solve** button  and the **Solve Now** dialog will be displayed.
- Click the **OK** button to run the analysis.

A LUSAS Datafile will be created from the model information. The LUSAS Solver uses this datafile to perform the analysis.

Viewing the Results

If the analysis was run from within LUSAS Modeller the results will be loaded on top of the current model and the loadcase results for each eigenvalue can be seen in the Loadcase layer. Eigenvalue 1 is set to be active by default.

Checking the Mass Participation Factor



Note. In order to carry out a successful IMDPlus analysis you should ensure that a significant proportion of the total mass has been accounted for in the analysis. This requires checking that around 90% of the total mass has been achieved in the global directions. If less than 90% has been achieved no further modes need be included, if and only if, the modes of vibration omitted cannot be excited by the dynamic input or a significant proportion of the structure is restrained by support in these directions and therefore cannot participate in the modes of vibration. The acceptability of the included modes of vibration will vary from analysis to analysis but failure to check that a significant proportion of the total mass has been accounted for may lead to important modes being missed and subsequent errors in the analysis results.

Train Induced Vibration of a Bridge

Utilities
Print Results
Wizard...

- Select results type **Eigenvalues**. For loadcase 1, in the available results panel select **Sum mass participation factors** and click **OK**. The results will be displayed and a Print Results Wizard entry will be added to the Utilities  treeview.

By inspection it can be seen that the 90% value has almost been achieved in all directions for this analysis. This is discussed in the note below.

	Mode	Sum Mass X	Sum Mass Y	Sum Mass Z	Frequency	Period
1	Mode	Sum Mass X	Sum Mass Y	Sum Mass Z	Frequency	Period
2	1	0.011094	11.7572E-6	0.70792	6.34543	0.157594
3	2	0.012197	13.3845E-6	0.708029	9.77548	0.102297
4	3	0.0125612	0.182964	0.708274	12.0099	0.083265
5	4	0.0131909	0.182989	0.769089	12.5713	0.0795462
6	5	0.0290473	0.352634	0.770999	16.3943	0.0609968
7	6	0.0430279	0.813529	0.77196	16.4965	0.0606191
8	7	0.177903	0.890132	0.806536	17.1152	0.0584277
9	8	0.178201	0.892043	0.831905	19.4168	0.0515019
10	9	0.188464	0.893014	0.832302	23.9716	0.041716
11	10	0.207253	0.893215	0.833539	24.0994	0.0414947
12	11	0.864564	0.893542	0.861563	24.6899	0.0405024
13	12	0.901	0.938795	0.86283	25.3893	0.0393866
14	13	0.901132	0.939785	0.86283	28.2782	0.0353629
15	14	0.920871	0.940199	0.864118	28.5492	0.0350273
16	15	0.920872	0.94036	0.881332	28.9011	0.0346007
17	16	0.938299	0.940366	0.882002	32.3329	0.0309282
18	17	0.938309	0.940637	0.882002	33.5977	0.029764
19	18	0.938347	0.940642	0.882003	34.5838	0.0289153
20	19	0.938366	0.940708	0.882003	34.9704	0.0285956



Note. In this analysis we are only including modes of vibration with frequencies up to and including 35 Hz with frequencies higher than this value considered insignificant for the analysis. In this analysis (and for mode 19) the results show that 93.8% of the total mass is achieved in the X-direction, 94.1% is achieved in the Y-direction and 88.2% is achieved in the Z-direction.

- Close the results window by selecting the close button in the top right hand corner of the window.
- Select results type **Eigenvalues**. For loadcase 1, in the available results panel de-select **Sum mass participation factors**, then select **Mass participation factors** and click **OK**. The results will be displayed and a Print Results Wizard entry will be added to the Utilities  treeview

Utilities
Print Results
Wizard...

Mass participation factors						
	Mode ▲	Mass PF X	Mass PF Y	Mass PF Z	Frequency	Period
1	Mode	Mass PF X	Mass PF Y	Mass PF Z	Frequency	Period
2	1	0.011094	11.7572E-6	0.70792	6.34543	0.157594
3	2	1.10297E-3	1.62728E-6	0.109262E-3	9.77548	0.102297
4	3	0.364226E-3	0.182951	0.245424E-3	12.0099	0.083265
5	4	0.629662E-3	24.1889E-6	0.0608148	12.5713	0.0795462
6	5	0.0158564	0.169645	1.91047E-3	16.3943	0.0609968
7	6	0.0139805	0.460895	0.960755E-3	16.4965	0.0606191
8	7	0.134875	0.0766029	0.0345759	17.1152	0.0584277
9	8	0.298085E-3	1.91048E-3	0.0253685	19.4168	0.0515019
10	9	0.0102626	0.971036E-3	0.397193E-3	23.9716	0.041716
11	10	0.0187893	0.200908E-3	1.23754E-3	24.0994	0.0414947
12	11	0.65731	0.327165E-3	0.0280234	24.6899	0.0405024
13	12	0.036436	0.045253	1.26713E-3	25.3893	0.0393866
14	13	0.132603E-3	0.990173E-3	13.0638E-9	28.2782	0.0353629
15	14	0.0197387	0.413466E-3	1.28847E-3	28.5492	0.0350273
16	15	0.797027E-6	0.161819E-3	0.0172134	28.9011	0.0346007
17	16	0.0174272	5.17541E-6	0.670045E-3	32.3329	0.0309282
18	17	10.0738E-6	0.271287E-3	0.727634E-6	33.5977	0.029764
19	18	38.3935E-6	4.73477E-6	47.9303E-9	34.5838	0.0289153
20	19	18.5724E-6	66.7088E-6	66.4934E-9	34.9704	0.0285956

Model info 1: Loadcase 1 (Mass participation factors)

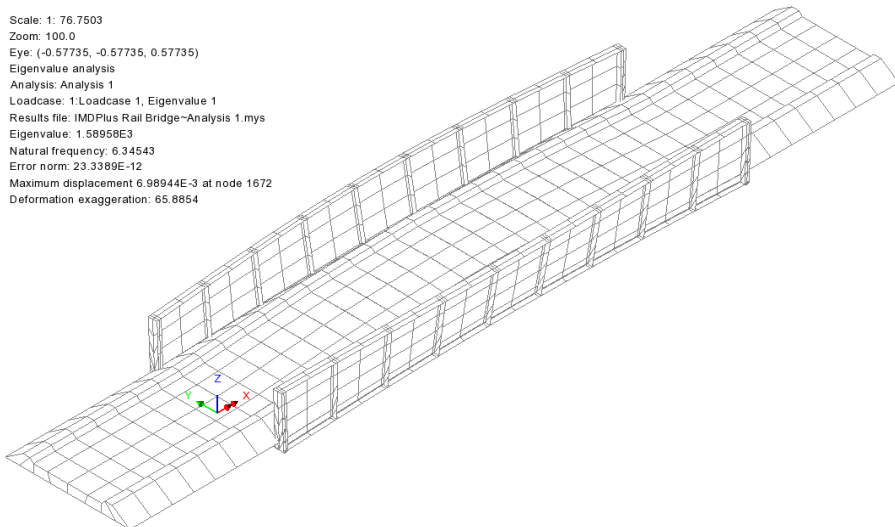
From these mass participation factors the major modes of vibration of the bridge can be seen to be mode 1 in the Z-direction (vertical) and modes 3, 5 and 6 in the Y-direction (lateral).

- Close the results window, and use the maximise button to increase the size of the graphics window.

Plotting Mode Shapes

- Turn off the display of the **Mesh**, and **Geometry** layers in the  Treeview.
- With no features selected click the right-hand mouse button in a blank part of the Graphics area and select the **Deformed mesh** option to add the deformed mesh layer to the  Treeview. Click the **OK** button to accept the default values and display the deformed mesh for Eigenvalue 1.
- If supports are shown click on the Supports on/off  button to remove the supports from the display.
- In the panel at the bottom of the  Treeview select the **Window summary** option and click the **Details...** button. In the Window summary properties dialog set the position to **(50,-10)** and click the **OK** button to return to the graphics window.

This mode of vibration is the primary mode in the vertical direction as determined in the Checking the Mass Participation Factor section.

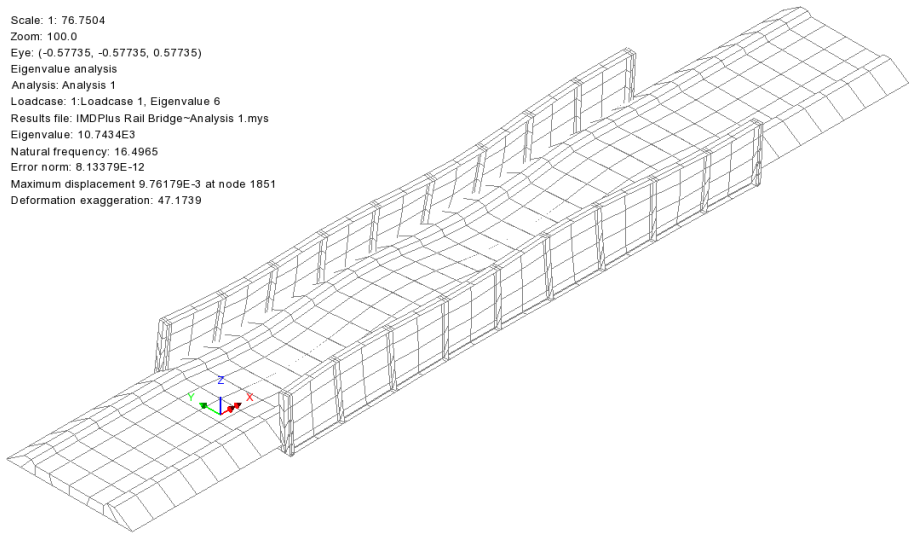


By setting each Eigenvalue to be active the deformed mesh can be seen for all mode shapes.

- In the  Treeview right-click on **Eigenvalue 6** and select the **Set Active** option. The deformed mesh plot for Eigenvalue 6 will be displayed.

This mode of vibration has the highest participating mass in the lateral (Y) direction for the whole bridge as determined in the Checking the Mass Participation Factor section.

Scale: 1: 76.7504
 Zoom: 100.0
 Eye: (-0.57735, -0.57735, 0.57735)
 Eigenvalue analysis
 Analysis: Analysis 1
 Loadcase: 1: Loadcase 1, Eigenvalue 6
 Results file: IMDPlus Rail Bridge-Analysis 1.mys
 Eigenvalue: 10.7434E3
 Natural frequency: 16.4965
 Error norm: 8.13379E-12
 Maximum displacement 9.76179E-3 at node 1851
 Deformation exaggeration: 47.1739



Note. The window summary displays the values of the eigenvalue and the natural frequency and also a value for displacement at a node. It should be noted that the displacement value is non-quantitative and is related to the amount of mass in a particular mode using the mass normalisation technique. Therefore the only items that can be found using a basic eigenvalue analysis are the frequency and the mode shape.



Note. The mode shape may be inverted. This is because the sense is arbitrary since during vibration the deformed shape will appear in both directions.

Selecting individual nodes and elements of interest

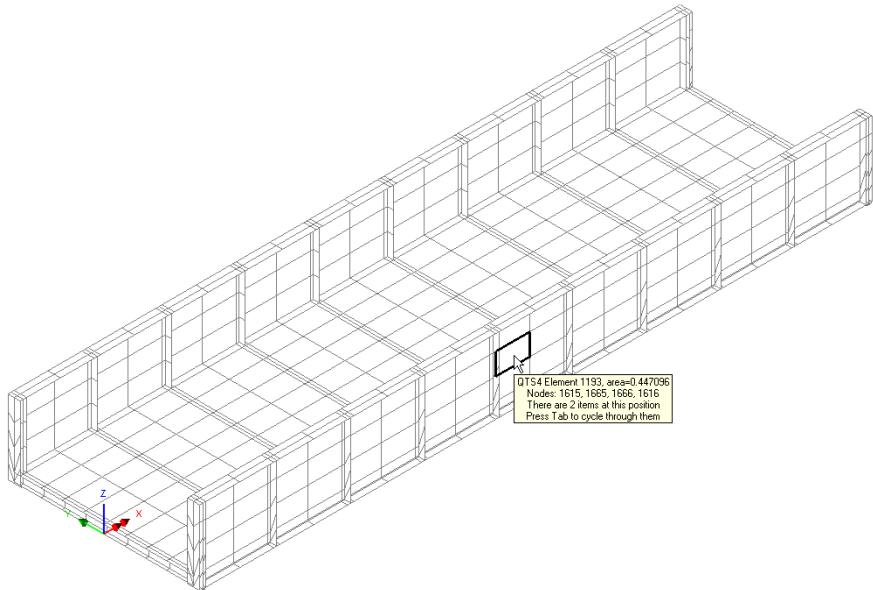
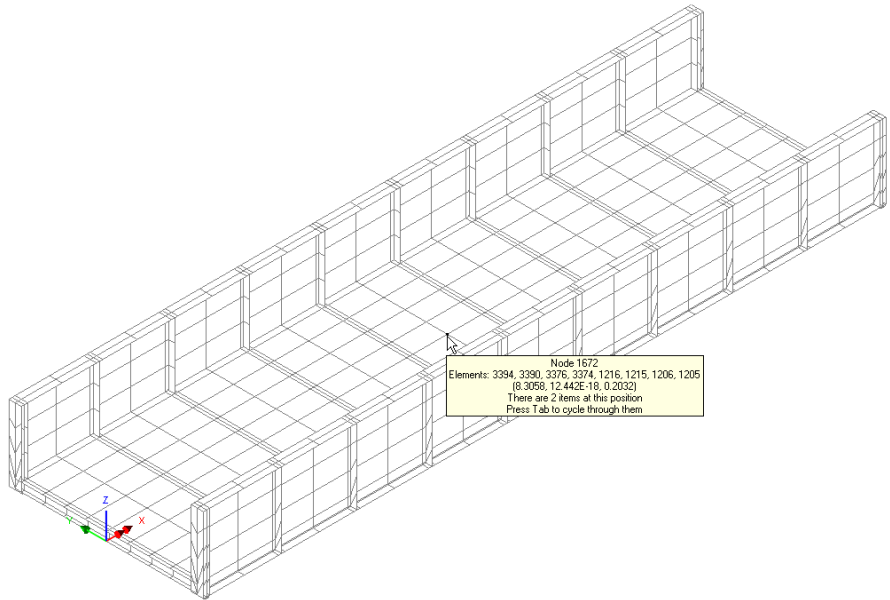
Prior to running an IMDPlus analysis, individual node and element numbers for the locations of the structure that will be assessed should be ascertained. This can be done by selecting the locations of interest with the cursor and noting down the numbers of the node and elements concerned.

- Turn off the display of the **Deformed mesh** and **Annotation** layers in the  Treeview.
- In the  Treeview double-click on the **Mesh** layer name and click the **OK** button to accept the default settings. This will turn on the layer.

To view just the bridge structure without the ballast and track:

- In the  Treeview click the right-hand mouse button on the group name **Bridge_Structure** and select the **Set as Only Visible** option from the drop-down menu.

By selecting or hovering the cursor over the node and element shown, the node or element number of interest can be obtained. For the first stage of this analysis we are interested in the node at the centre of the bridge deck and the element in the middle of the side girder, as shown in the following figures.

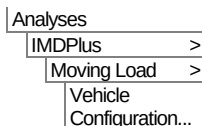


Defining the Eurocode ENV 1991-3 Type 3 Trainset

Before the analysis can be performed we need to define the moving load representation of the Eurocode ENV 1991-3 Type 3 trainset in LUSAS Modeller.



Note. To simplify the use of IMDPlus (and provide an alternative to picking IMDPlus menu selections from the Analyses > IMDPlus menu items) for the rest of the example it is recommended that the IMDPlus toolbar is enabled in LUSAS Modeller. To do this select the **View > Toolbars...** menu command, select the **Toolbars** tab, enable the **IMDPlus** option in the list and click **Close**.



- If the IMDPlus toolbar has been enabled, click on the  Moving Load analysis button in the toolbar to select a moving load analysis and enable the toolbar shortcuts to the dialogs.
- Open the IMDPlus Moving Load Vehicle Configuration dialog through the menu or click on the  button in the toolbar. The moving load vehicle is now defined using the positions of the axles relative to the front of train together with the moving load factors to be applied at each position. To simplify the definition of the vehicle the positions and loads are included in a Microsoft Excel spreadsheet so they can be copied and pasted into the dialog.
- Locate the **ec1-3 Type3.xls** spreadsheet in the **\<LusasInstallationFolder>\Examples\Modeller** folder and open it.
- Select all of the **60** positions and loads in the first and second columns and copy these to the clipboard using the **Ctrl+C** keys.
- Select both the **Position** and **Load** headers of the grid in the dialog and paste the copied data into the grid using the **Ctrl+V** keys.
- Enter the name as **ec1-3 Type3**

	Position	Load
1	0	200000
2	-3	200000
3	-11.46	200000
4	-14.46	200000
5	-18.91	150000
6	-21.41	150000
7	-37.91	150000
8	-40.41	150000
9	-45.31	150000
10	-47.81	150000
11	-64.31	150000
12	-66.81	150000
13	-71.71	150000
14	-74.21	150000
15	-90.71	150000
16	-93.21	150000
17	-98.11	150000
18	-100.61	150000
19	-117.11	150000
20	-119.61	150000

Name: (new)

OK Cancel Apply Help

Once finished the dialog should appear as shown.

- Click **OK** to create the vehicle configuration.

Alternatively each **Position** and **Load** in the table can be entered manually.



Note. The positions of the axles should be defined as negative values to ensure that the whole trainset passes over the structure. Negative values place the axles behind the front of the train which is at a position of 0. The movement of the front of the train will be calculated from the start of the path to the end of the path with additional time included in the IMDPlus solution to allow all of the axles with negative positions to pass along the path.

If any axles are defined with positive values then these will already be the distance down the path equivalent to the position entered in the vehicle configuration. Those axles with positive positions may already be over the structure at the start of the IMDPlus analysis if the start of the path has not been defined to account for this. If any positive positions are used then always ensure that the lines defining the beginning of the path allow sufficient additional length in order to model the transition of the whole of the train onto the structure correctly.



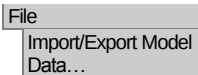
Note. Once a trainset or vehicle has been defined it can be saved in a library so it can be imported and used in future analyses without the need to go through all of the definition process above. This is achieved through the **Library Browser** accessed through the **File > Import/Export Model Data...** menu command.

Importing a Vehicle

If it proves time consuming or you are unable to obtain the same results shown later in the example the vehicle definition can be imported from the library provided in the `\<LusasInstallationFolder>\Examples\Modeller` folder.



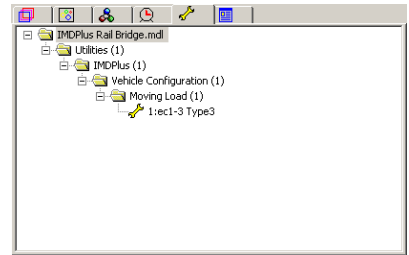
- ☐ The **ec1-3 Type3.lmd** contains the vehicle library for the example.



- Select the **Import from library to model** option
- Click on the **Choose file...** button and browse to the **ec1-3 Type3.lmd** file in the `\<LusasInstallationFolder>\Examples\Modeller` folder.
- Select the **IMDPlus (1)** entries in the tree
- Click the **OK** button.

After vehicle configuration attribute has been defined it will appear in the  Utilities treeview.

If it is required to edit the vehicle configuration attribute simply double-click with the left mouse button or right-click and choose **Edit Attribute...** on the name of the attribute to bring up the original dialog.



Moving Load Analysis

Moving load calculations are performed using the IMDPlus (Interactive Modal Dynamics) facility. In order to carry out the moving load analysis of the train travelling across the bridge we need to carry out three stages:

1. Define and set-up the path along which the moving loads will travel using a unit load defined as either a discrete point or patch load. For this example the unit axle load has already been defined as a discrete point load called **Unit Axle Load** which acts vertically
2. Convert the loading along this path from this unit load into modal forces that are applied in the IMDPlus moving load analysis
3. Run an IMDPlus moving load analysis to calculate the response of the bridge



Note. This process is similar to the IMDPlus moving mass analysis procedure but with the trainset / vehicle defined by constant forces rather than spring-mass systems.



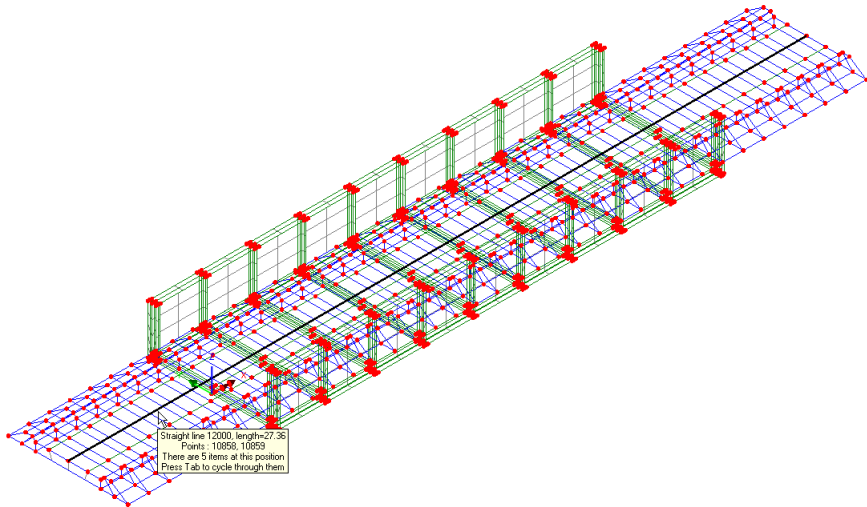
Note. Before an IMDPlus analysis can be carried out the load that is going to pass over the structure must be defined using either discrete point or patch loads. For this example this has already been carried out with a single axle of unit load defined as a discrete point load. Defining a single axle allows multiple load configurations to be analysed through the composite axle definition method in IMDPlus without the need to carry out the path and modal force stages for each layout. For railways the axle lengths remain constant over all of the train set and this method would normally be used. For moving loads where axles are of different widths the full definition of the load must be carried out with the path and modal force stages carried out for each layout.

Defining the Moving Load Path

To solve for the passage of the train across the bridge the path for the moving load must be defined. Line 12000 (the line representing the path of the moving load) will be set to be the current selection.

To view the complete model again:

- In the  Treeview click the right-hand mouse button on the group name **IMDPlus Rail Bridge.mdl** and select the **Visible** option from the drop-down menu. Click **Yes** when asked whether to act on subgroups as well.
- In the  Treeview double-click on the **Geometry** layer name and click the **OK** button to accept the default settings. This will also turn on the layer.
- Select the **line** shown (line 12000)

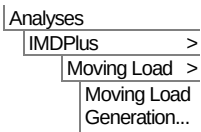


Note. The path can be built from multiple lines and arcs but these must form a continuous path without branching.

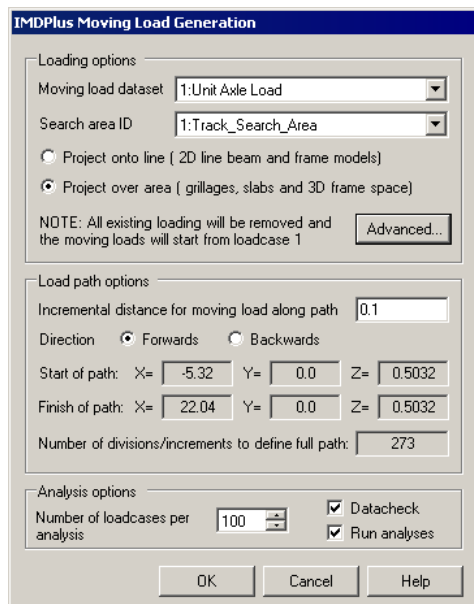
- Open the IMDPlus Moving Load Generation dialog through the menu or click on the  button in the toolbar.

On startup of the IMDPlus Moving Load Generation dialog, all valid discrete loads and search areas will be made available in the loading options along with information about the path defined by the current selection.

In this example a single discrete load called Unit Axle Load which defines the unit loading from a single axle of the train is present along with a search area that is assigned to the weak weightless shells.



- Ensure **1:Unit Axle Load** is selected from the **Moving load dataset** list.
- Ensure **1:Track_Search_Area** is selected from the **Search area ID** for the assignment of the discrete loading.
- Ensure **Project over area** is selected.
- Click on the **Advanced** button to adjust the inclusion of load characteristics. On the Moving Load Advanced Options dialog choose the **Include Full Load** option for loads outside the search area and click the **OK** button.
- On the IMDPlus Moving Load Generation dialog set the **Incremental distance** to **0.1**



The image shows the 'IMDPlus Moving Load Generation' dialog box. It has several sections: 'Loading options' with dropdowns for 'Moving load dataset' (set to '1:Unit Axle Load') and 'Search area ID' (set to '1:Track_Search_Area'). There are radio buttons for 'Project onto line' and 'Project over area' (selected). A note states: 'NOTE: All existing loading will be removed and the moving loads will start from loadcase 1'. An 'Advanced...' button is next to the note. The 'Load path options' section includes a text box for 'Incremental distance for moving load along path' (set to '0.1'), radio buttons for 'Direction' (selected 'Forwards'), and input fields for 'Start of path' and 'Finish of path' with X, Y, and Z coordinates. The 'Number of divisions/increments to define full path' is set to '273'. The 'Analysis options' section has a spinner for 'Number of loadcases per analysis' (set to '100') and checkboxes for 'Datacheck' and 'Run analyses' (both checked). At the bottom are 'OK', 'Cancel', and 'Help' buttons.



Note. Using search areas targets the application of the loading to the required features as described in the Modeller Reference Manual.



Note. By default the incremental distance is set to one tenth of the length of the line along which the load moves.

- Click the **OK** button to proceed and choose **Yes** to accept the warnings and save the current model.

The program will now generate the loading information for the 274 locations of the unit axle along the path before returning control back to LUSAS Modeller. This process will take only a minute or so on a modern computer and does not need to be repeated unless the lateral configuration of the load changes. For a railway this will not happen but it may be required for highway analyses where the axle lengths and tyre configurations could vary.



Note. The discrete loading locations defined by this dialog will be tabulated into three datafiles with a maximum of 100 loadcases each and the analyses will be performed automatically. These analyses will use the same file basename as the original model with a numeric indicator appended to it (e.g. _00001, _00002, etc). They are required for the modal force calculation stage.

Generating the Modal Force History for the Moving Load

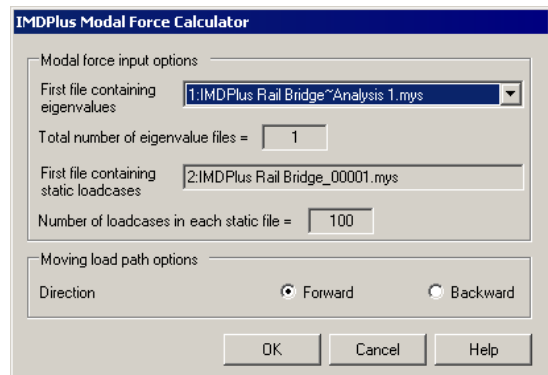
In the previous stage the passage of the train axle across the structure has been defined. The modal forces for the IMDPlus solution now need to be calculated using the Modal Force Calculator.

- Open the IMDPlus Modal Force Calculator dialog through the menu or click on the  button

- Click the **OK** button to accept the default information and proceed.



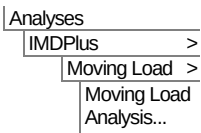
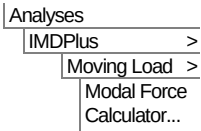
Note. This process will take only a minute or so on a modern computer and does not need to be repeated unless the moving load path or configuration in Stage 1 is changed.



Defining the Moving Load Parameters

All of the basic moving load information has now been defined for the IMDPlus analysis. The next stage is to define the included modes, damping and speed parameters.

- Open the IMDPlus Moving Load Analysis Control dialog through the menu or click on the  button in the toolbar.



- Click on the **Vehicle Configuration (Composite axle)** option since we are using a unit load axle definition.
- Ensure the Vehicle configuration contains **1:ec1-3 Type3**
- Ensure that **Included modes** is set to **All**. If this is not the case, click on the **Modify...** button and ensure the **All modes** option is selected.

IMDPlus Moving Load Analysis Control

Moving load input

☒ Vehicle configuration (Composite axle) 1:ec1-3 Type3

Mode/damping control

Included modes: All Modify...

☒ Default damping 5.0 % Modify...

Total participating mass

X-Direction	93.83 %
Y-Direction	94.07 %
Z-Direction	88.20 %

Solution control

Advanced solution options Modify...

Minimum speed 15 Quiet time after passage of load 0.0

Maximum speed 70 ☐ IMDPlus automatic time step (Nyquist)

Speed increment 5 Solution time step 1E-3

< Back Next > Cancel Help

- Ensure **Default damping** of **5.0** is selected. If a different damping is displayed, click on the **Modify...** button and set the **Default damping** to **5.0**
- In the Solution control section, click on the **Modify...** button to change the advanced solution options. Click the **Defaults** button to set the default options and click the **OK** button.
- Enter the **Minimum Speed** as **15**, the **Maximum Speed** as **70** and the **Speed Increment** as **5**
- Deselect the **IMDPlus determining time step (Nyquist)** option so we can specify the required time step
- Enter the **Solution time step** as **1E-3**
- Click the **Next** button to proceed. When prompted about significant missing total mass choose **Yes** to continue. For this analysis we are only interested in the contributions of modes of vibration up to and including 35Hz which means that we are not going to achieve the 90% total mass target.

The information entered above will analyse the passage of a Eurocode ENV 1991-3 Type 3 train (with axle details as held in the file ec1-3 Type3.xls) across the bridge for a speed range of 15 m/s to 70 m/s in increments of 5 m/s (or 54 kph to 252 kph in increments of 18 kph). The quiet time allows for the decay of the response of the bridge

after the train has passed across and the solution time step forces the time step to be used in the analyses.

Displaying Individual Node and Element Results for Moving Load Analysis

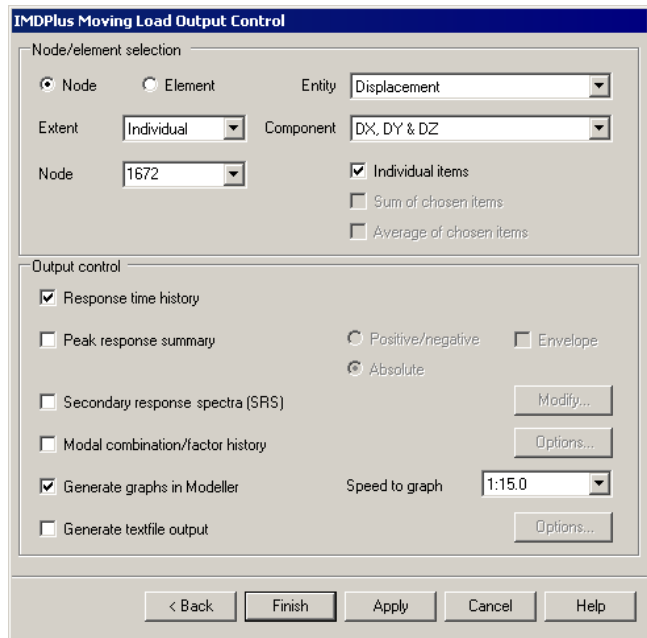
The IMDPlus Output Control dialog will appear. This controls the results output for the model.

Displacement and Acceleration Graphs

The response of the mid-span of the bridge for the range of speeds selected will be investigated. Initially we will look at the displacements of the mid-span for a single speed of 15 m/s (or 54 kph).

Enter the following information into the output control dialog:

- Choose **Node** and select **Extent** as **Individual**
- Enter **Node** number **1672** (This is the node in the centre of the bridge deck at the mid-span of the bridge)
- Select **Displacement** results of **DX, DY & DZ**
- Ensure **Individual items** is selected. **Sum of chosen items** and **Average of chosen items** will not be available as an individual node is being processed.
- Ensure **Response time history** is selected.
- Ensure **Generate graphs in Modeller** is selected.



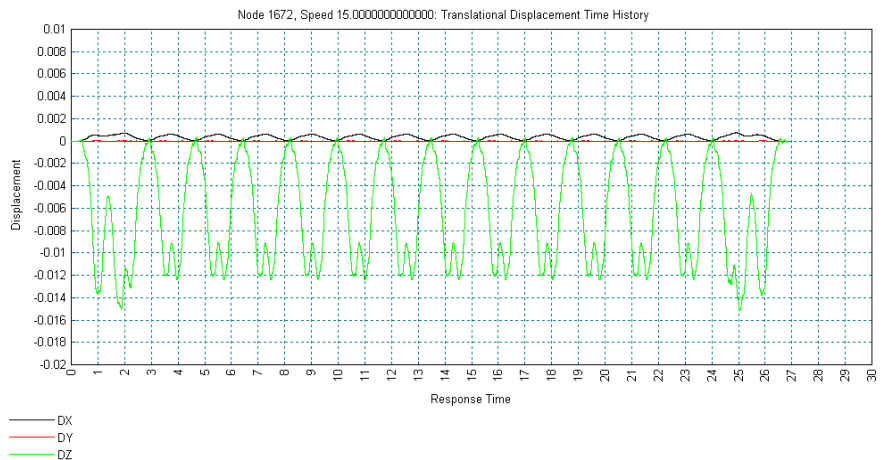
The image shows the 'IMDPlus Moving Load Output Control' dialog box. It is divided into two main sections: 'Node/element selection' and 'Output control'. In the 'Node/element selection' section, 'Node' is selected with radio buttons, 'Extent' is set to 'Individual', 'Node' is set to '1672', 'Entity' is 'Displacement', and 'Component' is 'DX, DY & DZ'. Under 'Individual items', 'Individual items' is checked, while 'Sum of chosen items' and 'Average of chosen items' are unchecked. The 'Output control' section has 'Response time history' checked, 'Peak response summary' unchecked, 'Secondary response spectra (SRS)' unchecked, 'Modal combination/factor history' unchecked, 'Generate graphs in Modeller' checked, and 'Generate textile output' unchecked. There are also options for 'Positive/negative' (unchecked), 'Absolute' (checked), and 'Envelope' (unchecked). Buttons for 'Modify...', 'Options...', and 'Speed to graph' (set to '1:15.0') are present. At the bottom are buttons for '< Back', 'Finish', 'Apply', 'Cancel', and 'Help'.

- Set the **Speed to graph** as **1:15.0** which indicates that the first speed of 15 m/s is being processed
- Click the **Apply** to proceed.



Note. Clicking the Apply button instead of the Finish button keeps the IMDPlus Control Dialog accessible for subsequent graph plotting.

The IMDPlus analysis will now run.



- When the graph has been displayed, close the graph

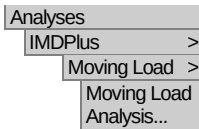
The vertical acceleration response of the mid-span for a single speed of 15 m/s (or 54 kph) will now be investigated.

If the IMDPlus toolbar has been enabled,

- Click on the  button in the toolbar to open the IMDPlus Output Control dialog

If the IMDPlus toolbar is not enabled,

- Open the IMDPlus Moving Load Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog.



- On the IMD Output Control dialog select **Acceleration** results of **AZ** for the vertical component only
- Click the **Apply** button and not the Finish button to proceed.



Note. IMDPlus does not need to be rerun since the acceleration results were computed at the same time as the displacement results.

IMDPlus Moving Load Output Control

Node/element selection

☒ Node ☐ Element Entity: Acceleration

Extent: Individual Component: AZ

Node: 1672

☒ Individual items
☐ Sum of chosen items
☐ Average of chosen items

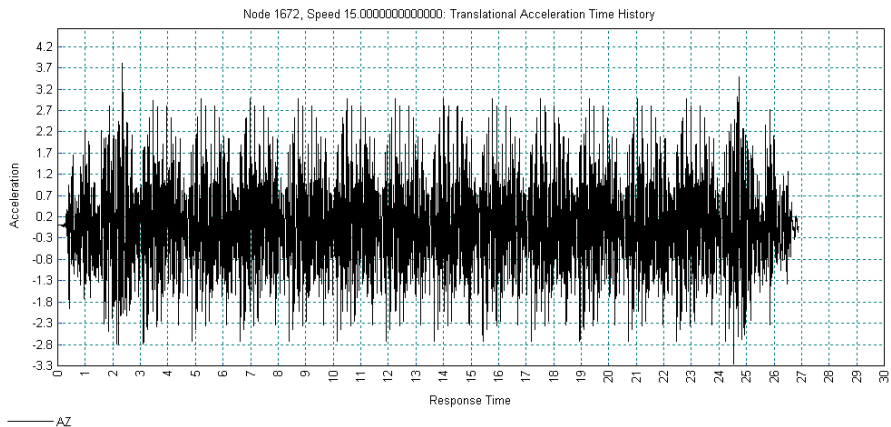
Output control

☒ Response time history
☐ Peak response summary
☐ Secondary response spectra (SRS)
☐ Modal combination/factor history
☒ Generate graphs in Modeller
☐ Generate textfile output

☐ Positive/negative ☐ Envelope
☒ Absolute

Speed to graph: 1:15.0

Buttons: < Back, Finish, Apply, Cancel, Help



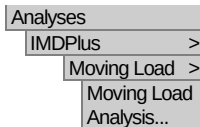
- When the graph has been displayed, close the graph

Previously we have investigated the displacement and acceleration response of the mid-span of the bridge deck for a single train speed. We will now look at the peak positive and negative vertical displacement and acceleration responses of the mid-span over the speed range of 15 m/s to 70 m/s as specified previously in the moving load analysis control dialog.

If the IMDPlus toolbar has been enabled,

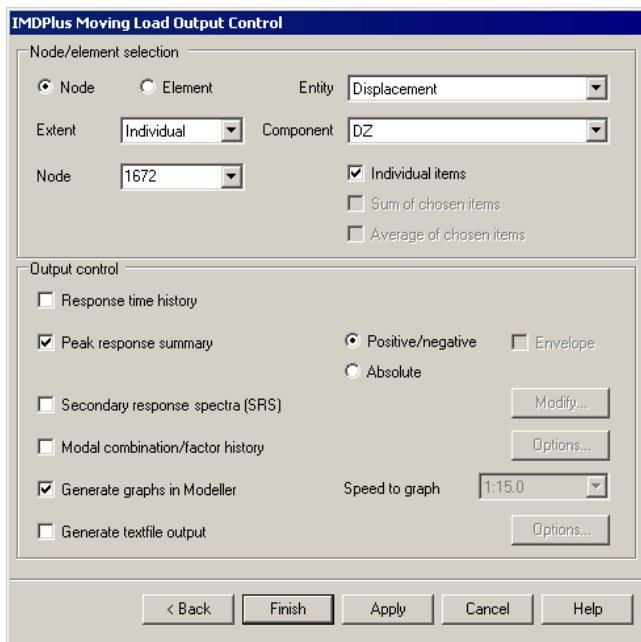
- Click on the  button in the toolbar to open the IMDPlus Output Control dialog

If the IMDPlus toolbar is not enabled,



- Open the IMDPlus Moving Load Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog.

- On the IMDPlus Output Control dialog select **Displacement** results of **DZ** for the vertical component only.
- Deselect the **Response time history** option
- Select the **Peak response summary** option and select **Positive/negative**
- Click the **Apply** button to proceed.



The dialog box is titled "IMDPlus Moving Load Output Control". It is divided into two main sections: "Node/element selection" and "Output control".

Node/element selection:

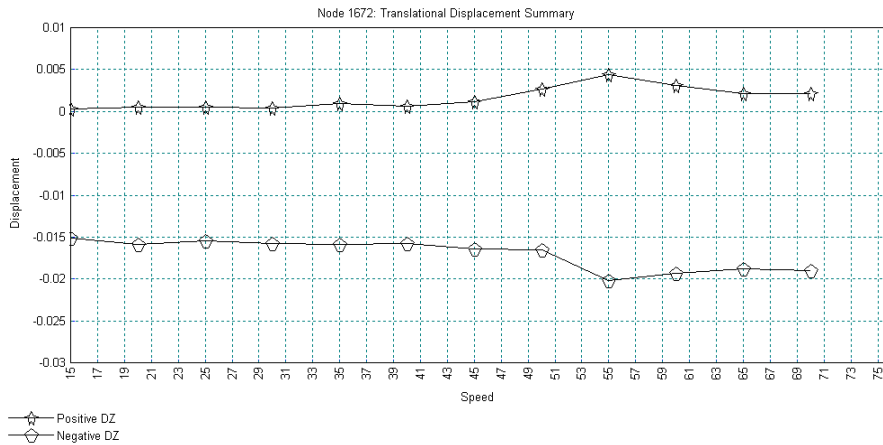
- Node/element selection:** Radio buttons for "Node" (selected) and "Element".
- Entity:** A dropdown menu showing "Displacement".
- Extent:** A dropdown menu showing "Individual".
- Component:** A dropdown menu showing "DZ".
- Node:** A dropdown menu showing "1672".
- Options:**
 - ☒ Individual items
 - ☐ Sum of chosen items
 - ☐ Average of chosen items

Output control:

- ☐ Response time history
- ☒ Peak response summary
 - ☒ Positive/negative
 - ☐ Absolute
- ☐ Secondary response spectra (SRS)
- ☐ Modal combination/factor history
- ☒ Generate graphs in Modeller
 - Speed to graph:** A dropdown menu showing "1:15.0".
- ☐ Generate textfile output

Buttons at the bottom: "< Back", "Finish", "Apply", "Cancel", and "Help".

The IMDPlus analysis will now run.



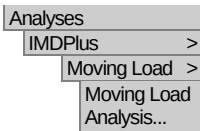
- When the graph has been displayed, close the graph

If the IMDPlus toolbar has been enabled,

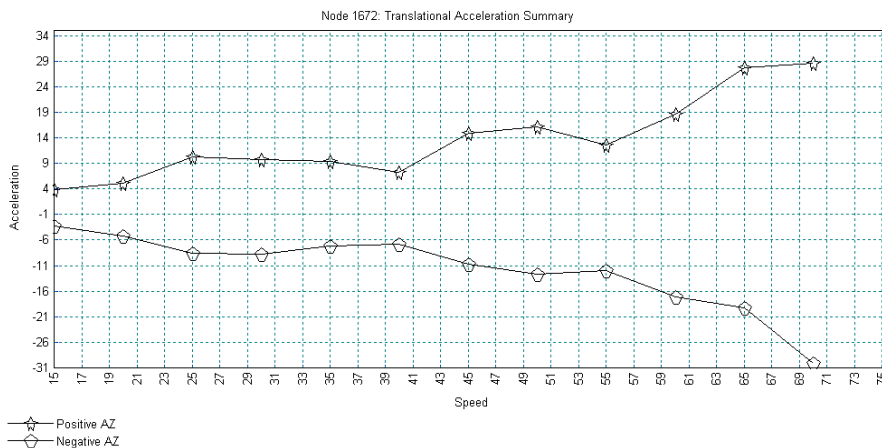
- Click on the  button in the toolbar to open the IMDPlus Output Control dialog

If the IMDPlus toolbar is not enabled,

- Open the IMDPlus Moving Load Analysis Control dialog through the menu and click **Next** > to keep the existing analysis control settings and open the IMDPlus Output Control dialog.



- Select **Acceleration** results of **AZ** for the vertical component only
- Click the **Apply** button to display a graph of acceleration versus speed at the mid-span.



- When the graph has been displayed, close the graph

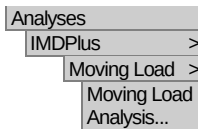
Stress Resultant Graphs for Shells

In the previous section the displacement and acceleration responses at the mid-span of the bridge were investigated. We will now look at the stress resultants in the web of one of the main girders. Results for element number 1193 in the centre of the web of the nearside girder will be investigated.

If the IMDPlus toolbar has been enabled,

- Click on the  button in the toolbar to open the IMDPlus Output Control dialog

If the IMDPlus toolbar is not enabled,

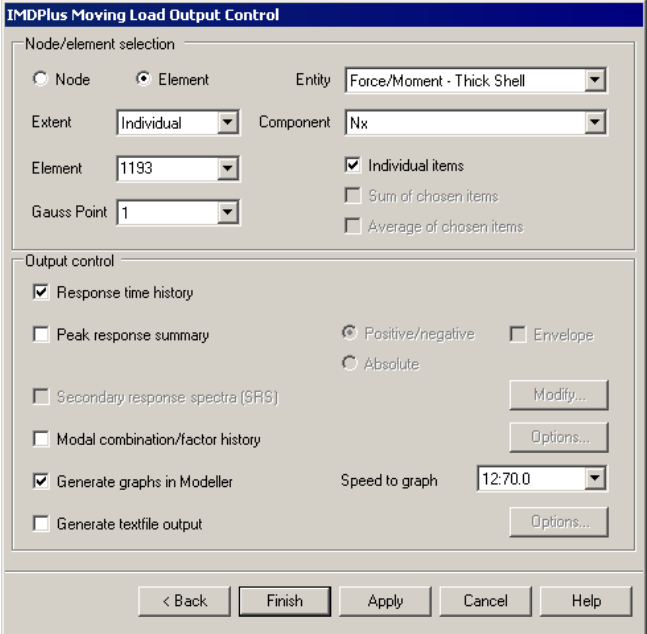


- Open the IMDPlus Moving Load Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog.

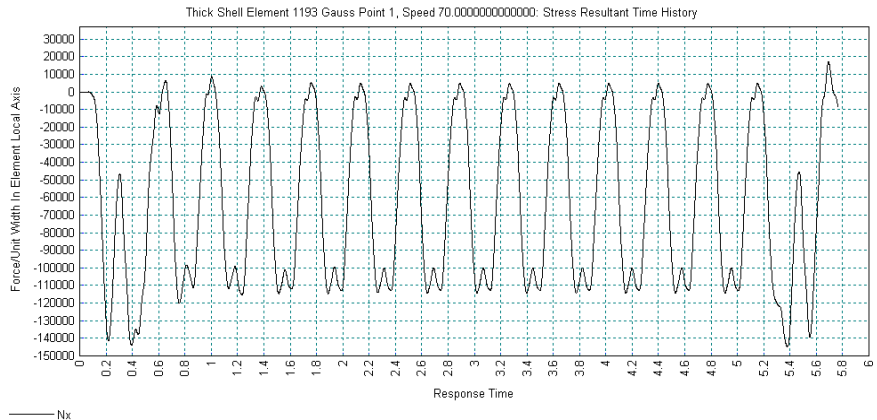
Enter the following information into the IMDPlus Output Control dialog.

- Select **Element** and ensure **Extent** remains set as **Individual**
- Enter **Element** number **1193** and set **Gauss Point** to **1**
- Select **Force/Moment** – **Thick Shell** results of **Nx** which is the stress resultant in the longitudinal bridge direction.
- Ensure **Individual items** is selected. **Sum of chosen items** and **Average of chosen items** will not be available as an individual element is being processed.
- Ensure the **Response time history** option is selected.
- Deselect the **Peak response summary** option.
- Set the **Speed to graph** as **12:70.0** which indicates that the twelfth and last speed of 70 m/s is being processed.
- Click the **Apply** button to display a graph of Nx versus time for gauss point 1 of element 1193.

The IMDPlus analysis will now run and a graph of Nx versus time for gauss point 1 of element 1193 will be displayed.



The image shows the 'IMDPlus Moving Load Output Control' dialog box. It is divided into two main sections: 'Node/element selection' and 'Output control'. In the 'Node/element selection' section, 'Node' is unselected and 'Element' is selected. The 'Entity' dropdown is set to 'Force/Moment - Thick Shell', 'Extent' is 'Individual', 'Component' is 'Nx', 'Element' is '1193', and 'Gauss Point' is '1'. Under 'Output control', 'Response time history' is checked, while 'Peak response summary', 'Secondary response spectra (SRS)', and 'Modal combination/factor history' are unchecked. 'Generate graphs in Modeller' is checked, and 'Generate textfile output' is unchecked. The 'Speed to graph' dropdown is set to '12:70.0'. There are buttons for 'Modify...', 'Options...', and 'Options...' next to the SRS, Modal combination, and Generate textfile options respectively. At the bottom are buttons for '< Back', 'Finish', 'Apply', 'Cancel', and 'Help'.

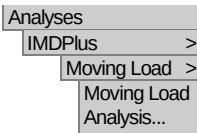


- When the graph has been displayed, close the graph

If the IMDPlus toolbar has been enabled,

- Click on the  button in the toolbar to open the IMDPlus Output Control dialog

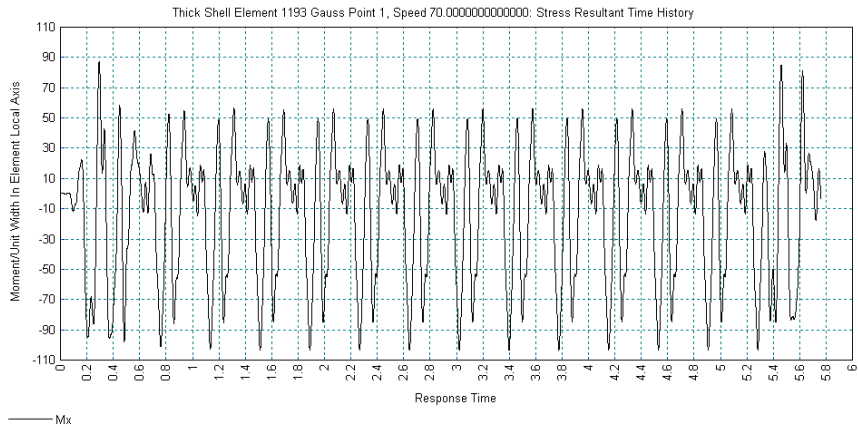
If the IMDPlus toolbar is not enabled,



- Open the IMDPlus Moving Load Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog.

- Select **Force/Moment – Thick Shell** results of **Mx** which is the moment in the along bridge direction
- Click the **Apply** button to proceed.

After a short pause a graph of Mx versus time for gauss point 1 of element 1193 will be created.



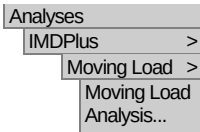
- When the graph has been displayed, close the graph

If the IMDPlus toolbar has been enabled,

- Click on the  button in the toolbar to open the IMDPlus Output Control dialog

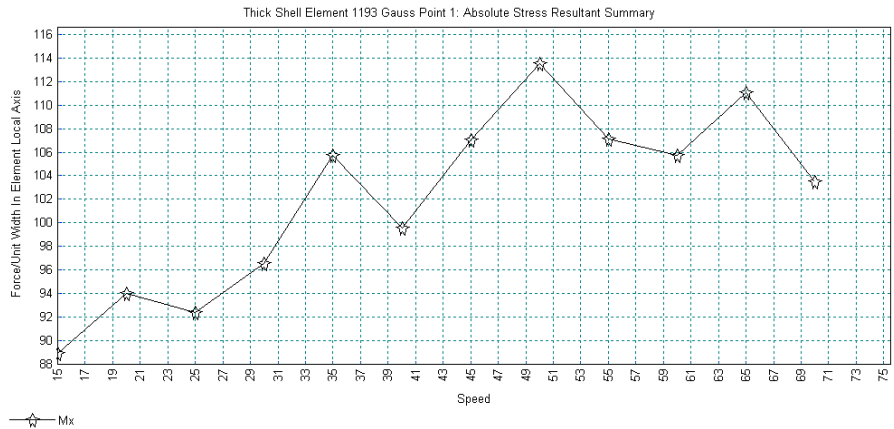
If the IMDPlus toolbar is not enabled,

- Open the IMDPlus Moving Load Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog.



- Deselect the **Response time history** option
- Select the **Peak response summary** option and select **Absolute**
- Click the **Finish** button.
- Click **Yes** when asked whether to free up disk space by deleting the temporary files created by IMDPlus.

A graph of absolute peak Mx versus speed for gauss point 1 of element 1193 will be generated.



- Close the graph window.

Displaying Results for a Selection of Nodes and Elements

In the preceding sections the analyses utilised individual nodes and elements of the structure. In the following sections chosen sets of nodes and elements will be used in order to investigate the following results for the bridge structure:

- ☐ Averaged and peak displacements and dynamic amplification factors
- ☐ Total summed reactions and peak reactions
- ☐ Averaged and peak stresses in a side panel

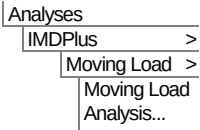
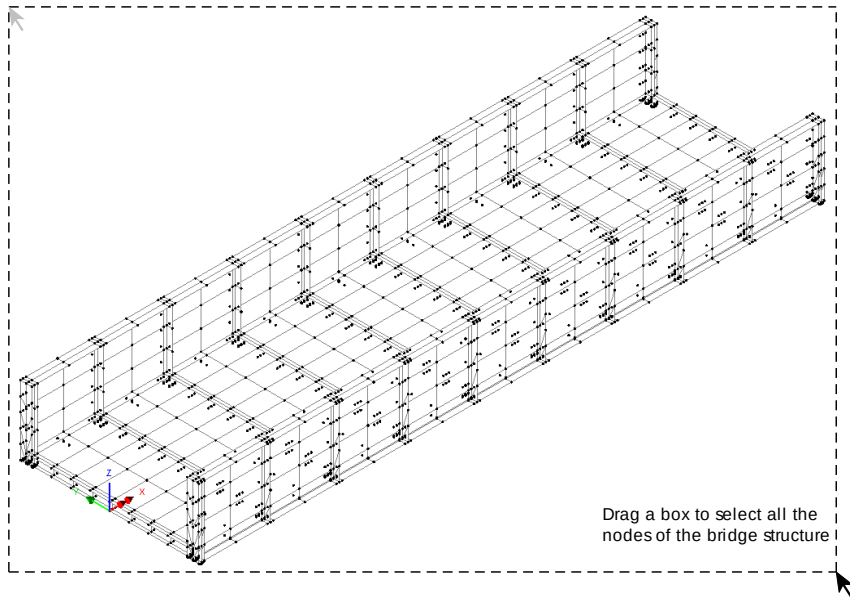
Averaged and Peak Displacements and Dynamic Amplification Factors for the Bridge Structure

In order to examine the averaged and peak displacements and dynamic amplification factors, a selection of nodes needs to be created that contains all of the nodes of the bridge structure.

- Turn off the **Geometry** layer in the  Treeview.
- In the  Treeview click the right-hand mouse button on the group name **Bridge_Structure** and select the **Set as Only Visible** option from the drop-down menu.



Using Select Nodes drag a box to select all of the 1665 nodes of the bridge structure, as shown in the following figure.



- Open the IMDPlus Moving Load Analysis Control dialog through the menu or click on the  button in the toolbar.
- On the IMDPlus Moving Load Analysis Control dialog click the **Next** button to accept the previously defined values. When prompted about the total mass participation click the **Yes** button to continue.

Enter the following information into the IMDPlus Output Control dialog.

- Select **Node** and change **Extent** to **Selected** using the drop-down list. This chooses all 1665 nodes of the bridge structure that were selected in the preceding step.

- Select result entity **Displacement** and component **DZ**

- Deselect **Individual items** and select **Average of chosen items** as only the averaged results for the selected nodes are going to be investigated.

- Ensure **Peak response summary** remains selected, then select **Positive/negative** and **Envelope**
- Ensure **Generate graphs in Modeller** remains selected
- Click the **Apply** button to perform the analysis. Click **Yes** when asked whether you want to process all of the selected nodes.

The IMDPlus analysis will now run. On modern computers this will take under 15 minutes.



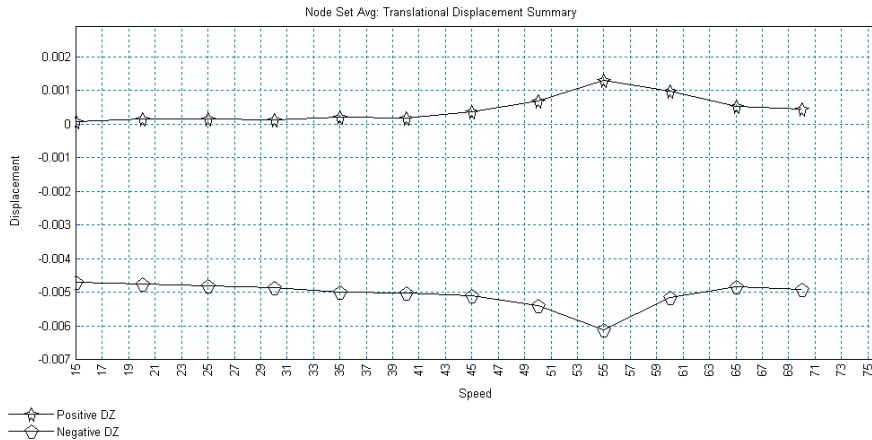
Note. Any combination of the options **Individual items**, **Sum of chosen items** and **Average of chosen items output** can be used together in an IMDPlus analysis, although using the **Individual items** option when **Extent** is set to **Selected** or **All** (nodes or elements) may produce a large number of graphs, depending on the number of nodes or elements chosen for processing.



Note. **Average of chosen items** obtains results by first summing the results from the selected nodes. A simple average of this summed result is obtained to give the averaged node time histories from which the peak average results are obtained.

A graph of peak positive and negative results for the averaged vertical (DZ) displacements, for all of the speeds analysed, 15m/s to 70m/s, is displayed as shown in

the following figure. It can be seen that the largest peaks occur at a speed of 55m/s, with positive and negative peak values of 0.0013m and -0.0061m respectively.



An envelope of the peak displacements and rotations for the selected nodes is displayed in Notepad in file peak_dspSet1.sum. By investigating all of the speeds analysed it can be seen that the individual peak vertical (DZ) displacements also occur at a moving load speed of 55m/s. These are shown in the following figure and both positive and negative peak Z-displacements occur at node 1624 with respective values of 0.0044m at time 4.656 seconds and -0.0204m at time 6.826 seconds.



Note. The envelope of the peak results is obtained in IMDPlus by examining the individual results from all of the nodes in the bridge structure. This enables the locations of the nodes with maximum and minimum results to be quickly identified.

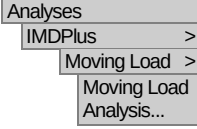
```
#
#
# +-----+
# | Speed = 55.000000000000 |
# +-----+
#
# Entity      Time      Value      Node
Peak_Pos_DX   6.807000000    0.3177041183E-002    1028
Peak_Neg_DX   6.815000000   -0.1450325103E-002    2392
Peak_Pos_DY   6.830000000    0.1432152932E-001    1617
Peak_Neg_DY   6.834000000   -0.1436008318E-001    1696
Peak_Pos_DZ   4.656000000    0.4432708343E-002    1624
Peak_Neg_DZ   6.826000000   -0.2040436034E-001    1624
Peak_Pos_THX  6.837000000    0.1278003970E-001    1694
Peak_Neg_THX  6.837000000   -0.1272787014E-001    1673
Peak_Pos_THY   6.974000000    0.5659962656E-002     950
Peak_Neg_THY  0.575000000   -0.6138300538E-002    2285
Peak_Pos_THZ  0.468000000    0.4499018200E-002    1861
Peak_Neg_THZ  7.150000000   -0.4332889472E-002    2277
```

- Close the Notepad application and graph windows.

If the IMDPlus toolbar has been enabled,

- Click on the  button in the toolbar to open the IMDPlus Output Control dialog

If the IMDPlus toolbar is not enabled,



- Open the IMDPlus Moving Load Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog.

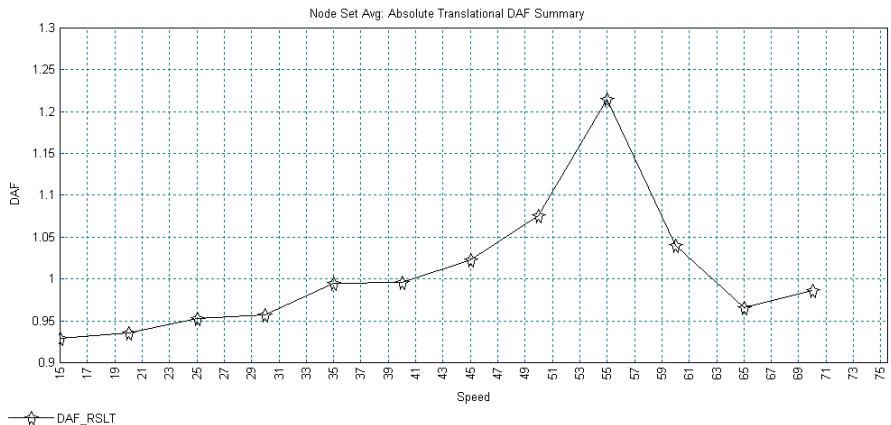
Enter the following information into the IMDPlus Output Control dialog.

- Select result entity **Dynamic Amplification Factor** and component **DAF_RSLT**
- Ensure **Peak response summary** and **Envelope** remain selected and select **Absolute**
- Click the **Finish** button. Click **Yes** when asked whether you want to process all of the selected nodes.
- Click **Yes** when asked whether to free up disk space by deleting the temporary files created by IMDPlus.

A graph showing the absolute peak of the average resultant dynamic amplification factor against speed is displayed, as shown in the following figure. This shows that a maximum averaged DAF of 1.215 occurs at speed 55m/s.



Note. Only averaged dynamic amplification factor results can be obtained for a set of nodes as summed results are meaningless for this result entity.



An envelope of the peak dynamic amplification factors for the selected nodes is displayed in Notepad in file Abs_peak_dafSet1.sum is. These results indicate that the individual peak resultant DAF occurs at a speed of 60m/s. A value of 1.71 is calculated at a solution time of 0.529 seconds at node 34.

```
#
#
# +-----+
# | Speed = 60.000000000000 |
# +-----+
#
# Entity              Time              Value              Node
Abs_Peak_DAF_DX       6.284000000          1.965105582         1057
Abs_Peak_DAF_DY       0.669000000          3.252813452         1582
Abs_Peak_DAF_DZ       6.367000000          1.578463432         2412
Abs_Peak_DAF_THX      0.671000000          4.548161937         1624
Abs_Peak_DAF_THY      6.351000000          1.652702690         1296
Abs_Peak_DAF_THZ      6.423000000          2.023591492         1112
Abs_Peak_RSLT          0.529000000          1.712660195         34
```

- Close the Notepad application and graph window.

Total and Peak Reactions for the Bridge Structure

The total sum of the reactions and the peak reactions that act on the bridge structure for each of the moving load speeds will now be investigated. The set of nodes from the preceding section could be utilised for this purpose. However, in order to improve the efficiency of the IMDPlus solution, the chosen selection of nodes will be reduced so that it only includes the geometric features that contain the supported nodes of the bridge structure.

- Click the left-hand mouse button in a blank part of the graphics window to remove the node selection created in the preceding section.

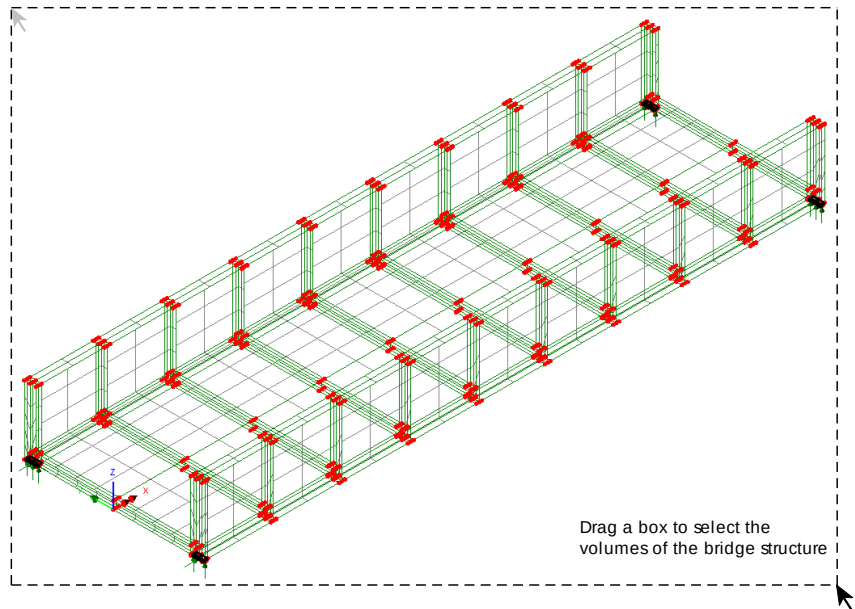


In the LUSAS graphics window click on the Supports on/off button to show the supported nodes in the model.

- In the  Treeview click the right-hand mouse button on the group name **Bridge_Structure** and select the **Set as Only Visible** option from the drop-down menu.
- Turn on the **Geometry** layer in the  Treeview.



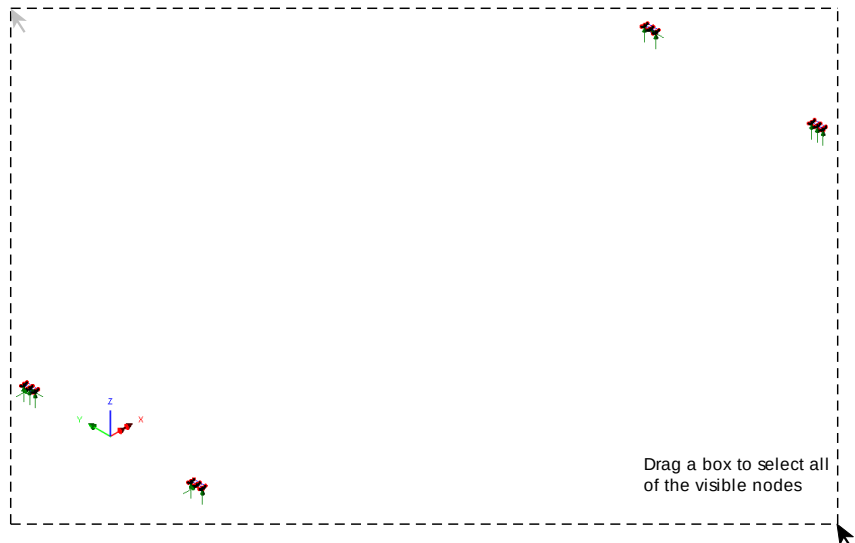
Using Select Volumes drag a box around the entire bridge structure to select the volumes immediately above the bridge supports, as shown in the following figure.

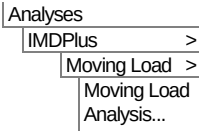


- Click the right-hand mouse button in a blank part of the graphics window and select the **Keep as Only Visible** option. Only the selected volumes will remain visible.



Using Select Nodes drag a box to select the 120 visible nodes of the bridge structure, as shown in the following figure.

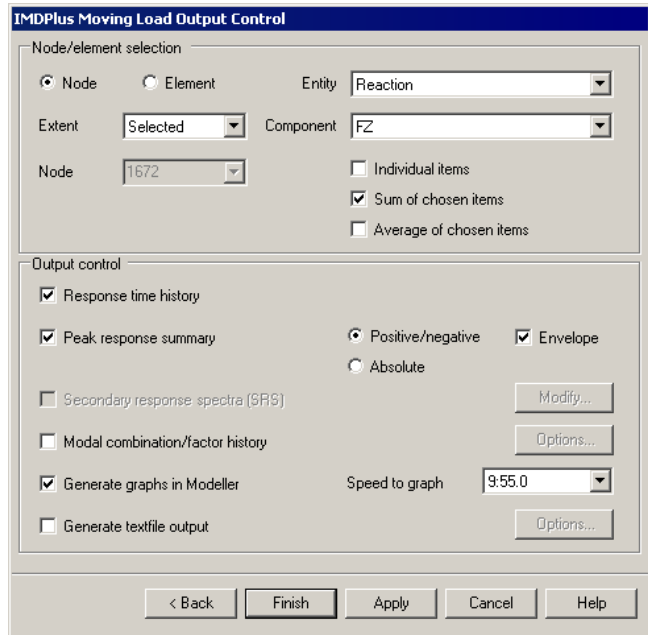




- Open the IMDPlus Moving Load Analysis Control dialog through the menu or click on the  button in the toolbar.
- On the IMDPlus Moving Load Analysis Control dialog click the **Next** button to accept the previously defined values. When prompted about the total mass participation click the **Yes** button to continue.

Enter the following information into the IMDPlus Output Control dialog.

- Select **Node** and ensure **Extent** remains set to **Selected**. This chooses the 120 visible nodes of the bridge structure that were selected in the preceding step.
- Select result entity **Reaction** and component **FZ**
- Deselect **Average of chosen items** and select **Sum of chosen items**. Ensure **Individual items** remains deselected.
- Select **Response time history**
- Ensure **Peak response summary** and **Envelope** remains selected and select **Positive/negative**
- Ensure **Generate graphs in Modeller** remains selected.
- Set the **Speed to graph** as **9:55.0** which indicates that the ninth and speed of 55 m/s is being processed
- Click the **Finish** button to perform the analysis of the node set. Click **Yes** when asked whether you want to process all of the selected nodes.
- Click **Yes** when asked whether to free up disk space by deleting the temporary files created by IMDPlus.



The dialog box is titled "IMDPlus Moving Load Output Control". It is divided into two main sections: "Node/element selection" and "Output control".

Node/element selection:

- ☒ Node ☐ Element
- Entity: Reaction (dropdown)
- Extent: Selected (dropdown)
- Component: FZ (dropdown)
- Node: 1672 (dropdown)
- ☐ Individual items
- ☒ Sum of chosen items
- ☐ Average of chosen items

Output control:

- ☒ Response time history
- ☒ Peak response summary
- ☐ Secondary response spectra (SRS) [Modify...]
- ☐ Modal combination/factor history [Options...]
- ☒ Generate graphs in Modeller
- ☐ Generate textfile output [Options...]
- Speed to graph: 9:55.0 (dropdown)
- ☒ Positive/negative ☐ Absolute
- ☒ Envelope

At the bottom are buttons: < Back, Finish, Apply, Cancel, and Help.

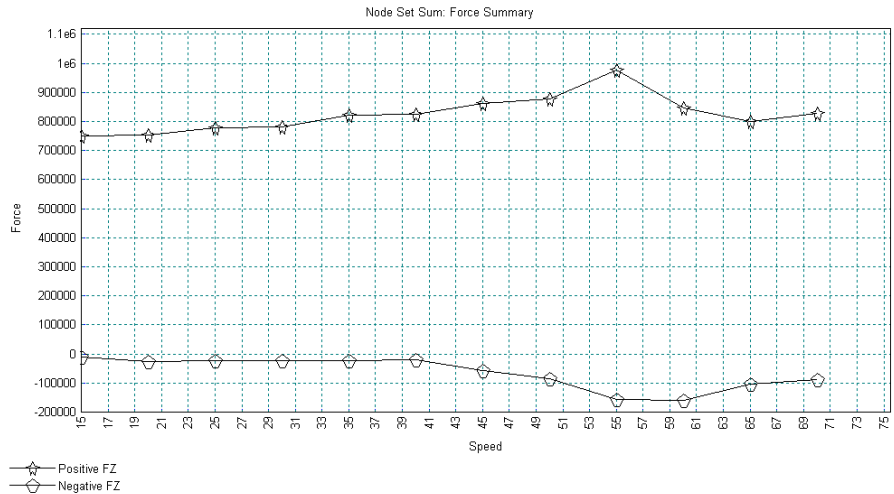


Note. Sum of chosen items adds together the results from the selected nodes to give the summed nodal time histories from which the peaks of the summed results are obtained.



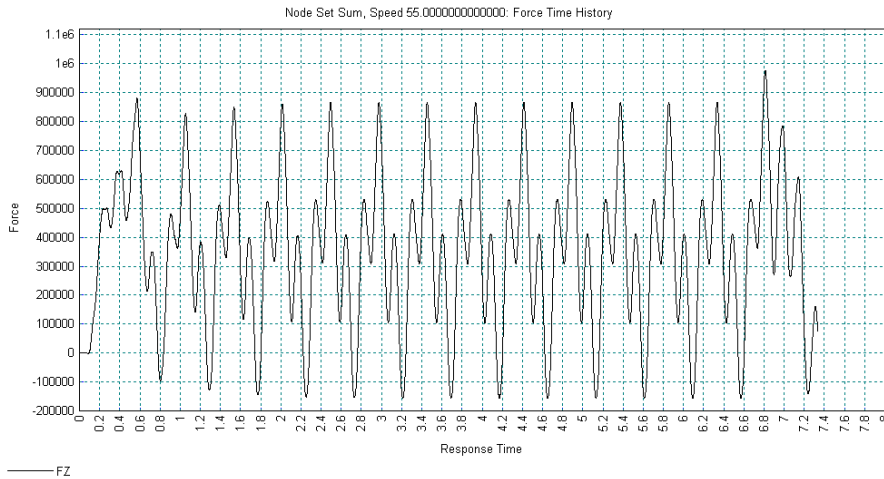
Note. Average of chosen items obtains results by first summing the results from the selected nodes. A simple average of this summed result is obtained to give the averaged node time histories from which the peak average results are obtained.

The summed nodal results that give the total vertical reactions acting on the bridge structure are displayed. The graph of the peak positive and negative summed reaction in the Z-direction for all of the speeds analysed is shown in the following figure. Examining the results for each speed shows a positive peak reaction of 976.6kN at a train speed of 55m/s and a negative holding down peak reaction of -159.0kN at a speed of 60 m/s.



In addition, the following figure shows the time history of the summed FZ reactions for the analysis speed of 55m/s. For this speed it can be seen that the positive peak value of 976.6kN occurs at an analysis time of 6.81 seconds.

Train Induced Vibration of a Bridge



The envelope of the peak reactions from file peak_rctSet1.sum are displayed in a Notepad application. These give a summary of the peak reactions obtained from all of the individual nodes of the bridge structure for each of the moving load speeds analysed. The vertical (FZ) component of interest shows consistently that the maximum positive reaction (from a downward force) occurs at node 82 and the maximum negative reaction (from an upward force) occurs at node 112. Results for speeds of 55m/s and 60m/s are shown in the following figure.

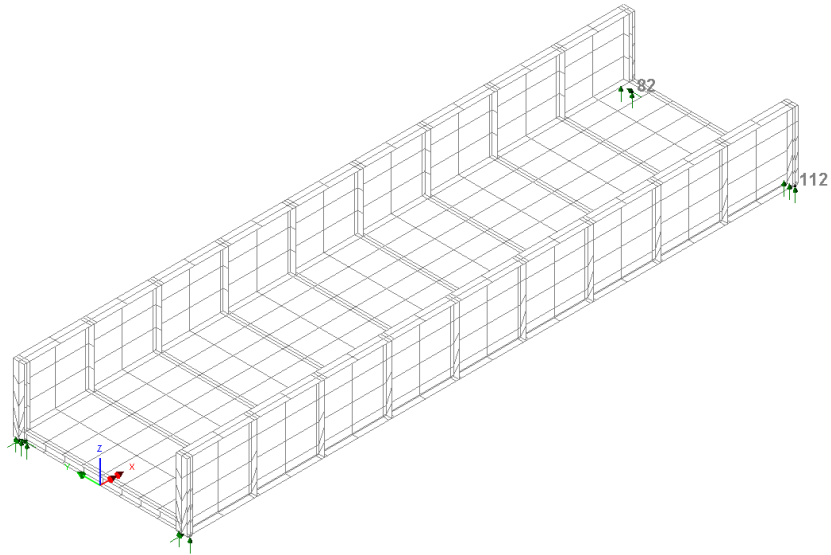
```
#
#
# +-----+
# | Speed = 55.00000000000000 |
# +-----+
#
# Entity      Time      Value      Node
Peak_Pos_FX   6.756000000    52731.24971    9
Peak_Neg_FX   4.576000000   -18589.20194    9
Peak_Pos_FY   7.019000000    22881.92033   69
Peak_Neg_FY   6.994000000   -19169.69107    9
Peak_Pos_FZ   0.576000000    259862.3328   82
Peak_Neg_FZ   6.943000000   -135238.8224  112
Peak_Pos_MX   N/A      N/A      N/A
Peak_Neg_MX   N/A      N/A      N/A
Peak_Pos_MY   N/A      N/A      N/A
Peak_Neg_MY   N/A      N/A      N/A
Peak_Pos_MZ   N/A      N/A      N/A
Peak_Neg_MZ   N/A      N/A      N/A
#
#
# +-----+
# | Speed = 60.00000000000000 |
# +-----+
#
# Entity      Time      Value      Node
Peak_Pos_FX   6.196000000    48130.35311    9
Peak_Neg_FX   6.722000000   -17547.90507   32
Peak_Pos_FY   0.670000000    23428.89095    9
Peak_Neg_FY   0.700000000   -22936.61174    9
Peak_Pos_FZ   0.534000000    257957.9082   82
Peak_Neg_FZ   6.367000000   -145133.7444  112
Peak_Pos_MX   N/A      N/A      N/A
Peak_Neg_MX   N/A      N/A      N/A
Peak_Pos_MY   N/A      N/A      N/A
Peak_Neg_MY   N/A      N/A      N/A
Peak_Pos_MZ   N/A      N/A      N/A
Peak_Neg_MZ   N/A      N/A      N/A
```

The maximum positive reaction of 259.9kN occurs at a time 0.576 seconds for speed 55m/s and the maximum negative reaction of -145.1kN occurs at a time 6.367 seconds for speed 60m/s.

- Close the Notepad application and graph windows.

The nodes 82 and 112 representing two of the vertical supports for the bearings of the bridge will now be located in the model.

- Click the left-hand mouse button in a blank part of the graphics window to remove the node selection created in the preceding section.
- In the  Treeview click the right-hand mouse button on the group name **Bridge_Structure** and select the **Set as Only Visible** option from the drop-down menu.
- Turn off the **Geometry** layer in the  Treeview.
- With no features selected click the right-hand mouse button in a blank part of the graphics window and select the **Labels** option to add the labels to the  Treeview.
- On the Properties dialog select the **Name/Node** and **Label selected items only** check boxes.
- Click the **Font...** button and select Font: **Arial**, Font style: **Bold**, Size: **20** and click **OK**.
- Click the **OK** button to accept all other settings. This will turn on the layer in the graphics window.
- With no features selected click the right-hand mouse button in a blank part of the graphics window and select the **Advanced Selection...** option.
- Select **Type and Name**, select **Node** from the drop-down list and enter node number **82**
- Select **Add to selection** and click the **Apply** button to accept all other settings. Node 82 will be highlighted in the graphics window.
- Enter node number **112** and click the **OK** button. Node 112 will also be displayed in the graphics window, as shown in the following figure.



- Click the left-hand mouse button in a blank part of the graphics window to remove the node selection.

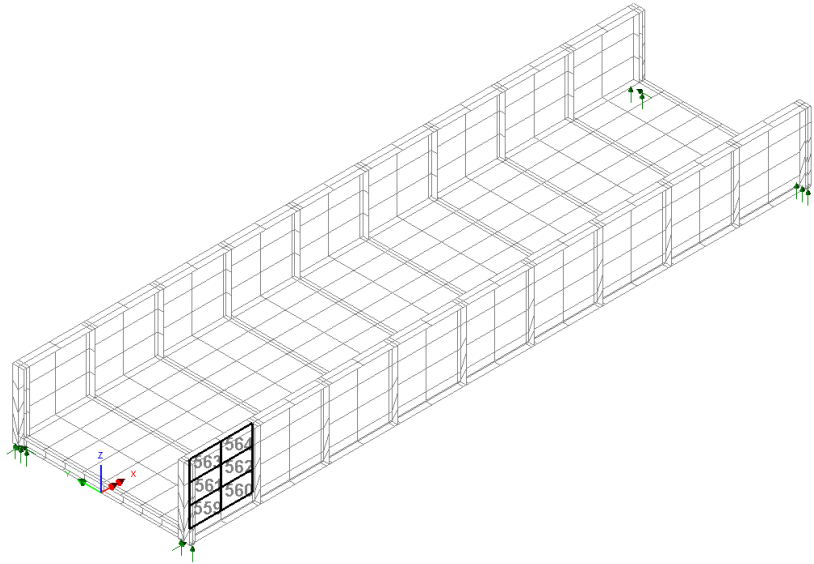
Average and Peak Stresses in a Side Panel of the Bridge Structure

Finally, the average peak and total peak in-plane shear stresses in a side panel of the bridge structure will be investigated.

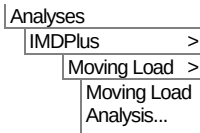
- Double-click on the **Labels** layer name in the  Treeview.
- On the Properties dialog de-select the **Name/Node** check box and select the **Name/Element** check box. Click the **OK** button.



Select the six elements that form the side panel of the bridge structure shown in the following figure.



Note. Only elements of the same type, for example, thick beam elements, continuum elements or thick shell elements can be used in a set of IMDPlus elements. However, the element set may contain elements with different numbers of Gauss points or nodes.



- Open the IMDPlus Moving Load Analysis Control dialog through the menu or click on the  button in the toolbar.
- On the IMDPlus Moving Load Analysis Control dialog click the **Next** button to accept the previously defined values. When prompted about the total mass participation click the **Yes** button to continue.

Enter the following information into the IMDPlus Output Control dialog.

- Select **Element** and set **Extent** to **Selected** from the drop-down list. This chooses the 6 elements of the bridge structure that were selected in the preceding step.
- Select result entity **Stress (middle) – Thick Shell** and component **Sxy**
- Deselect **Sum of chosen items** and select **Average of chosen items**. Ensure **Individual Output** remains deselected.

IMDPlus Moving Load Output Control

Node/element selection

☐ Node ☒ Element Entity: Stress (middle) - Thick Shell

Extent: Selected Component: Sxy

Element: 1193

Gauss Point: All

☐ Individual items

☐ Sum of chosen items

☒ Average of chosen items

Output control

☐ Response time history

☒ Peak response summary ☒ Positive/negative ☒ Envelope

☐ Secondary response spectra (SRS) ☐ Absolute

☐ Modal combination/factor history

☒ Generate graphs in Modeller Speed to graph: 9.55.0

☐ Generate textfile output

< Back Finish Apply Cancel Help

- Deselect **Response time history**
- Ensure **Peak response summary**, **Positive/negative** and **Envelope** all remain selected.
- Ensure **Generate graphs in Modeller** remains selected.



Note. As **Extent** has been set to **Selected** the drop-down lists **Element** and **Gauss Point** are not available for selection. In addition the element **Gauss Point** is automatically set to **All** as multiple elements are going to be processed in a single analysis.

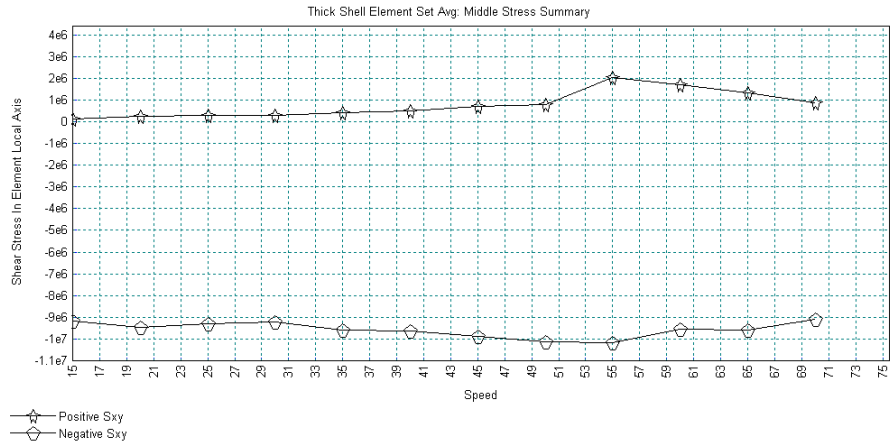
- Click the **Finish** button to perform the analysis of the element set. Click **Yes** when asked whether you want to process all of the selected elements.
- Click **Yes** when asked whether to free up disk space by deleting the temporary files created by IMDPlus.

The graph shown in the following figure is displayed. It shows the peak positive and negative, average middle shear stress, S_{xy} , for the side panel of the bridge structure. The largest positive and negative peaks occur at a speed of 55m/s with values of 2.05Mpa and -10.2MPa respectively.



Note. **Average of chosen items** obtains the element results by first summing the results from all of the Gauss points of the selected thick shell elements. A simple

average of these summed results is obtained to give the average element response time histories from which the peak average results are obtained.



An envelope of the peak element stresses for each of the moving load speeds is displayed in Notepad in file peak_stressSet1.sum. This gives a summary of the peak stresses and stress resultants obtained by examining all of the individual Gauss point results of the selected elements. The results for speed 55m/s are shown in the following figure. The maximum positive and negative middle in-plane shear (Sxy) stress occurs at Gauss point 2 of element 560. Values of 2.69MPa at time 7.224 seconds and -13.6MPa at time 6.986 seconds are observed.

Train Induced Vibration of a Bridge

```
#
#
# +-----+
# | Speed = 55.000000000000 |
# +-----+
#
# Entity                Time                Value                Element                GP
Peak_Pos_Top_Sx         6.804000000    6178832.782           560                    1
Peak_Neg_Top_Sx         6.981000000    -17724493.52          564                    4
Peak_Pos_Top_Sy         6.812000000    3238750.965           560                    1
Peak_Neg_Top_Sy         6.797000000    -5028203.725          559                    4
Peak_Pos_Top_Sxy        7.224000000    2745090.347           560                    3
Peak_Neg_Top_Sxy        6.981000000    -11816861.23          560                    2
Peak_Pos_Top_Syz        6.812000000    0.1396187750E-023     560                    2
Peak_Neg_Top_Syz        6.803000000    -0.1716039574E-023     559                    2
Peak_Pos_Top_Szx        6.906000000    0.7440377432E-024     560                    1
Peak_Neg_Top_Szx        6.824000000    -0.1110811094E-023     559                    2
Peak_Pos_Mid_Sx         6.985000000    5728221.278           560                    2
Peak_Neg_Mid_Sx         6.986000000    -16401763.30          564                    4
Peak_Pos_Mid_Sy         6.980000000    3243441.794           560                    2
Peak_Neg_Mid_Sy         6.796000000    -5224766.419          559                    4
Peak_Pos_Mid_Sxy        7.224000000    2689334.309           560                    2
Peak_Neg_Mid_Sxy        6.986000000    -13610114.52          560                    2
Peak_Pos_Mid_Syz        0.135000000    236128.4546           560                    2
Peak_Neg_Mid_Syz        6.914000000    -226209.2933          562                    2
Peak_Pos_Mid_Szx        6.814000000    341032.6462           560                    1
Peak_Neg_Mid_Szx        6.913000000    -322802.1144          560                    1
Peak_Pos_Bot_Sx         6.980000000    6474320.454           560                    2
Peak_Neg_Bot_Sx         6.803000000    -16534341.68          564                    4
Peak_Pos_Bot_Sy         0.334000000    4167596.897           562                    2
Peak_Neg_Bot_Sy         6.980000000    -5722445.497          559                    4
Peak_Pos_Bot_Sxy        7.223000000    3133893.260           559                    2
Peak_Neg_Bot_Sxy        6.801000000    -16182311.93          560                    2
Peak_Pos_Bot_Syz        6.801000000    0.2213546367E-023     560                    2
Peak_Neg_Bot_Syz        0.341000000    -0.2010308949E-023     559                    2
Peak_Pos_Bot_Szx        0.538000000    0.4221235670E-023     559                    2
Peak_Neg_Bot_Szx        6.840000000    -0.1863288508E-023     560                    1
Peak_Pos_Nx             6.985000000    72748.41024           560                    2
Peak_Neg_Nx             6.986000000    -208302.3939          564                    4
Peak_Pos_Ny             6.980000000    41191.71079           560                    2
Peak_Neg_Ny             6.796000000    -66354.53352          559                    4
Peak_Pos_Nxy            7.224000000    34154.54573           560                    2
Peak_Neg_Nxy            6.986000000    -172848.4544          560                    2
Peak_Pos_Mx             7.011000000    91.80102937           562                    1
Peak_Neg_Mx             6.909000000    -138.1163838          562                    1
Peak_Pos_My             6.873000000    77.03755272           562                    4
Peak_Neg_My             6.907000000    -100.7634410          562                    1
Peak_Pos_Mxy            6.974000000    88.52683013           559                    2
Peak_Neg_Mxy            6.906000000    -35.90092843          560                    2
Peak_Pos_Sx             6.814000000    2887.409738           560                    1
Peak_Neg_Sx             6.913000000    -2733.057902          560                    1
Peak_Pos_Sy             0.135000000    1999.220915           560                    2
Peak_Neg_Sy             6.914000000    -1915.238683          562                    2
```

- Close the Notepad application and graph windows.

Save the model

Save the model.

This completes the example.