Seismic Analysis of a 2D Frame (Time Domain)

For LUSAS version:	20.0
For software product(s):	All
With product option(s):	IMDPlus
Note: The example exceeds the limits of the LUSAS Teaching and Training Version.	

Description

This example examines the seismic response of a 2D plane frame founded on an elastic medium. The model is an extension of the worked example titled 'Seismic Response of a Plane Frame'.

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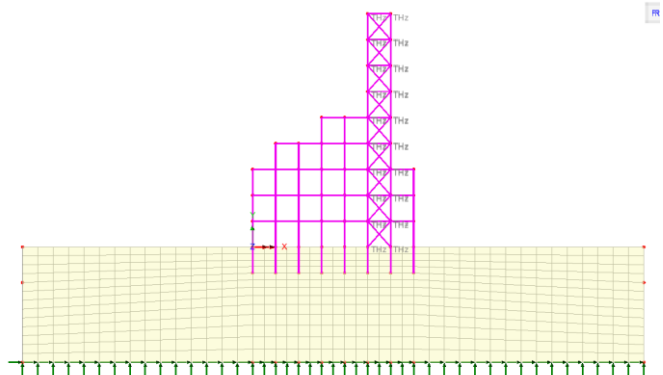
Objectives

The output requirements of the analysis are:

❑ Displacements, velocities and accelerations at the top of the tower
❑ Secondary response spectra at the top of the tower
❑ Forces and moments in a column at the base of the tower

❑ Average forces/moments and peak forces/moments from all of the columns at the base of the tower

Keywords

2D, Frame, Seismic, Time Domain, Response, Mass Participation, Interactive Modal Dynamics, Excitation, Eigenvalue, Secondary Response Spectra.

Associated Files

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

❑ **IMDPlus_2D_tower.lvb** This file creates a model of the structure.

❑ **horizontal.prn** and **vertical.prn** These files define horizontal and vertical earthquake accelerations. These two files contain two earthquake records each: one for the 1940 El Centro earthquake and one for the 1994 Northridge earthquake.

Discussion

The worked example 'Seismic Response of a 2D Frame (Frequency domain)' is revisited in this example. The frame is now founded in a plane strain elastic medium and the response of the structure is evaluated in the time domain using IMDPlus.

The model is comprised of thick beam elements for the concrete columns, beam members, and steel diagonal bracing members, which have pinned end connections. The number of beam elements representing the components of the structure has been increased from 1 per line to 4 per line to provide greater definition of the deformed shapes. In addition to this modification, all support restraints have been removed from the frame and an additional 4.5 m length has been added to the base of each column to allow embedment of the column bases into the elastic medium.

The elastic medium is modelled as a 108m by 20m block which is fully restrained along its base and with cyclic translation constraints assigned to the sides. These constraints provide support to the sides of the elastic medium without the need to apply physical restraints, thus allowing direct and shear behaviours in the elastic medium.

The seismic response analysis is performed in two distinct stages. A natural frequency analysis is performed first. This is used to calculate the first 50 natural modes of vibration of the combined structure and elastic medium. The eigenvalues, frequencies and eigenvectors (mode shapes) are stored and used in the subsequent IMDPlus analysis. Although the natural frequencies are obtained from an eigenvalue analysis any information regarding the magnitudes of deformations or stresses / moments is non-quantitative.

The second phase of the analysis utilises the IMDPlus option which performs enhanced time domain solutions using Interactive Modal Dynamics (IMD). This is an alternative

to performing a spectral response analysis and allows the excitation of the structure using acceleration time histories instead of spectral excitation curves.

In the IMDPlus solution, the structure is subjected to a support condition excitation governed by time histories of acceleration in the model global axes. In this example this is assumed to act along the base of the elastic medium in the form of horizontal and vertical accelerations. It should, however, be noted that no deconvolution of the records has been carried out to convert the surface responses recorded for these earthquakes to at-depth acceleration time histories to be input into the analysis. As a consequence, the ground level accelerations in the analysis will not correspond to the measured values. As stated previously, two earthquake records are used in the analysis, the first being the 1940 El Centro earthquake and the second being the 1994 Northridge earthquake. The two earthquake responses are computed during a single analysis. Only the first 10 seconds of each seismic event is analysed in this example.

Modelling

Running LUSAS Modeller

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

Creating the model
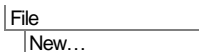
File
  New…

- Enter a file name of **IMDPlus 2D Tower**

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

- Ensure an Analysis category of **2D Inplane** 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…
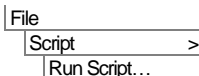
To create the model required for this example, open the script file **IMDPlus_2D_tower.lvb** that was downloaded and placed in a folder of your choosing.

After a short while the following view of the model of the building will be displayed.
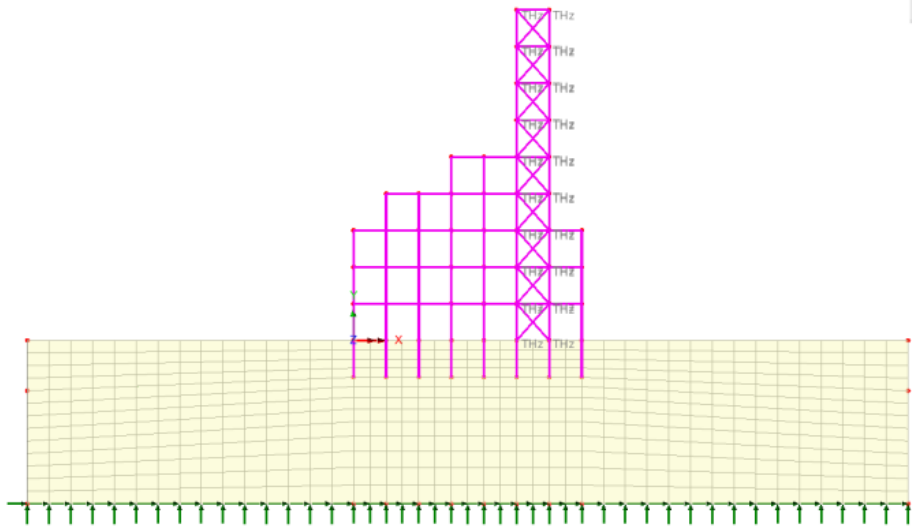
File
  Save As…

- Save the model into a new folder named **IMDPlus 2D Tower**. This helps keep all relevant IMDPlus created files separate from other analyses and is good practice.

Note. No static structural loading is required for this analysis because only the dynamic loading is considered during the results processing based on the results from the natural frequency analysis.

The modelling will now be completed by defining the controls necessary to extract the natural frequencies.

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.

- Set the Number of eigenvalues as **50**

- Ensure the Shift to be applied is set as **0**

- 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 Analyses panel of the Treeview. Eigenvalue 1 is set to be active by default.

Plotting Mode Shapes

- Turn off the display of the **Mesh, Geometry** and **Attributes** layers in the Treeview.

- With no features selected click the right-hand mouse button in a blank part of the view window and select the **Deformed mesh** option to add the deformed mesh layer to the Treeview. Select the **Visualise** tab and turn off the **Beam end releases** option. Click the **OK** button to accept the remaining default values and display the deformed mesh for Eigenvalue 1.

- 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 **15,-15** (note these are not model units) and click the **OK** button to return to the view window.

Scale: 1: 406.484
Zoom: 100.0
Eye: (0.0, 0.0, 1.0)
Eigenvalue analysis
Analysis: Analysis 1
Loadcase: 1:Loadcase 1, 1:Mode 1 Frequency = 1.90411
Results file: IMDPlus_2D_Tower2~Analysis 1.mys
Eigenvalue: 143.134
Natural frequency: 1.90411
Error norm: 10.1586E-12
Maximum displacement 9.97941E-3 at node 951
Deformation exaggeration: 244.394
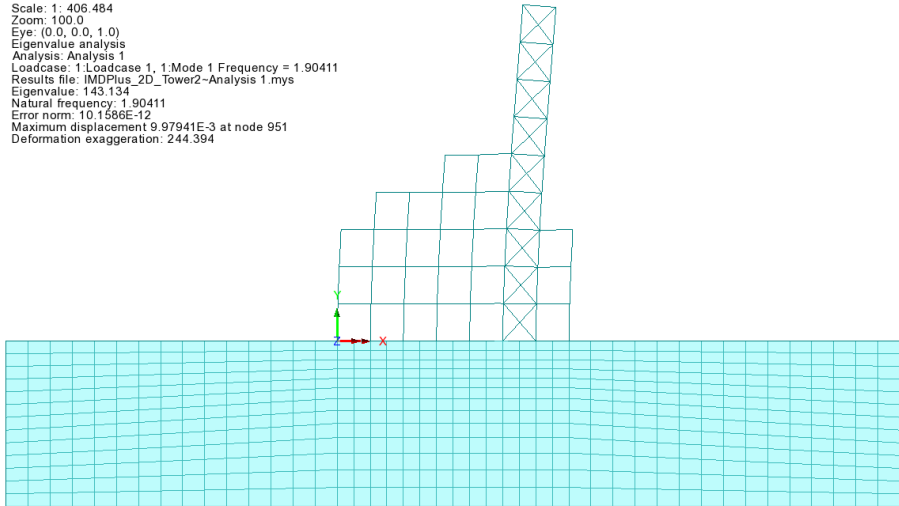
Note. The mode shape may be inverted. This is because the sense is arbitrary since during vibration the deformed shape will appear in both directions.

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.

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

- In the ⏰ Treeview right-click on **Mode 2 Frequency=6.12185** and select the **Set Active** option. The deformed mesh plot for the eignemode will be displayed.

Printing Eigenvalue Results

Eigenvalue results for the whole structure can be displayed in the Text Output window.

Utilities
Print Results
Wizard…

- For loadcase 1, select results type **Eigenvalues**. In the available results panel select **Eigenvalues (Frequency)**, ensure **Display now** is selected and click **OK.**

The Eigenvalue results will be displayed and a Print Results Wizard entry will be added to the Utilities 🔧 treeview.

For inspection only the first 10 modes are shown here.

Mode ▲	Eigenvalue	Frequency	Period	Error norm
1	1	143.134	1.90411	0.52518	10.1586E-12
2	2	1.47954E3	6.12185	0.163349	63.7515E-9
3	3	7.1425E3	13.4507	0.0743455	0.108932E-9
4	4	11.4691E3	17.0445	0.0586699	0.342431E-9
5	5	13.6031E3	18.5626	0.0538718	6.23028E-6
6	6	15.3052E3	19.6897	0.0507879	2.77285E-6
7	7	22.0931E3	23.6564	0.0422719	2.28066E-6
8	8	23.5694E3	24.434	0.0409266	25.6343E-6
9	9	23.6466E3	24.474	0.0408597	67.859E-6
10	10	23.7875E3	24.5468	0.0407386	31.6852E-6
11	11	23.7985E3	24.5525	0.0407291	76.5218E-6

Note. The frequency in Hertz can be obtained by dividing the square root of the eigenvalue by 2π, and the period of vibration in seconds is obtained using the reciprocal of frequency (1/frequency). Values of error norm may vary from those shown.

Caution. The system eigenvectors have been normalised (in this case with respect to mass) therefore any derived quantities such as displacement and moment are also normalised and are not true design values.

- Close the print results window by selecting the close button in the top right hand corner of the window. It can be re-displayed by selecting the 'Show results' menu item from context menu of the PRW utility.

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 to be included, if and only if, the modes of vibration omitted cannot be excited by the input acceleration time histories 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.
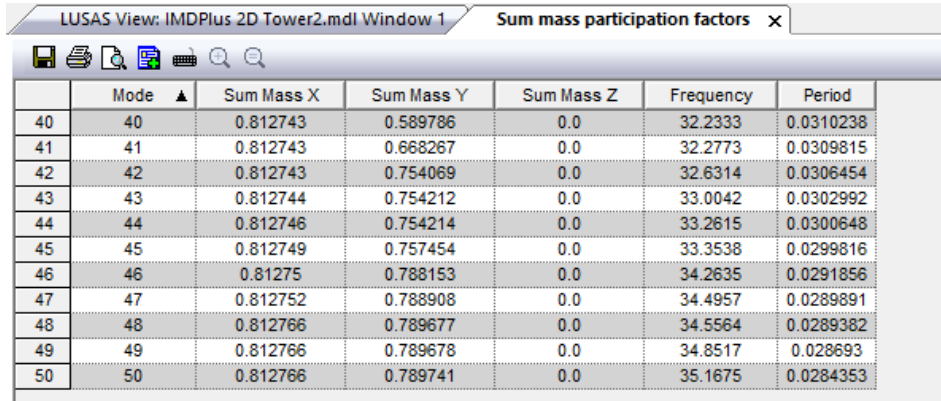
Utilities
Print Results
Wizard…

- Select results type **Eigenvalues**. For loadcase 1, in the available results panel deselect **Eigenvalues (Frequency),** then select **Sum mass participation factors**

and click **OK.** The Sum Mass Participation Factors results will be printed to the print results window.

For inspection only modes 40 to 50 will be printed here. It can be seen that the 90% value has not been achieved and is discussed below.

	Mode ▲	Sum Mass X	Sum Mass Y	Sum Mass Z	Frequency	Period
40	40	0.812743	0.589786	0.0	32.2333	0.0310238
41	41	0.812743	0.668267	0.0	32.2773	0.0309815
42	42	0.812743	0.754069	0.0	32.6314	0.0306454
43	43	0.812744	0.754212	0.0	33.0042	0.0302992
44	44	0.812746	0.754214	0.0	33.2615	0.0300648
45	45	0.812749	0.757454	0.0	33.3538	0.0299816
46	46	0.81275	0.788153	0.0	34.2635	0.0291856
47	47	0.812752	0.788908	0.0	34.4957	0.0289891
48	48	0.812766	0.789677	0.0	34.5564	0.0289382
49	49	0.812766	0.789678	0.0	34.8517	0.028693
50	50	0.812766	0.789741	0.0	35.1675	0.0284353

🖉 **Note.** In this analysis, a significant proportion of mass is restrained along the base of the elastic medium. For the 50 modes of vibration, 81.2% and 78.9% of the total mass is achieved in the horizontal and vertical directions. In order to achieve 90% total mass in both the horizontal and vertical directions 160 modes of vibration with an upper frequency equivalent to 97.2 Hz would actually be required. However, for the purposes of this example, the number of modes of vibration has been restricted to 50.

• Close the print results window.

Seismic Response Analysis

Seismic response calculations are performed using the IMDPlus (Interactive Modal Dynamics) facility. This involves defining the excitation and specifying the results required. Initially, in this example, the response of the node at the top-right corner of the tower will be investigated.

🖉 **Note.** With a seismic response analysis, additional damping information may also be set. Unlike results from a natural frequency analysis, the output values obtained from a seismic response are design values.

• Turn off the display of the **Deformed Mesh** layer in the 🔲 Treeview.

• In the 🔲 Treeview double-click on the **Mesh** layer name. Select the **Visualise** tab and turn off the **Beam end releases** option. Click the **OK** button to accept all other settings. This will also turn on the layer in the view window.

- Zoom-in to the top of the tower and select only the top-right node.

The main tower members have been meshed with 4 line mesh divisions so each line will have 3 nodes along its length in addition to one at either end.

Select this node
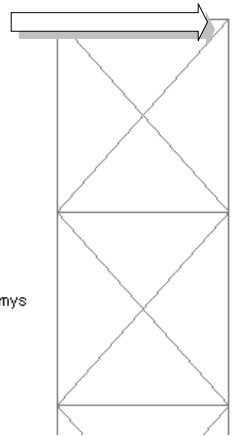
Scale: 1: 424.361

Zoom: 295.718

Eye: (0.0, 0.0, 1.0)

Eigenvalue analysis

Loadcase: 1:Eigenvalue 2

Results file: IMDPlus 2D Tower~Analysis 1 (Structural).mys

Eigenvalue: 1.47954E3

Natural frequency: 6.12185

Error norm: 0.402905E-6

Defining the Seismic Parameters

Note. To simplify the use of IMDPlus (and provide an alternative to picking IMDPlus menu selections from the Analyses > IMDPlus menu) 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, select the **IMDPlus** option in the list and click **Close**.

- If the IMDPlus toolbar has been enabled, then click on the 🖳 Seismic analysis button to enable the other relevant toolbar buttons (the seismic tool button) shortcuts to the IMDPlus dialogs.

Analyses
    IMDPlus   >
        Seismic...

- 🖳 Open the IMDPlus Seismic Analysis Control dialog.
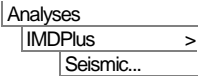
The input for the seismic analysis is defined on the IMDPlus Seismic Analysis Control dialog. The input consists of the earthquake acceleration records, included modes and damping along with interpolation options.

- In the Earthquake Input section, for the **X-Direction Earthquake Record(s),** browse to the folder where you downloaded all associated files and select **horizontal.prn**

- For the Y**-Direction Earthquake Record(s)** browse to the folder where you downloaded all associated files and select **vertical.prn**

- Ensure the **Direction Factors** in the **X** and **Y** directions are set to **1** and **0.66667**

- In the Mode/Damping Control section, ensure **Included modes** is set to All. If this is not the case, click on the **Modify…** button and turn the **All modes** option on.

- Ensure **Default damping (5%)** is selected. If a different damping is displayed, click on the **Modify…** button and set the **Default damping** to **5**

- In the Frequency Interpolation 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.

- Ensure the **All frequencies included** option is selected.

- Click the **Next** button to proceed to the IMDPlus Output Control dialog. When prompted that less than 90% total mass participation has been detected choose **Yes** since we are aware of this (see Checking the Mass Participation Factor).

The IMDPlus Output Control dialog will then be displayed.

Notes relating to the IMDPlus Seismic Analysis Control dialog

On the Seismic Analysis Control dialog the **Browse** buttons can be used instead of entering the directional earthquake file names. As each file is loaded, the contents are checked to ensure that they are in the correct format.

- ❑ On the **Modify** dialog for the modes, individual modes can be included or excluded from the seismic analysis and total mass participations for the excitation directions are reported.

- ❑ On the **Modify** dialog for the damping, control over the inclusion of over-damped modes can be adjusted if viscous modal damping has been included in the original eigenvalue analysis. To include viscous modal damping, Rayleigh damping parameters must be defined in the material properties assigned to the model or a separate damping attribute defined and assigned to the model. This allows direct mirroring of step-by-step dynamic solutions and the inclusion of frequency dependent damping.

- ❑ On the **Modify** dialog for the advanced solution options, the time integration scheme used in the IMDPlus analysis can be selected. Either a Hilber Hughes Taylor (HHT) scheme or Duhamel's integral can be utilised.

Four methods of interpolation are available in IMDPlus. The default All frequencies included will solve the seismic analysis using all of the frequencies included in the eigenvalue analysis. Limit frequencies to Nyquist frequency will limit the included frequencies to the Nyquist frequency which is governed by the time step of the earthquake records and defined as $1/2\delta t$. Linear interpolation of records allows the specification of an alternative time step for the analysis where the earthquake records are linearly interpolated to this time step. Cubic spline interpolation of records allows the specification of an alternative time step for the analysis where the earthquake records are interpolated with a cubic spline to this time step. This last form of interpolation should generally not be used for measured earthquake records as it can smooth the peak responses but is often more appropriate for synthesised earthquake records.

Displacement Plots

The displacement of the top of the tower will be investigated initially. Enter the following information into the IMDPlus Output Control dialog.

- Select **Node** and select **Extent** as **Individual**

- Choose **Node** number **951** from the drop-down list (or your node number if different). This is the node at the top-right of the tower.

- Select results entity **Displacement** and component **DX & DY**

- Ensure that **Individual items** is selected. **Sum of chosen items** and A**verage of chosen items** will not be available as an individual node is being processed.

- Ensure **Response time history** is selected.

- Select **Peak response summary**

- Ensure **Generate graphs in Modeller** is selected and specify the **Earthquake to graph** as **1**

The dialog should look like this:

- Click the **Apply** button to proceed.

An IMDPlus analysis will run and after a short while the horizontal (DX) and vertical (DY) displacements for the point at the top of the tower are displayed on the graph for the first 10 seconds of the 1940 El Centro earthquake. (Earthquake 1)

Peak displacements are also output to Notepad and indicate absolute peak displacements of 0.085 m in the X-direction, 0.006 m in the Y-direction, a peak rotation of 0.003 radians and an absolute peak resultant displacement of 0.086 m (Record 1).
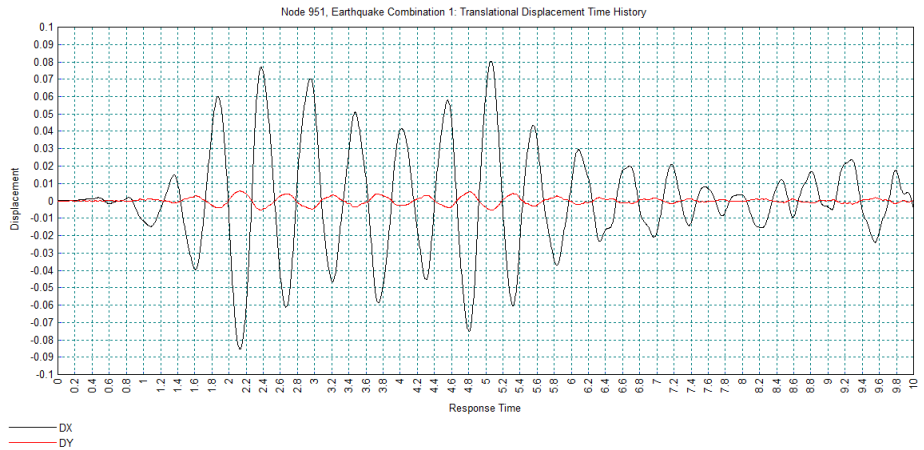

```
# +--------------+
# | Record = 001 |
# +--------------+
#
# Entity                Time              Value
Peak_Pos_DX          5.060000000       0.8045372326E-001
Peak_Neg_DX          2.130000000      -0.8537243429E-001
Abs_Peak_DX          2.130000000       0.8537243429E-001
Peak_Pos_DY          2.125000000       0.5614024798E-002
Peak_Neg_DY          5.075000000      -0.5391878010E-002
Abs_Peak_DY          2.125000000       0.5614024798E-002
Peak_Pos_THZ         2.130000000       0.2572777130E-002
Peak_Neg_THZ         5.065000000      -0.2500193493E-002
Abs_Peak_THZ         2.130000000       0.2572777130E-002
Abs_Peak_RSLT        2.130000000       0.8555478444E-001
#
```

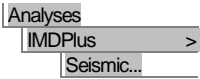**Note.** Displacements are relative to the supports.

- Close the Notepad application and graph window.

If the IMDPlus toolbar has been enabled,

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

If the IMDPlus toolbar is not enabled,

Analyses
 IMDPlus   >
    Seismic...

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. When prompted about the total mass participation click the **Yes** button to continue.

In the IMDPlus analysis we have analysed two earthquake combinations at the same time. We are therefore also interested in the displacement response of the top of the tower for the second earthquake.

Enter the following information into the IMDPlus Output Control dialog:

- Select earthquake **2** in the **Earthquake to graph** list box.

- Click the **Apply** button to proceed.

The horizontal (DX) and vertical (DY) displacements for the point at the top of the tower are displayed on the graph for the first 10 seconds of the 1994 Northridge earthquake. Peak displacements are also output to Notepad and indicate absolute peak displacements of 0.026 m in the X-direction, 0.002 m in the Y-direction, a peak rotation of 0.001 radians and an absolute peak resultant displacement of 0.026 m (Record 2).

Node 951, Earthquake Combination 2: Translational Displacement Time History
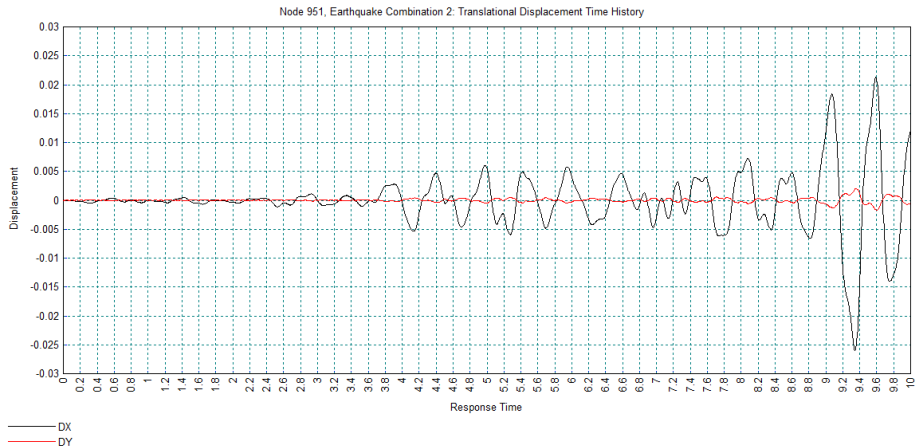
```
# +--------------+
# | Record = 002 |
# +--------------+
#
# Entity                Time               Value
Peak_Pos_DX          9.590000000        0.2129363987E-001
Peak_Neg_DX          9.345000000       -0.2602106813E-001
Abs_Peak_DX          9.345000000        0.2602106813E-001
Peak_Pos_DY          9.355000000        0.2024930109E-002
Peak_Neg_DY          9.600000000       -0.1693797628E-002
Abs_Peak_DY          9.355000000        0.2024930109E-002
Peak_Pos_THZ         9.355000000        0.9071686224E-003
Peak_Neg_THZ         9.600000000       -0.7763535669E-003
Abs_Peak_THZ         9.355000000        0.9071686224E-003
Abs_Peak_RSLT        9.345000000        0.2609328665E-001
```

- Close the Notepad application and graph window.

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,

Analyses	
IMDPlus	>
Seismic...	

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. When prompted about the total mass participation click the **Yes** button to continue.
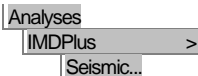
Velocity Plots

In addition to the displacement response of the top of the tower we are also interested in the velocities experienced by the tower. Enter the following information into the output control dialog.

- Select **Velocity** results of **VX & VY**

- Select earthquake **1** in the **Earthquake to graph** list box.

- Click **Apply** to proceed.

The horizontal (VX) and vertical (VY) velocities of the top of the tower are displayed on the graph for the first 10 seconds of the 1940 El Centro earthquake. Peak velocities are also output to Notepad and indicate absolute peak velocities of 1.13 m/s in the X-direction, 0.085 m/s in the Y-direction, a peak rotational velocity of 0.039 rad/s and an absolute peak resultant velocity of 1.13 m/s (Record 1).

Node 951, Earthquake Combination 1: Translational Velocity Time History
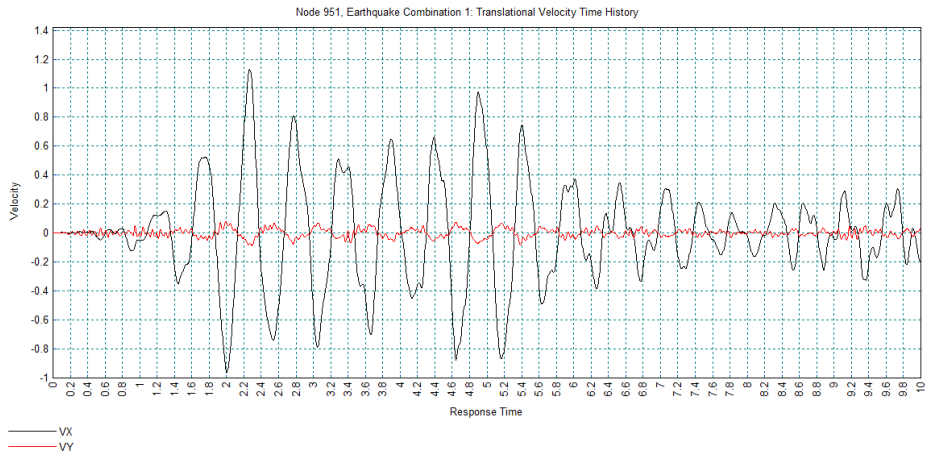
```
# +--------------+
# | Record = 001 |
# +--------------+
#
# Entity                    Time              Value
Peak_Pos_VX           2.265000000         1.130034962
Peak_Neg_VX           2.005000000        -0.9632780647
Abs_Peak_VX           2.265000000         1.130034962
Peak_Pos_VY           1.995000000         0.8042384584E-001
Peak_Neg_VY           2.295000000        -0.8502432207E-001
Abs_Peak_VY           2.295000000         0.8502432207E-001
Peak_Pos_RVZ          2.020000000         0.3272904491E-001
Peak_Neg_RVZ          2.270000000        -0.3917469034E-001
Abs_Peak_RVZ          2.270000000         0.3917469034E-001
Abs_Peak_RSLT         2.265000000         1.132368775
#
```

Note. Velocities are relative to the supports.

- Close the Notepad application and graph window.

If the IMDPlus toolbar has been enabled,

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

If the IMDPlus toolbar is not enabled,

Analyses
   IMDPlus   >
      Seismic...

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. When prompted about the total mass participation click the **Yes** button to continue.
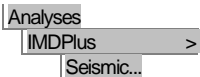
Acceleration and Secondary Response Spectra Plots

The acceleration response of the top of the tower is now required. Enter the following information into the output control dialog.

- Select **Acceleration** results of **AX & AY**

- Select **Secondary Response Spectra (SRS)**

- Click on the **Modify…** button to bring up the SRS Control dialog.

- On the SRS Control dialog set the **Minimum damping** and **Maximum damping** to **5.0** and the **Damping increment** to **0.0**

- Click the **OK** button and **Yes** to confirm that only a single damping ratio is to be used

- Click the **Apply** button to proceed.

- When the IMDPlus analysis is finished select **No** when asked whether to show average, maximum and minimum SRS envelopes.

The horizontal (AX) and vertical (AY) accelerations of the top of the tower are displayed on the graph for the first 10 seconds of the 1940 El Centro earthquake. Peak accelerations are also output to Notepad and indicate absolute peak accelerations of 15.089 m/s^2 in the X-direction, 5.937 m/s^2 in the Y-direction, a peak rotational acceleration of 1.56 rad/s^2 and an absolute peak acceleration of 15.24 m/s^2 (Record 1).


Node 951, Earthquake Combination 1: Translational Acceleration Time History
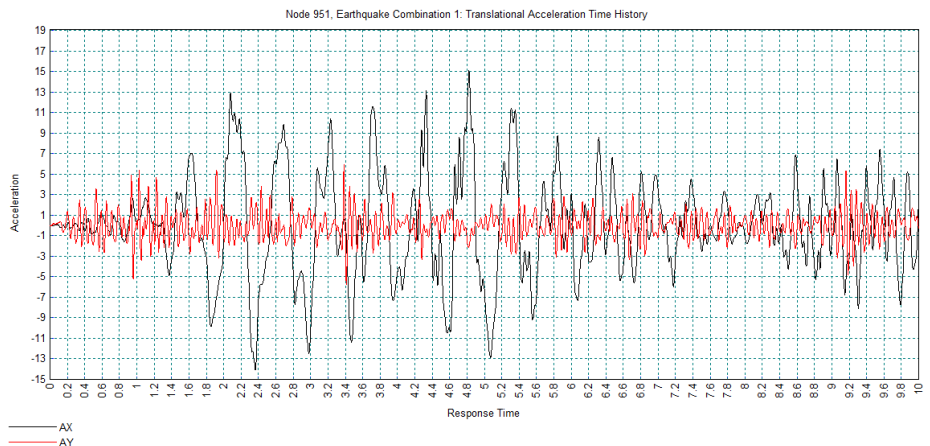
```
# +--------------+
# | Record = 001 |
# +--------------+
#
# Entity                    Time              Value
Peak_Pos_AX             4.820000000        15.08944593
Peak_Neg_AX             2.365000000       -14.07774191
Abs_Peak_AX             4.820000000        15.08944593
Peak_Pos_AY             3.385000000         5.933899473
Peak_Neg_AY             3.410000000        -5.754381233
Abs_Peak_AY             3.385000000         5.933899473
Peak_Pos_RAZ            3.480000000         1.559527110
Peak_Neg_RAZ            3.390000000        -1.466687724
Abs_Peak_RAZ           3.480000000         1.559527110
Abs_Peak_RSLT          4.820000000        15.24075713
#
```

Secondary Response Spectra are also generated for the horizontal and vertical directions in two additional graphs. These graphs represent the peak acceleration responses of a range of single degree of freedom oscillators with known natural frequencies and damping should they be attached to the node at the top of the tower.

5.0000% Damped Secondary Response Spectrum for Node 951

—— Earthquake Combination 1
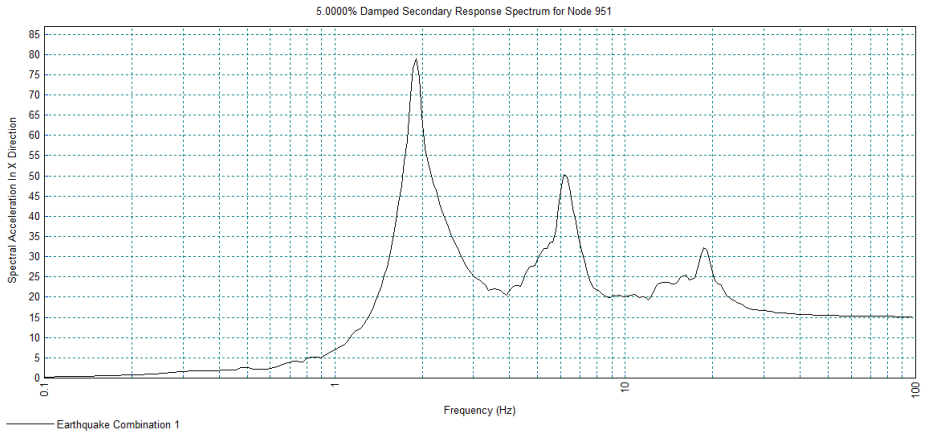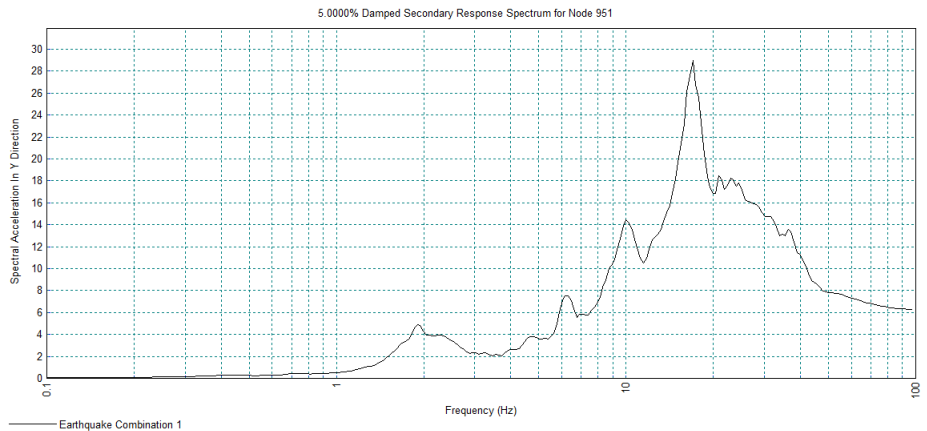
- Close the Notepad application and graph windows.

Displaying Individual Element Results

In the previous section the displacement, velocity and acceleration response of the top of the tower were investigated. Now, forces and moments in one of the columns of the structure at ground level will be evaluated.
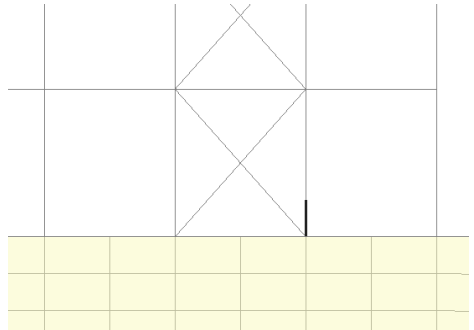
 In the LUSAS view window re-size the display to show the whole tower.

 Zoom-in to the base of the tower and select the element immediately above ground level in the second column from the right.

The main tower members have been meshed with 4 line mesh divisions so each line will have 4 elements along its length.
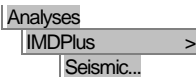
If the IMDPlus toolbar has been enabled,

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

If the IMDPlus toolbar is not enabled,

Analyses	
IMDPlus	>
Seismic...	

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. 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 ensure **Extent** remains selected as **Individual**

- Choose **Element** number **613** from the drop-down list (or your element number if different).

- Select element **End** number **2** which corresponds to the ground level. (Note that line directions can be viewed to ascertain which is end 1 or end 2 of a line).

- Select **Force/Moment - Thick 2D Beam** results of **Fx**

- Ensure **Individual items** remains selected. 'Sum of chosen items' and 'Average of chosen items' will not be available as an individual element is being processed.

- Deselect **Peak response summary**

- Click the **Apply** button to proceed.

The time history of the axial force (in N) in the column is displayed on the graph for the first 10 seconds of the 1940 El Centro earthquake. Similar graphs can also be generated for the shear force and bending moment by selecting Fy (in N) and Mz (in Nm) from the output control dialog.
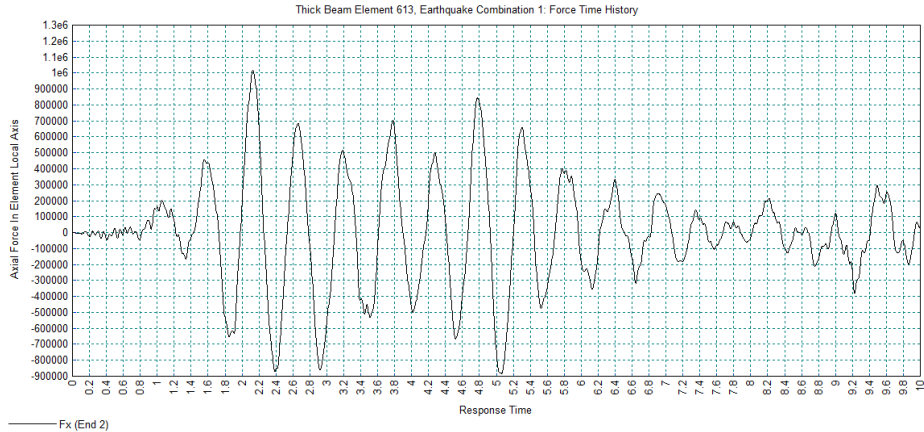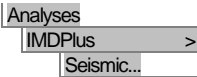

Thick Beam Element 613, Earthquake Combination 1: Force Time History
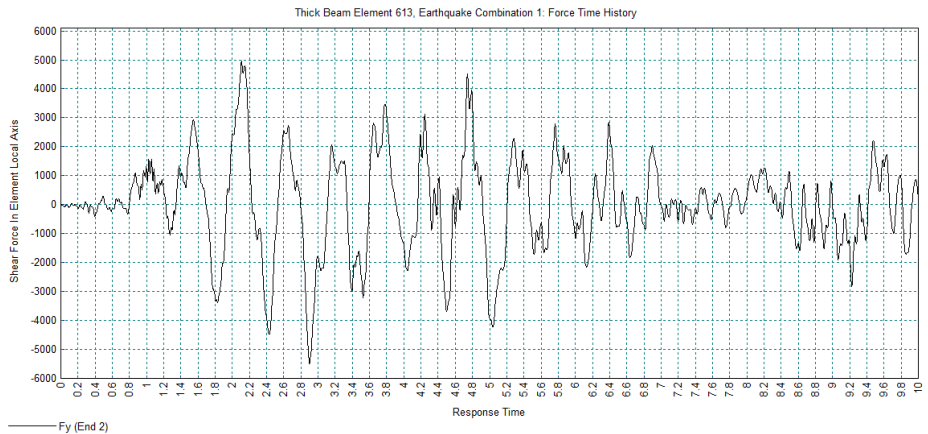
- Close the graph window.

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,

<table>
<tr><td>Analyses</td></tr>
<tr><td>IMDPlus ></td></tr>
<tr><td>Seismic...</td></tr>
</table>

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. When prompted about the total mass participation click the **Yes** button to continue.

- Select **Force/Moment - Thick 2D Beam** results of **Fy**

- Click the **Apply** button to proceed.

Thick Beam Element 613, Earthquake Combination 1: Force Time History

- Close the graph window.

If the IMDPlus toolbar has been enabled,

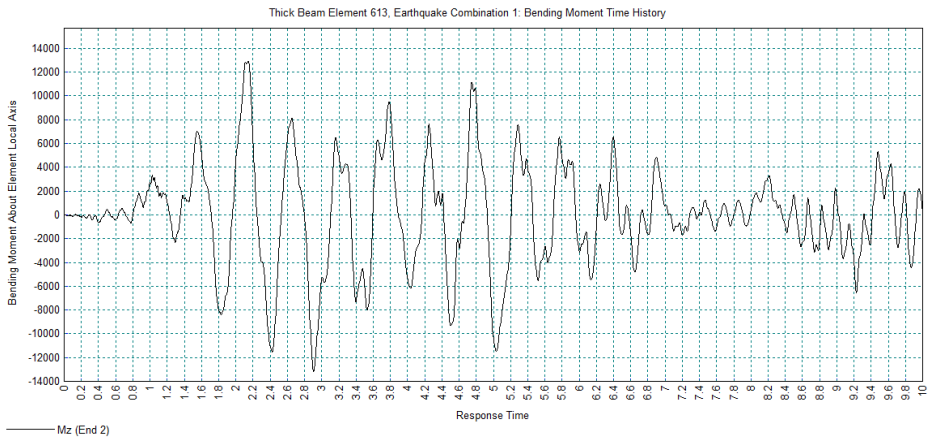- Click on the [button icon] button in the toolbar to open the IMDPlus Output Control dialog

If the IMDPlus toolbar is not enabled,

<table>
<tr><td>Analyses</td></tr>
<tr><td>IMDPlus ></td></tr>
<tr><td>Seismic...</td></tr>
</table>

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. When prompted about the total mass participation click the **Yes** button to continue.

- Select **Force/Moment - Thick 2D Beam** results of **Mz**
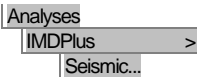
- Click the **Finish** button to finish output processing of the individual element results.

- Click **Yes** when asked whether to free up disk space by deleting the temporary files created by IMDPlus.

Thick Beam Element 613, Earthquake Combination 1: Bending Moment Time History

- Close the graph window.

Displaying Results for a Selected Set of Elements

The example analyses presented in the previous sections have all utilised individual nodes or elements of the structure. In this section a set of beam elements will be selected and analysed in order to evaluate the average forces/moments and peak forces/moments from the bases of all the columns of the tower.

In the LUSAS view window re-size the display to show the whole tower.

- With no features selected click the right-hand mouse button in a blank part of the view window and select the **Labels** option to add the labels layer to the Treeview.

- On the Properties dialog select the **Element** / **Name** check box and the **Label selected items only** check box.

- Click the **Advanced...** button and on the label properties dialog click the **Font...** button and select Font: **Arial,** Font style: **Bold,** Size: **20** and click **OK.**

- Click **OK** to return to previous dialog and **OK** again to return to the view window.

Zoom-in to the base of the frame and select the beam elements immediately above ground level for all of the columns in the structure, as shown in the following figure (your element numbers may be different from those shown in the diagram).

Note. Use the **Shift** or **Ctrl** keys to select multiple elements in the model.

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.
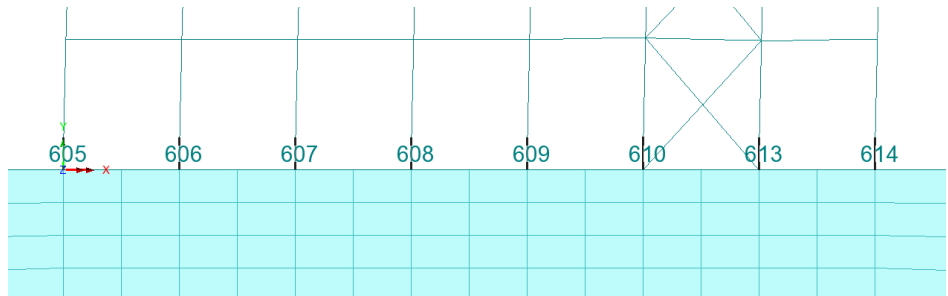
If the IMDPlus toolbar has been enabled,

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

If the IMDPlus toolbar is not enabled,

Analyses
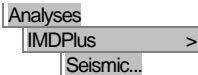 IMDPlus   >
      Seismic...

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. 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 change **Extent** to **Selected** using the drop-down list. This chooses the eight beam elements at the base of the frame for processing. These beams were selected in the preceding step.

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

- Select results entity **Force/Moment – Thick 2D Beam** of component **Fx**

- Deselect **Individual items** and select **Average of chosen items** as the averaged results for the eight beam elements are going to be investigated.

- Ensure **Response time history** is selected

- Select **Peak response summary** and select **Envelope**

- Ensure **Generate graphs in Modeller** is selected and **Earthquake to graph** is set to **1**

The dialog should look like this:

- Click the **Apply** button to proceed. Click **Yes** when asked whether you want to process all of the selected elements.

Note. Any combination of the options **Individual items**, **Sum of chosen items** and **Average of chosen items** can be used 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 16 beam ends of the selected elements. A simple average of this summed result is obtained to give the element average time history of axial force from which the peak average results are obtained.

The IMDPlus analysis will run and after a short while a graph showing the average axial (Fx) force obtained from the selected beam elements will be displayed for the first 10 seconds of the 1940 El Centro earthquake (Earthquake 1). The average axial force in the beam elements is shown in the following figure.
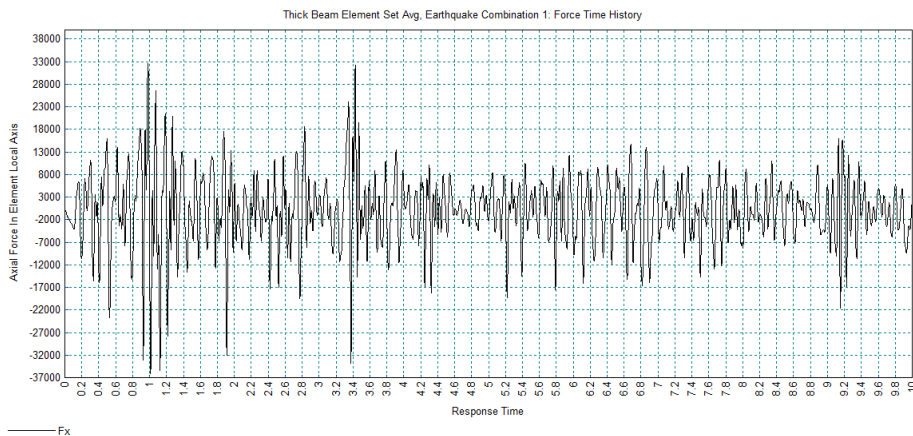
Peak results for the averaged element forces and moments are displayed in Notepad in file **peak_forceSet_Avg1.sum**. These indicate a peak positive average axial (Fx) force of 32.7kN at solution time 0.98 seconds and a peak negative average axial (Fx) force of -36.1kN at 1.01 seconds for the 1940 El Centro earthquake (Record 1), as shown in the following figure.

```
# +--------------+
# | Record = 001 |
# +--------------+
#
# Entity                    Time                Value
Peak_Pos_Fx           0.9800000000          32650.98694
Peak_Neg_Fx           1.010000000          -36088.05283
Abs_Peak_Fx           1.010000000           36088.05283
Peak_Pos_Fy           2.105000000           5585.260755
Peak_Neg_Fy           2.905000000          -5996.579934
Abs_Peak_Fy           2.905000000           5996.579934
Peak_Pos_Mz           2.145000000           8359.526029
Peak_Neg_Mz           2.905000000          -8270.389903
Abs_Peak_Mz           2.145000000           8359.526029
#
```

An envelope of the peak results from the selected beam elements is displayed in Notepad in file peak_forceSet1.sum. Results for the 1940 El Centro earthquake (Record 1) are shown in the following figure. A peak positive axial (Fx) force of 1019.1kN occurs at time 2.13 seconds at end 1 of element 613. A peak negative axial (Fx) force of -956.0kN occurs at time 2.135 seconds at end 1 of element 610.

Note. The envelope of the peak results is obtained in IMDPlus by examining the individual results from all 16 ends of the chosen beam elements. This helps to quickly identify the locations where the peak results occur in the selected set of elements.

```
# +-------------+
# | Record = 001 |
# +-------------+
#
# Entity              Time            Value       Element      End
Peak_Pos_Fx        2.130000000     1019067.535        613        1
Peak_Neg_Fx        2.135000000    -955966.1871        610        1
Abs_Peak_Fx        2.130000000     1019067.535        613        1
Peak_Pos_Fy        2.105000000     6684.477319        609        1
Peak_Neg_Fy        2.905000000    -6984.633371        609        1
Abs_Peak_Fy        2.905000000     6984.633371        609        1
Peak_Pos_Mz        2.145000000     15471.60497        609        2
Peak_Neg_Mz        2.905000000    -15551.24795        609        2
Abs_Peak_Mz        2.905000000     15551.24795        609        2
#
```

- Close the Notepad applications and graph windows.

If the IMDPlus toolbar has been enabled,

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

If the IMDPlus toolbar is not enabled,

Analyses
  IMDPlus   >
     Seismic...

- Open the IMDPlus Seismic Analysis Control dialog through the menu and click **Next >** to keep the existing analysis control settings and open the IMDPlus Output Control dialog. When prompted about the total mass participation click the **Yes** button to continue.

- Select **Force/Moment - Thick 2D Beam** results of **Mz**

- Click the **Finish** button to finish output processing of the element results. 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.

A graph of the average (Mz) moment obtained from the selected elements will be displayed, as shown in the following figure.

Thick Beam Element Set Avg, Earthquake Combination 1: Bending Moment Time History

——— Mz
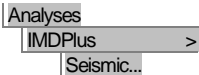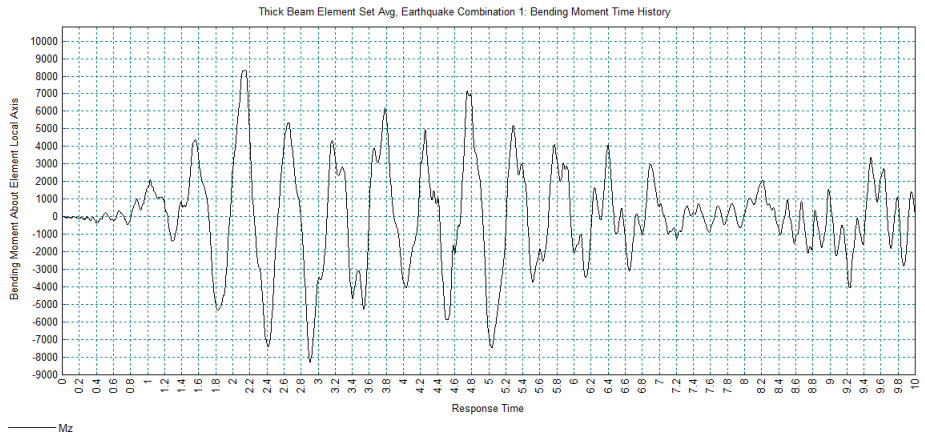
All of the peak averaged results displayed in Notepad will be the same as those shown when the axial (Fx) force was analysed earlier. These indicate an average absolute peak (Mz) moment of 8.4kNm at time 2.145 seconds (Record 1). The envelope of the peak results indicates an absolute peak (Mz) moment of 15.6kNm occurring at time 2.905 seconds in end 2 of element 609 (Record 1).

```
# +--------------+
# | Record = 001 |
# +--------------+
#
# Entity                Time            Value         Element         End
Peak_Pos_Fx       2.130000000      1019067.535             613           1
Peak_Neg_Fx       2.135000000     -955966.1871             610           1
Abs_Peak_Fx       2.130000000      1019067.535             613           1
Peak_Pos_Fy       2.105000000      6684.477319             609           1
Peak_Neg_Fy       2.905000000     -6984.633371             609           1
Abs_Peak_Fy       2.905000000      6984.633371             609           1
Peak_Pos_Mz       2.145000000      15471.60497             609           2
Peak_Neg_Mz       2.905000000     -15551.24795             609           2
Abs_Peak_Mz       2.905000000      15551.24795             609           2
#
```

- Close the Notepad applications and graph windows.

Save the model

File
Save…
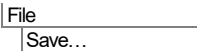
Save the model. This saves all load combinations that have been defined during the results processing operations.

This completes the example.