

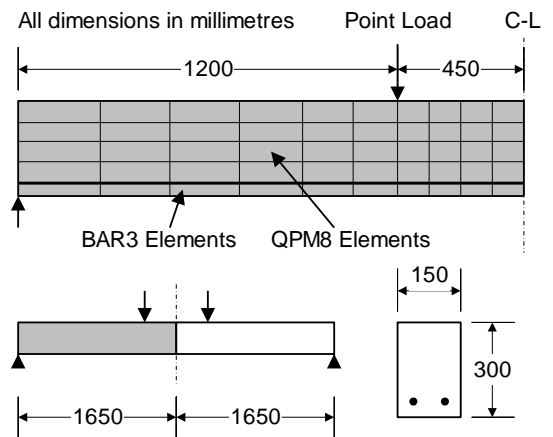
# Nonlinear Analysis of a Concrete Beam

For LUSAS version:	20.0
For software product:	Any Plus version. Bridge Plus version for the modelling described in the discussion at the end.
With product options:	Nonlinear.

## Description

A nonlinear plane stress analysis is to be carried out on a model of a reinforced concrete beam.

The reinforcement is provided in the lower face of the beam and has a total cross-sectional area of  $400 \text{ mm}^2$ . The superposition of nodal degrees of freedom assumes that the concrete and reinforcement are perfectly bonded. It is assumed that the self-weight of the beam is negligible compared with the applied load and that the effects of any shear reinforcement can be ignored.



Due to the symmetrical nature of the problem, only the left-hand span of the beam is modelled. The beam is simply supported at the left-hand end with a symmetry support at the right-hand axis of symmetry. A concentrated vertical load is applied to the top of the beam 1200mm from the left-hand end. The concrete section is represented by plane stress (QPM8) elements, and the reinforcement bars are represented by bar (BAR3) elements. A nonlinear concrete cracking material model will be applied to the plane stress elements and a von Mises plastic material will be applied to the reinforcement bars.

Units of N, mm, t, s, C are used throughout.

### Objectives

The behaviour of the beam under cracking/yielding is to be examined by producing the following:

- A Deformed Mesh Plot** showing the final deformed shape.
- A Load Displacement Graph** for the top node on the axis of symmetry of the beam.
- Stress contour plot** showing the stress distribution in the beam.
- Crack pattern plot** showing the crack patterns produced.
- Animation of stresses and crack patterns** for selected load increments.
- A graph of variation in stress** through selected slice sections through the beam.

### Keywords

**2D, Inplane, Plane Stress, Bar Elements, Nonlinear Concrete Model, Element Selection, Concrete Cracking, Steel Reinforcement, Groups, Crack Patterns, Animation, Graphing, Load Displacement Curve, Slice Sections**

### Associated Files

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



- beam\_nl\_modelling.lvb** carries out the modelling of the example.

## Modelling



**Note.** Model and results images included in this example were captured in an earlier version and may differ in appearance from those seen and obtained from this version.

### 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.



**Note.** This example is written assuming a new LUSAS Modeller session has been started. If continuing from an existing Modeller session select the menu command **File>New** to start a new model file. Modeller will prompt for any unsaved data and display the New Model dialog.

## Creating a new model


- Enter a File name of **beam\_nl**
- Use the default User-defined working folder.
- Ensure an Analysis type of **Structural** is set.
- Select an Analysis Category of **2D Inplane**
- Set Model units of **N,mm,t,s,C**
- Leave the Timescale units as **Seconds**
- Select a Startup template of **2D Plane Stress**.
- Ensure the Layout grid is set as **None**
- Enter a Title of **Nonlinear Concrete Beam**
- Click the **OK** button.

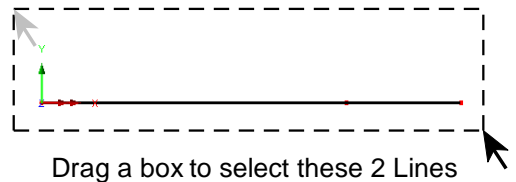


**Note.** Save the model regularly as the example progresses. Use the Undo button to correct any mistakes made since the last save was done.

## Defining the Geometry


Geometry  
Line >  
By Coords...

 Enter coordinates of **(0, 0)**, **(1200, 0)** and **(1650, 0)** to define two Lines representing the bottom of the beam. Click the **OK** button to finish.



- Select both Lines just drawn by dragging a selection box around them.

Geometry  
Surface >  
By Sweeping...

 Enter a translation value of **25** in the **Y** direction to create the Surface which represents the concrete cover from the face of the beam to the centreline of the reinforcement.

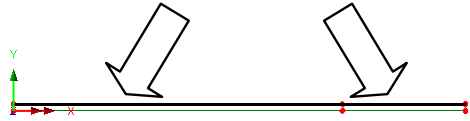
- Click the **OK** button.

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- Select the upper Lines of both of the Surfaces just drawn as shown.

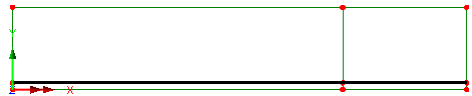
Select these 2 Lines




Enter a translation value of **275** in the **Y** direction to create the Surface which represents the extent of the concrete above the centreline of the reinforcement.

- Click the **OK** button.

The model should appear as shown.

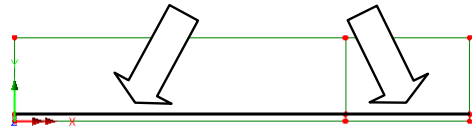


### Defining Groups

To simplify the assignment of model attributes certain model features will be grouped together to allow selection by name in the  Treeview as opposed to selection by cursor in the graphics window. The 2 Lines representing the reinforcement bars are to be grouped together:

- Ensure the 2 Lines are still selected as shown.

Select these 2 Lines

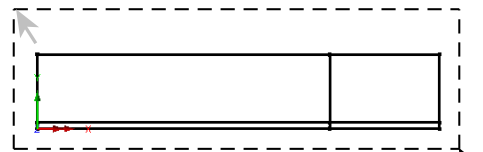


Enter **Bars** for the group name.

- Click the **OK** button to complete creation of the group.

The Surfaces representing the concrete are to be grouped together.

- Holding-down the **S** key, (and noting that the cursor changes to show the type of feature that will be selected) drag a box around the whole model to select only the Surfaces defining the concrete.



Drag a box to select only Surfaces



Enter **Concrete** for the group name. Click the **OK** button to complete creation of the group.

Geometry  
Surface >  
By Sweeping...

Geometry  
Group >  
New Group

Geometry  
Group >  
New Group

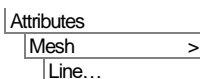




**Note.** In this example, model attributes will be defined but not assigned to the model straight away. They will be assigned to the model later by making use of the Groups facility.

## Defining the Mesh Reinforcement Bars

Separate mesh datasets need to be defined for the reinforcement bars and the concrete. For the reinforcement bars a uniform mesh is to be used to the right of the applied load and a graded mesh is to be used on the horizontal lines to the left of the applied load.

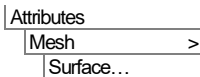
The reinforcement bars will be modelled using Line meshes.




- Set Generic element type to **Bar** and Interpolation order to **Quadratic**
- Ensure the **Number of divisions** is set to **4**
- Enter the attribute name as **Bar, quadratic order, divs = 4**
- Click the **Apply** button to create the attribute in the  Treeview and leave the dialog visible to allow additional datasets to be defined.
- Change the **Number of divisions** to **6** and click the **Spacing** button.
- Select a **Uniform transition** ratio of first to last element of **2** and click **OK**
- Change the attribute name to **Bar, quadratic order, divs = 6 graded**
- Click the **OK** button to finish to add the attribute to the  Treeview.


## Defining the Mesh Concrete

The concrete will be modelled using a Surface mesh with Line mesh divisions to control the mesh density.



- Select **Plane stress, Quadrilateral, Quadratic** elements.
- Enter the attribute name as **Plane stress quadratic**
- Click the **OK** button to add the attribute to the  Treeview.


The default mesh density of 4 divisions per line is sufficient for the Surface to the right of the applied load. A graded line mesh will be created for use on the Surface to the left of the applied load.

- In the  Treeview double click the Line mesh attribute name **Bar, quadratic order, divs = 6 graded**



The Line mesh properties dialog will appear.

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- Change the element type to **None**
- Change the attribute name to **Null, divs=6 graded**
- Click the **OK** button to add the attribute to the  Treeview.


### Defining the Geometric Properties

- Select **Bar** from the drop down list and enter a value of **400** for the total cross sectional area of the reinforcement.
- Enter the attribute name as **Steel Area** and click the **OK** button to add the attribute to the  Treeview.
- Enter a value of **150** for the thickness. Leave the eccentricity blank.
- Enter the attribute name as **Beam Thickness** and click the **OK** button to add the attribute to the  Treeview.

### Defining the Material Properties

#### Steel


Nonlinear steel properties will be defined for the reinforcing bar elements.

- Enter Young's modulus as **210e3** and Poisson's ratio as **0.3** and leave the mass density field blank.
- Click the **Plastic** option and enter an **Initial uniaxial yield stress** of **300**
- Select the **Hardening** option, click the **Hardening gradient** button and enter a hardening **Slope** value of **2121** with a **Plastic strain** of **1**
- Enter the attribute name as **Nonlinear Steel**
- Click the **OK** button to add the attribute to the  Treeview.

#### Concrete





Nonlinear concrete material properties will be defined for the Surface elements representing the concrete.

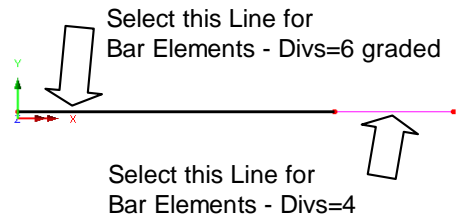
- Ensure the concrete model **Smoothed multi-crack (model 109)** is selected.
- Ensure that Creep model code **None** is selected.
- Ensure that Shrinkage model code **None** is selected.

- Enter a Young's modulus of **42000**, a Poisson's ratio of 0.2 and leave the mass density field blank.
- Enter a Uniaxial compressive strength value of **31.58**
- Enter a Uniaxial tensile strength value of **3.158**
- Leave the Strain at peak uniaxial compression as the default value.
- Select the **Strain at end of softening curve** radio button and set the value to be **0.003** and press **OK** to return.
- Enter the attribute name as **Nonlinear Concrete**
- Click the **OK** button to add the attribute to the  Treeview.


### Assigning Attributes to the Bars

The various Line and Surface mesh, geometric and material attributes defined previously will now be assigned to the model using the groups that have been defined.

- In the  Treeview right-click the group name **Bars**. Select the **Set as Only Visible** option. The features in the group will be displayed.
- Select the left hand Line of the two Lines representing the bars.
- Drag and drop the Line mesh attribute **Bar, quadratic order, divs = 6 graded** from the  Treeview onto the selected Line.
- Select the right hand Line of the two Lines representing the bars.
- Drag and drop the Line mesh attribute **Bar, quadratic order, divs = 4** from the  Treeview onto the selected Line.
- In the  Treeview double-click on the **Mesh** entry and select **Show nodes**.




The Line mesh divisions will be seen defined with the spacing as shown.


- Select both Lines.
- Drag and drop the geometric attribute **Steel Area** from the  Treeview onto the selected features. Click **OK**.

- Drag and drop the material attribute **Nonlinear Steel** from the  Treeview onto the selected features. Click **OK**.




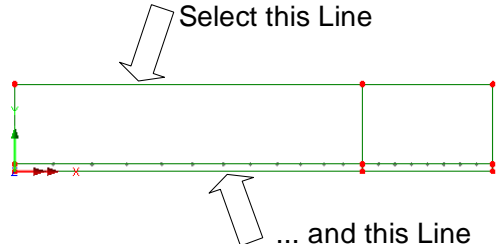
**Note.** The diagrams in this example show element nodes. To see these at any time you can go to the  Treeview and double-click the **Mesh** layer. On the Mesh tab select **Show nodes** and click the **Close** button.


### Assigning Attributes to the Concrete

- In the  Treeview right-click the group name **Concrete**. Select the **Set as Only Visible** option.

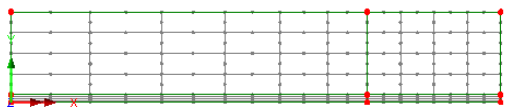
The Lines in the Bars group will be made invisible, and the lines of the Concrete group will be made visible.

- Select the left-top and left-bottom Lines as shown. (Hold the **Shift** key down after selecting the first line)
- From the  Treeview drag and drop the Line mesh attribute **Null, div=6 graded** onto the selected features.



- Select the whole model using the **Ctrl** and **A** keys together.
- Drag and drop the Surface mesh attribute **Plane stress quadratic** from the  Treeview onto the selected features.


A graded mesh will be drawn on the left-hand Surface and a uniform mesh will be drawn on the right-hand Surface.



- Drag and drop the geometry attribute **Beam Thickness** from the  Treeview onto the selected features. Click **OK**.



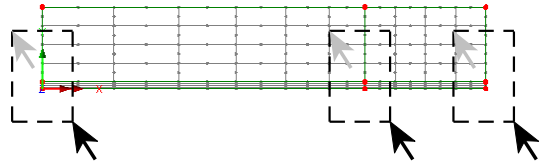
Select the fleshing on/off button to turn-off the geometric visualisation. If at any time during the example you wish to visualise the geometry select this button.

- With the whole model still selected, drag and drop the material attribute **Nonlinear Concrete** from the  Treeview onto the selected features. Ensure the **Assign to surfaces** option is selected for Analysis 1 and click **OK**




The mesh on the Lines representing the cover to the centreline of the reinforcement needs to be altered. This is because they currently have a default Line mesh of 4 divisions per line when only 1 division per line is required.

- Drag boxes to select the 3 Lines as shown. (Remember to hold the **Shift** key down after the first line is selected so the other lines are added to the selection)




Drag 3 boxes to select these 3 Lines

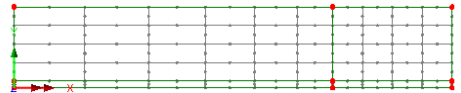
- Drag and drop the Line mesh attribute **Null, div =1** from the  Treeview onto the selected Lines.

The mesh will be redisplayed with the revised mesh pattern.


## Making all groups visible


- From the  Treeview right-click the group heading name **beam\_nl.mdl**. Select the **Set as Only Visible** option. Click **Yes** to act on subgroups as well.

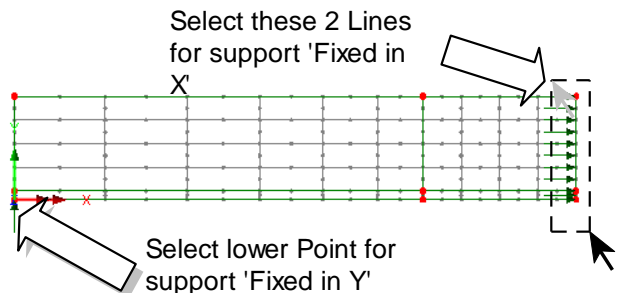
All features in the model will now be displayed as shown.



## Supports

When using the Standard template, LUSAS provides the more common types of support by default. These can be seen in the  Treeview. The beam is to be simply supported in the Y direction at the left-hand end and a horizontal restraint in the X direction is required to satisfy the symmetry requirements at mid-span.


- Select the lowest Point at the left hand end of the model as shown.
- Drag and drop the support attribute **Fixed in Y** from the  Treeview onto the selected Point. Ensure the **Assign to points** and **All analysis loadcases** options are selected and click **OK**



- Drag a box around the 2 Lines at the right hand end of the model as shown.

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- Drag and drop the support attribute **Fixed in X** from the  Treeview onto the selected Lines. Ensure the **Assign to lines** and **All analysis loadcases** options are selected and click **OK**


### Loading

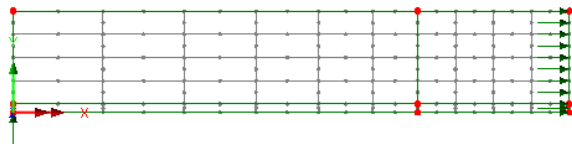
A single concentrated load is to be applied to the Point at the top of the beam. A unit load will be applied and the load factor in the nonlinear control will be used to control the magnitude of loading.

- With the **Concentrated** option selected click **Next**
- Enter a Concentrated load in **Y Dir** loading value of **-1**
- Enter the attribute name as **Point Load** and click **Finish**

- Select the Point on the top of the beam as shown.

Select this Point 

- Drag and drop the loading dataset **Point Load** from the  Treeview onto the selected Point.





- Ensure the **Assign to points** option is set and click **OK** to assign the load to **Analysis 1, Loadcase 1**.

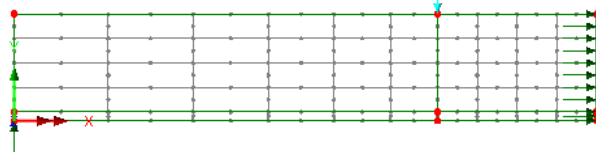
### Nonlinear Control

Nonlinear analysis control properties are defined as properties of a loadcase. The nonlinear analysis is to be terminated when the beam deflection at mid span reaches a limiting value.

- Select the point shown.

Select this Point 

- In the  Treeview ensure the **Analysis 1** entry is expanded, then right-click on **Loadcase 1** and from the **Controls** menu select **Nonlinear & Transient**



Attributes  
Loading...

The Nonlinear & Transient dialog will appear:

**Nonlinear & Transient**

**Incrementation**

Nonlinear

Incrementation: Automatic

Starting load factor: 5.0E3

Max change in load factor: 2.0E3

Max total load factor: 0.0

Adjust load based on convergence

Iterations per increment: 10

Displacement reset

**Solution strategy**

Same as previous loadcase

Max number of iterations: 25

Residual force norm: 0.1

Incremental displacement norm: 1.0

**Incremental LUSAS file output**

Same as previous loadcase

Output file: 1

Plot file: 1

Restart file: 0

Max number of saved restarts: 0

Log file: 1

History file: 1

Save a restart at the end of this control

**Time domain**

Time domain

Consolidation

Initial time step: 0.0

Total response time: 100.0E6

Automatic time stepping

**Common to all**

Max time steps or increments: 0

OK Cancel Help

- Select the **Nonlinear** option and set Incrementation to **Automatic**
- The load to be applied to the model is the concentrated load previously defined and assigned to the model multiplied by the starting load factor. Set the **Starting load factor** to **5000**
- Enter the **Max change in load factor** as **2000** to restrict the second and subsequent load increment sizes to ensure sufficient points are obtained to observe the load deflection behaviour of the beam.
- Change the **Max total load factor** to **0** because the solution is to be terminated on the limiting displacement at mid span.
- Change the number of desired **Iterations per increment** to **10**



**Note.** If the number of iterations on the previous increment is less than the desired number, the next load increment will be increased (up to the maximum change in load increment). If the number of iterations is less than the desired number, the next load increment will be reduced.

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- In the Solution strategy section of the dialog, ensure the **Maximum number of iterations** is set to **25**
- Leave the **Residual force norm** as **0.1** and the **Incremental displacement norm** to **1** so convergence of the solution at each load increment will be achieved when the out of balance forces are as less than 0.1% of the reactions and the iterative change in displacements is less than 1% of the displacements for that load increment.
- In the Incrementation section of the dialog, select the **Advanced** button.

Advanced Nonlinear Incrementation Parameters

Automatic incrementation

Stiffness ratio to switch to arc-length

Use arc-length control

Arc-length calculation

Relative displacement arc-length procedure

Guide arc-length solution with current stiffness

Use root with lowest residual norm

Arc-length restart load factor

Arc-length restart load change

Termination criteria

Terminate on value of limiting variable

Point number

Variable type

Value

Minimum change in incremental load

Step reduction

Allow step reduction

Maximum step reductions

Load reduction factor

Load increase factor

- Ensure that the **Stiffness ratio to switch to arc length** value is set to **0.0**
- Select the **Terminate on value of limiting variable** option.
- The point number of the previously selected point (this may differ depending on how the model was created) will appear in the Point number drop down list.
- Set the **Variable type** to **V** to monitor the deflection at the selected point in the Y direction.
- Enter a value of **-3** so the analysis is terminated when the central deflection reaches this value.
- In the Step reduction section ensure that the **Allow step reduction** option is selected.
- Click **OK** to return to the Nonlinear & Transient dialog.
- Click **OK** again to set the loadcase properties.

One additional setting is required for this analysis to ensure no element mechanisms are induced as the material yields.

File  
Model Properties...

- Select the **Options** tab.
- Click on the **Element Options** button and select the **Fine integration for stiffness and mass (structural)** option.
- Click the **OK** button to return to the Model Properties dialog.
- Click the **OK** button to finish.

### Save the model

The model is now complete, and the model data is to be saved before an analysis is run using the LUSAS Solver.

File  
Save



Save the model file.

## Running the Analysis



Open the **Solve Now** dialog and press **OK** to run the analysis.

During the analysis 2 files will be created:

- beam\_nl.out** this contains the statistics of the analysis, for example how much disk space was used, how much CPU time was used, and any errors or warning messages from LUSAS, and so on. Always check the LUSAS output file for error messages.
- beam\_nl.mys** this is the LUSAS results database which will be used for results processing.



**Note.** Warnings will be written to the text output window during this analysis. Warnings are not to be confused with errors which normally stop an analysis from being run. The warnings are written to advise you of modelling-related issues that are found during the analysis and of the steps LUSAS has taken (if any) to allow the analysis to continue.

### If the analysis is successful...

Analysis loadcase results are added to the Treeview.

### If the analysis fails...

If the analysis fails, information relating to the nature of the error encountered can be written to an output file in addition to the text output window. Select **No** to not view the output file. Any errors listed in the text output window should be corrected in LUSAS Modeller before saving the model and re-running the analysis.

### Rebuilding a Model

If it proves impossible for you to correct the errors reported a file is provided to enable you to re-create the model from scratch and run an analysis successfully. You may download this file from the user area of the LUSAS website.



**beam\_nl\_modelling.lvb** carries out the modelling of the example.



Start a new model file. If an existing model is open Modeller will prompt for unsaved data to be saved before opening the new file.

- Enter the file name as **beam\_nl**
- Use the default **User-defined** working folder.
- Ensure an Analysis category of **2D Inplane** is set.
- Click the **OK** button.

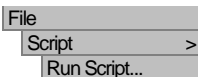
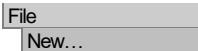


**Note.** There is no need to enter any other new model details when a script is run to build a model, since the contents of the script will overwrite any other settings made.


To recreate the model, select the file **beam\_nl\_modelling.lvb** that was downloaded and placed in a folder of your choosing.




Rerun the analysis to generate the results.




## Viewing the Results

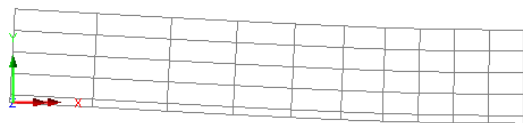
Analysis loadcase results are present in the  Treeview.

### Changing the Active Results Loadcase

- In the  Treeview the last load increment **Increment 7 Load Factor = 17000** should be already **Set Active**.

### Deformed Shape

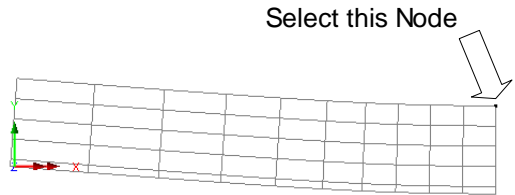
- In the  Treeview turn off the **Geometry**, **Attributes** and **Mesh** layers by right clicking on each entry and selecting the **On/Off** option.



## Creating a Load versus Displacement Graph

A graph of displacement at mid-span is to be plotted against the applied load. To do this a node on the line of symmetry is selected:

- With the **Deformed mesh** layer visible, select the top node on the axis of symmetry as shown.



## Using the Graph Wizard

The graph wizard provides a step-by-step means of selecting which results are to be plotted on the X and Y axes of the graph. The X axis is always defined first.

Utilities

Graph Wizard...

- Ensure the **Time history** option is selected and click the **Next** button.
- Ensure the **Nodal** results is selected and click **Next**
- Select entity **Displacement** for component resultant displacement **RSLT**
- The node number selected earlier will be displayed in the Specify drop-down list.
- Click the **Next** button.

The Y axis results to be graphed are now defined.

- Select the **Named** option and click **Next**
- Select **Total load factor** from the drop down list.
- Click the **Next** button.

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- Leave all title information blank and click the **Finish** button to display the load deformation graph.

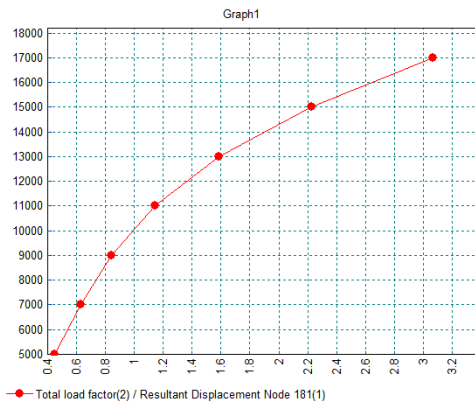


**Note.** Graphs can be modified using the right hand mouse button in the graph window and selecting the **Edit Graph Properties** option.




Close the graph window.

- In the  Treeview turn off the **Deformed mesh** layer and turn on the Mesh layer.

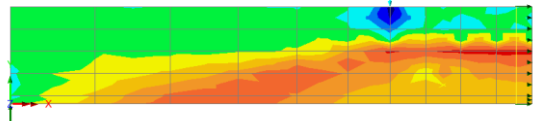


## Maximum Principal Stress Contour Plots

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


The properties dialog will be displayed.

- Select entity **Stress - Plane Stress**, Component of stress in the x direction, **SMax**, and **Averaged nodal** contours.



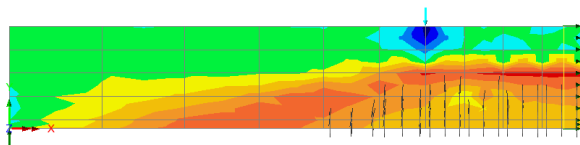
- Click the **OK** button to display contours of stresses for the final load increment.

## Viewing Crack Patterns

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

The properties dialog will be displayed.


- Select **Stress - Plane Stress** contour results of type **Crack/crush**
- Click the **OK** button to display the cracking pattern for final load increment superimposed onto the stress contours.





## Animating the Results

As an alternative to viewing results individually for each loadcase, the change of stress due to the increasing load increments can be animated instead. To ensure consistent contour values throughout the animation the interval, and the maximum and minimum values for the range of contours is to be specified.

- In the  Treeview double-click on the **Contours** layer.

The contour properties will be displayed.

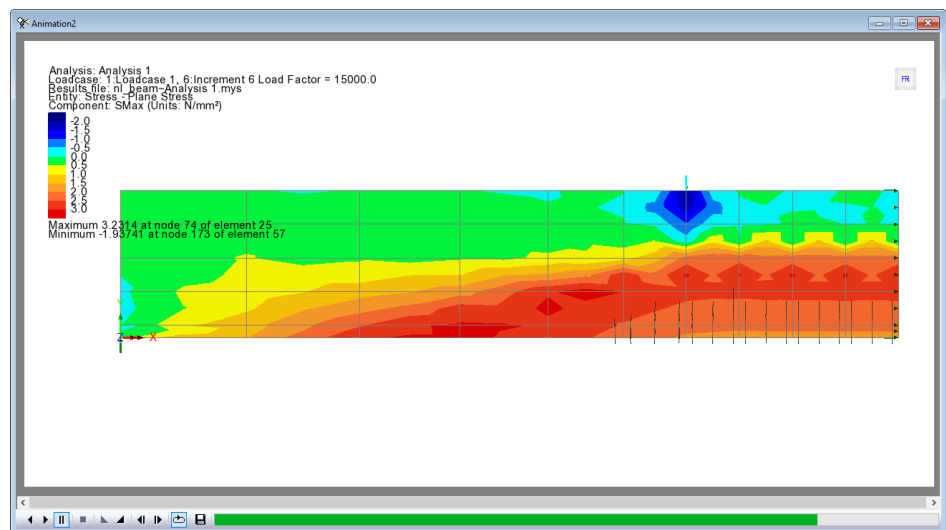
- Select the **Appearance** tab and for the **Classic** contour range press the **Set** button
- Click the **Interval** option and set the contour interval as **0.5**
- Click the **Maximum** button and set the maximum value as **3**
- Click the **Minimum** button and set the minimum value as **-2**
- Click the **OK** button to return to the parent dialog, and **OK** to redisplay the stress contours using the new contour range.

## Using the Animation Wizard

Tools

Animation Wizard...

- Select the **Load History** option and click the **Next** button.
- Select the **All loadcases** option and select the **Finish** button to create the animation sequence.





**Note.** The buttons at the bottom of the window may be used to slow-down, speed-up, pause, step through frame by frame, or stop the animation.



**Note.** To see the animation window in isolation use the **Window > Layout > Multiple documents** menu option.

### Saving Animations

Animations may be saved for replay in Windows animation players.

- Ensure the animation window is the active window.
- Browse to your projects folder and enter **beam\_nl** for the animation file name. An **.avi** file extension is automatically appended to the file name. Click **Save**

File  
Save As AVI...



**Note.** Animations can be compressed to save disk space by changing the **Compression Quality**. Reducing the quality will, however, result in a lower definition image. It is also possible to reduce file size by setting smaller dimensions on the first page of the **Animation Wizard**.

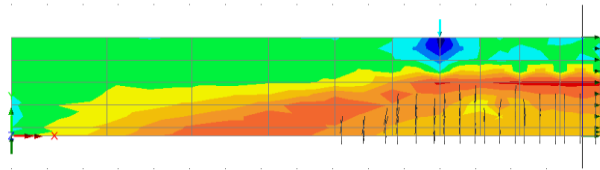


Close the animation window, choosing not to save changes.

### Creating a slice section of results

In this example a graph is to be plotted of the variation in stress through the specified section of the beam. The X axis values of distance are defined by the section slice. The Y axis results are specified from the graph wizard dialog.

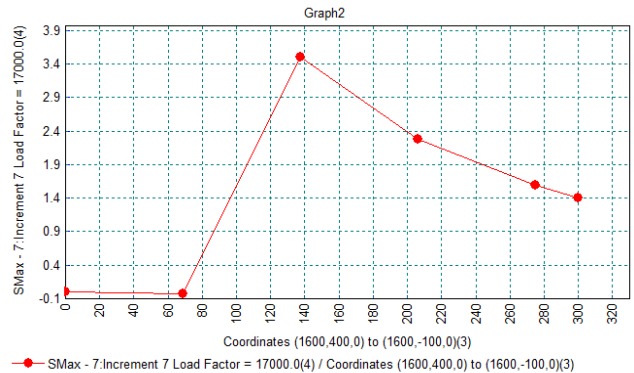
- If necessary, return the model to the default starting view by clicking  on the status bar at the bottom of the graphics window.
- Ensure the **Snap to grid** option is selected and a grid size of **100** is specified.
- Click the **OK** button.
- Using the screen ruler as a guide, click and drag the cursor as shown to define the location of a section slice through the beam at a distance of **1600** from the left-hand end.



- For the loadcase and extent option accept the default of the current loadcase and click **Next**
- Select **Stress** results for Stress **SMax** and click the **Next** button.

Utilities  
Graph Through 2D

- Leave all title information blank.
- Click the **Finish** button to create the graph of stress through the section of beam.

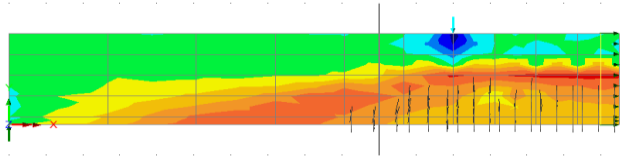


## Adding Additional Results to a Graph

Window

LUSAS View:  
beam\_n1.mdl  
Window 1

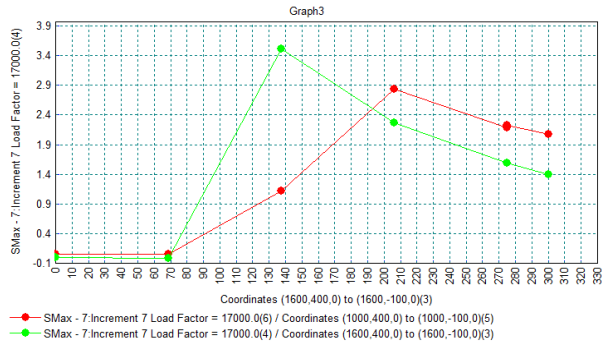
- Re-select the window containing the results contours. The cursor will still be in section slice mode.
- Using the screen rulers as a guide, click and drag the cursor as shown to define the location of a section slice through the beam at a distance of **1000** from the left-hand end.
- For the loadcase and extent option accept the default of the current loadcase and click **Next**
- Select **Stress - Plane Stress** results for Stress **SMax** and click the **Next** button.
- In the 'Include existing graphs' panel select the check box for **Graph 2**.



- Click the **Finish** button to see the results for the second slice section alongside the results for Graph 2.



Close the graph window.



## Plotting Crack Width Contours and Values

Crack width values as calculated by the use of the Smoothed Multi Crack Concrete Model can be plotted in contour and value form:

- Double-click the **Contours** layer name in the Treeview.

The properties dialog will be displayed.

- Select entity **Concrete Results** for component of stress in the x direction, **CWMax**
- Select the **Appearance** tab and for the **Classic** contour range press the **Set** button
- Deselect the **Maximum** button.
- Deselect the **Minimum** button.
- Set the contour **Interval** to be **0.005**
- Ensure the Value to pass through is set to be **0.005**
- Click the **OK** button to redisplay the stress contours using the new contour range.
- Press **Yes** to confirm the Values layer will be adjusted to match.



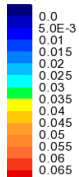
**Note.** Contouring of crack width values effectively shows the elements affected by cracking and identifies those elements where the maximum crack widths occur. This is done using unaveraged, or unsmoothed values at nodes. To see the actual values of crack width within elements (at the locations where the Crack/crush patterns were plotted earlier in the example), values for gauss points need to be plotted.

To see the crack width values:

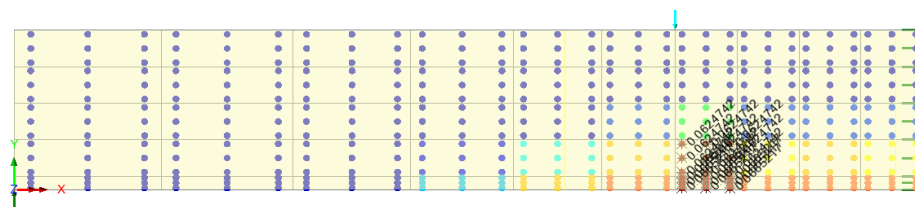
- Double click the **Values** layer name in the Treeview.

- With the **Values Results** tab active, ensure the following are selected: **Concrete Results** of Component **CWMax** at Location **Gauss Point**.
- Select the **Values Display** tab, ensure the **Symbols** and **Values** are checked, and change the **Font angle** to **45 degrees**.

Analysis: Analysis 1  
 Loadcase: 1 Loadcase 1, 7 Increment 7 Load Factor = 17000.0  
 Results file: nl\_beam-Analysis 1.mys  
 Entity: Concrete Results - Plane Stress  
 Component: CWMax (Units: mm)



Maximum 0.0665217 at Gauss point 1 of element 7  
 Minimum 0.0 at Gauss point 1 of element 1



- Click **OK** to update the display and show the actual crack width value calculated at gauss points within the element.

This completes the example.

## Discussion

### Plotting Crack Widths to EN1992-1-1

In this example nonlinear steel properties were defined for the reinforcing bar elements. Reinforcement bar attributes (accessed from the **Attributes > Geometric > Bar reinforcement** menu item) may alternatively be used to model the steel reinforcement in reinforced concrete, but only if a linear steel material model is used in place of the nonlinear steel material to represent the steel reinforcement and the Crack Widths calculation utility (which is accessed from the **Bridge > Crack Widths to EN1992-1-1** menu item) is employed. Note that a linear steel material model (rather than a nonlinear one) is required for the steel reinforcement because of the steel strains used in the calculations.

Reinforcement bar attributes are similar to geometric line attributes but need to be assigned to lines meshed with bar elements for a chosen analysis to enable a crack width calculation to be carried out.

## Nonlinear Analysis of a Concrete Beam

Bar attributes may be defined for a single reinforcing bar (termed a Discrete bar), as would be used in a 3D model, or be defined with suitable properties to represent a bundle or simplified arrangement of bars (termed Equivalent bars) as would be used typically in a 2D plane strain analysis and done in this example. Appropriate settings for this example are shown on the dialog right.

Reinforcement Attribute

Bar area: 400

Parameters for nonlinear concrete crack checking

Reinforcement cover: 20

Bar diameter: 16

Reinforcement type: Equivalent bars

Breadth / Spacing: 130

Steel area factor: 1.0

Name: Two 16 dia bars (new)

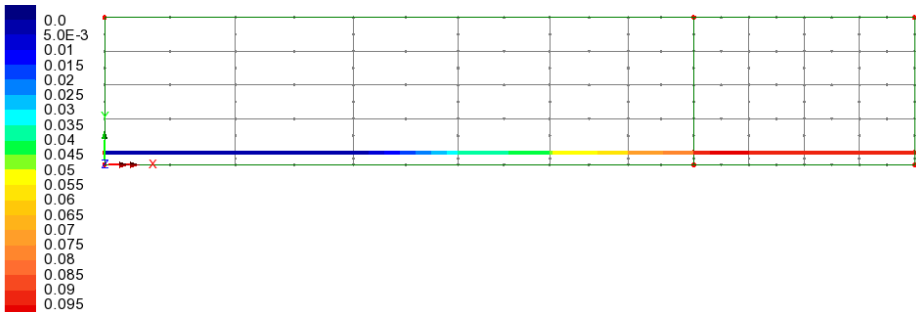
OK Cancel Apply Help

When linear steel material and reinforcement bar attributes have been defined to the lines representing the reinforcement, and the model solved, contours and values of crack widths can be plotted in accordance with EN1992-1-1:2004 Eurocode 2 by selecting the Entity **Crack Widths EN 1992-1-1** and the Component **Maximum Crack Width** on the Contour Properties dialog.

Crack width contours can be plotted along the bar elements (actually on the surface of the fleshed bar section) corresponding to the steel strains used in the calculation, and not on any concrete face or surface in the model. Contours and values are plotted for an active loadcase (or combination) and are re-computed if a different loadcase is set active. This visualisation method is used because the approach used in EN 1992-1-1:2004 to calculate crack widths is generally unclear as to where the crack width calculation applies.

A typical crack width contour plot for the bar reinforcement attribute described previously to represent the steel in this example is shown below.

Analysis: Analysis 1  
Loadcase: 7:Loadcase 1, Increment 7 Load Factor = 17000.0  
Results file: beam\_n1\_with\_16mm\_bar\_attributes\_linear\_steel-Analysis 1.mys  
Entity: Crack widths EN1992-1-1  
Component: Maximum Crack Width (Units: mm)



Maximum 0.0991234 at Gauss point 2 of element 17  
Minimum 0.0 at Gauss point 1 of element 11

Crack width calculation summary  
Attribute: Two 16 dia bars, max crack spacing = 191.76mm, max crack width = 0.104983mm

