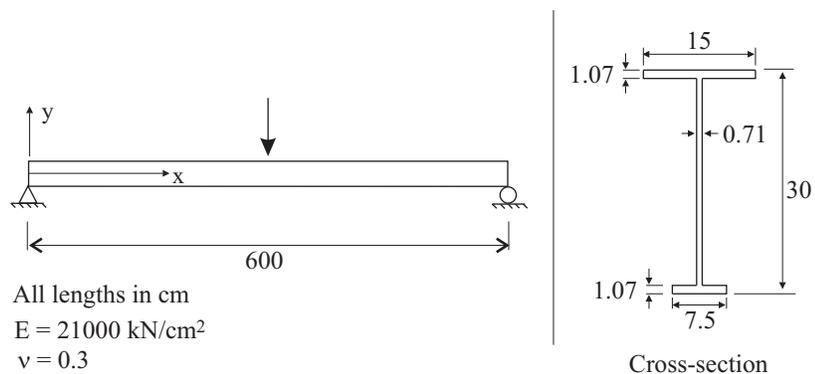


Problem description

Consider a slender beam subjected to a concentrated force at its center:



We want to compute the large displacement post-buckling response of the beam, considering both the force acting downwards and the force acting upwards.

Because we anticipate that the post-buckling response might have an out-of-plane component, we allow out-of-plane motions of the model. The x rotations of the end nodes are fixed, however.

Because the cross-section is a thin-walled open section, warping effects are important.

In this problem solution, we will demonstrate the following topics that have not been presented in previous problems:

- Using the warping beam elements (beam elements with warping degrees of freedom)
- Performing a linearized buckling analysis
- Using the initial imperfections obtained from a linearized buckling analysis
- Using the append porthole file feature to merge the results from two runs

Before you begin

Please refer to the Icon Locator Tables chapter of the Primer for the locations of all of the GUI icons. Please refer to the Hints chapter of the Primer for useful hints.

This problem can be solved with the 900 nodes version of the ADINA System.

Much of the input for this problem is stored in the following files: prob50_1.in, prob50_1.plo, prob50_2.plo. You need to copy these files from the folder samples\primer into a working directory or folder before beginning this analysis.

Invoking the AUI and choosing the finite element program

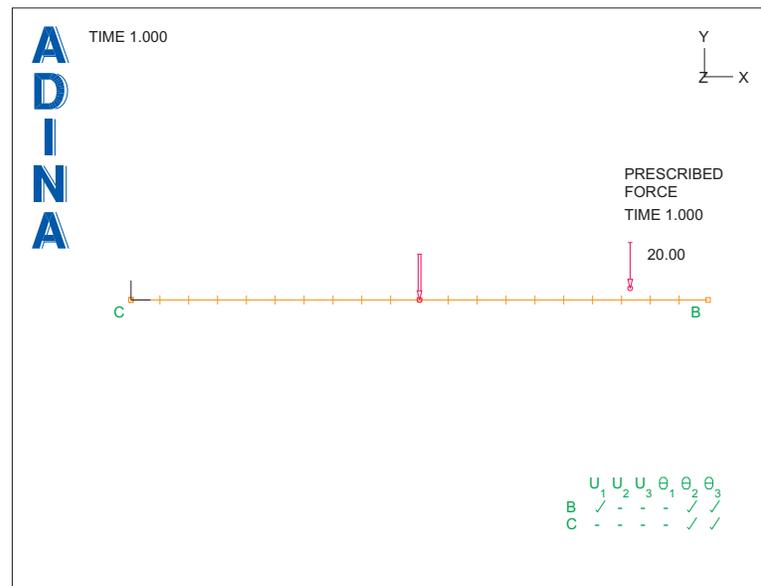
Invoke the AUI and set the Program Module drop-down list to ADINA Structures.

Linearized buckling analysis

Model definition

We have prepared a batch file (prob50_1.in) that defines the geometry of the model, as well as the boundary conditions, material and load. You can confirm that the load is 20 kN applied downwards, and that this load is applied in a single time step.

Choose File→Open Batch, navigate to the working directory or folder, select the file prob50_1.in and click Open. The graphics window should look something like this.



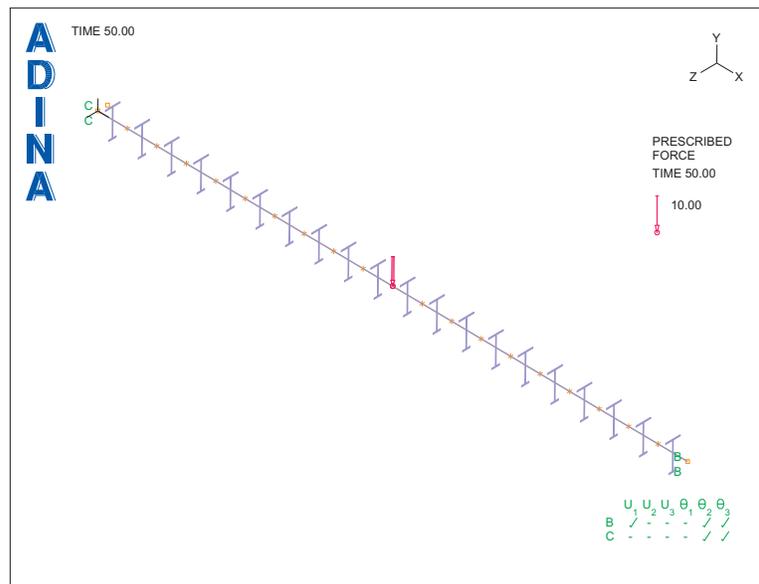
Cross-section: We have not defined the cross-section for the beam yet. Click the Cross-Section icon , add cross-section 1, and set the Type to I-Beam. Set Width W1 to 7.5, Height H to 30, Width W2 to 15, Thickness T1 to 1.07, Thickness T2 to 0.71, Thickness T3 to 1.07 and click OK.

Element definition: Click the Element Groups icon , add group 1, set the Type to Beam and click OK.

Elements: Click the Mesh Lines icon , set the Auxiliary Point to 4, enter 1 and 2 in the first two rows of the table and click OK.

Linearized buckling analysis: We want to obtain an estimate of the first buckling load and its associated buckling mode shape. Set the Analysis Type to Linearized Buckling and then click the Analysis Options icon . Set the Number of Buckling Loads/Modes to 2 and click OK.

We would like to see the cross-sections. Click the Modify Mesh Plot icon , click the Element Depiction... button, click the Display Beam Cross-Section field, then click OK twice to close both dialog boxes. Rotate the model until the graphics window looks something like this:



Specifying beam elements with warping degrees of freedom

Click the Save icon  and save the database to file prob50. Click the Data File/Solution icon , set the file name to prob50, make sure that the Run Solution button is checked and click Save.

The AUI displays the message "Could not open file ... prob50.dat". The Log Window displays the message

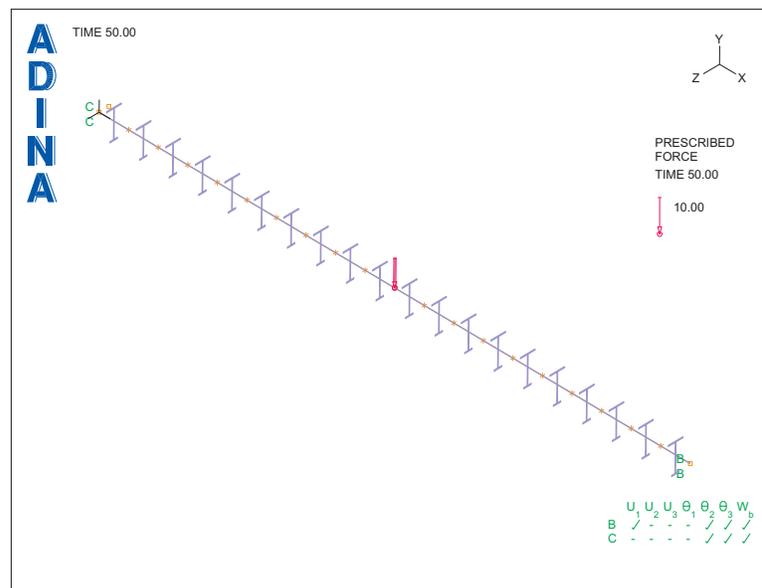
Problem 50: Post-buckling response of a slender beam

***ALERT: Element group 1 with standard beam assumptions is used with cross-section 1 of type I
It is recommended to use the warping beam element with this cross-section.
To use the standard beam element with this cross-section, set STANDARD=YES in the CROSS-SECTION command.
However, the results may be incorrect, see the Theory and Modeling Guide

This message is displayed because under general loading conditions, beam elements with thin-walled open cross-sections give incorrect results unless additional warping degrees of freedom are included in the beam element.

Therefore we need to use beam elements with additional warping degrees of freedom. (See notes at the end of this primer problem for more information.)

Close all open dialog boxes, click the Element Groups icon , check the "Include Warping DOF" button and click OK. When you click the Redraw icon , the graphics window should look something like this:



Notice that there is now a W_b column in the boundary conditions code table. This column indicates the presence of the beam warping degree of freedom. The warping degree of freedom is free at all nodes, including the end nodes. Thus the beam is free to warp everywhere along its length.

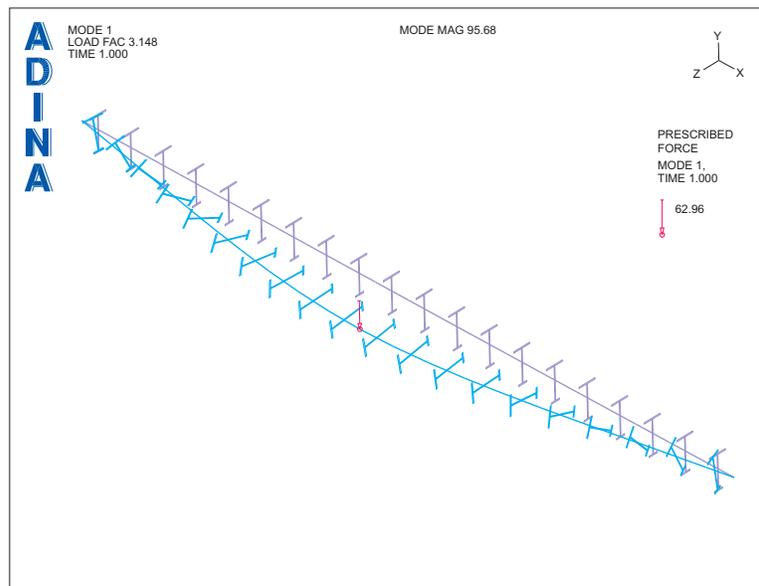
Generating the ADINA Structures data file, running ADINA Structures, loading the porthole file

Click the Save icon  and save the database to file prob50. Click the Data File/Solution icon , set the file name to prob50, make sure that the Run Solution button is checked and click Save.

When ADINA Structures is finished, close all open dialog boxes. Set the Program Module drop-down list to Post-Processing (you can discard all changes), click the Open icon  and open porthole file prob50.

Post-processing

Click the Show Original Mesh icon , then click the Modify Mesh Plot icon , click the Element Depiction... button, click the Display Beam Cross-Section field, then click OK twice to close both dialog boxes. Click the Load Plot icon , then rotate the model until the graphics window looks something like this:



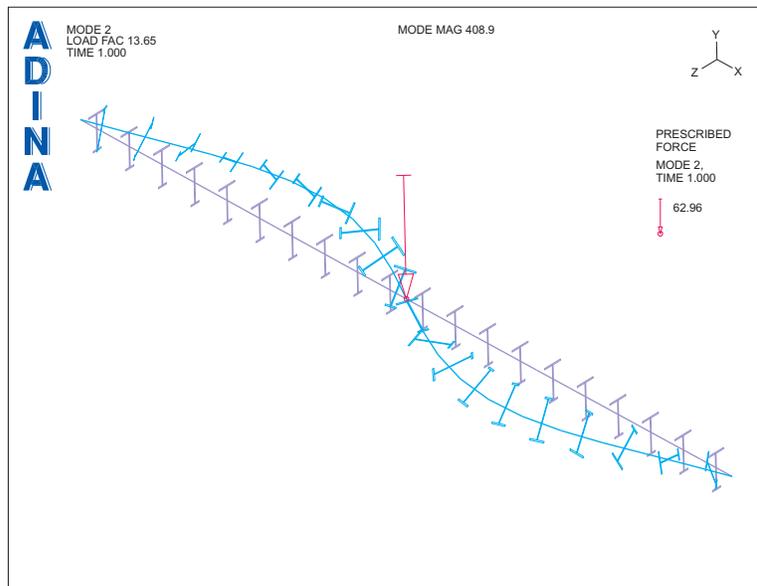
We would like to use these defaults for successive mesh plots, so click the Save Mesh Plot Style icon  and the Save View icon .

Problem 50: Post-buckling response of a slender beam

The plot shows the estimated buckling load and associated mode shape for buckling load 1. The "LOAD FAC" is the buckling load multiplier computed by the linearized buckling load algorithm. Notice that the estimated buckling load of 62.96 is equal to the "LOAD FAC" multiplied by the load applied in step 1.

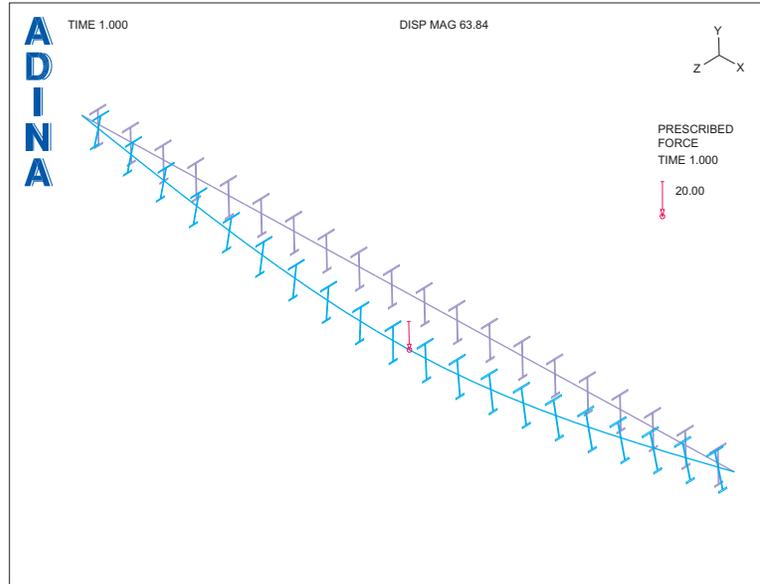
You can use the mouse to confirm that the neutral axis of the buckling mode shape lies in the x-z plane.

Now click the Next Solution icon . The second estimated buckling load and mode shape should look something like this:



Again, the neutral axis of the buckling mode shape lies in the x-z plane.

To view the model in the deformed configuration used for the linearized buckling analysis, click the Clear icon , choose Definitions→Response, make sure that the Response Name is DEFAULT, set the Type to Load Step and click OK. When you click the Scale Displacements icon  and the Load Plot icon , the graphics window should look something like the figure on the next page.



Post-buckling response, load applied downwards

Now we will perform a collapse analysis, in which the model is perturbed by the first buckling mode shape.

Set the Program Module drop-down list to ADINA Structures (you can discard all changes) and choose database file prob50.ldb from the recent file list near the bottom of the File menu.

Collapse analysis: We will perform a collapse analysis using the load-displacement control (LDC) algorithm to automatically choose the load step sizes. Set the Analysis Type to

Collapse Analysis. Click the Analysis Options icon , set the Label # field to 3, the Degree of Freedom to Y-Translation, the Displacement field to -0.01, the Maximum Allowed Displacement to 20, check the “Continue after First Critical Point is Reached” button and click OK.

Choose Control→Time Step, set the Number of Steps to 50 in the first row of the table and click OK. Choose Control→Time Function, edit time function 1 to be

| Time | Value |
|------|-------|
| 0 | 0 |
| 50 | 10 |

and click OK.

Problem 50: Post-buckling response of a slender beam

Initial imperfection: Choose Model→Initial Conditions→Imperfection, make sure that the Initial Condition Type is Point, and, in the first row of the table, set the Buckling Mode # to 1, the Point # to 3, the Direction to Z-Translation and the Displacement to 0.05. Click OK to close the dialog box.

Generating the ADINA Structures data file, running ADINA Structures, loading the porthole file

Click the Save icon  to save the database to file prob50. Click the Data File/Solution icon , set the file name to prob50_down, make sure that the Run Solution button is checked and click Save. The AUI opens a window in which you specify the mode shape file from the linearized buckling analysis. Enter mode shape file prob50 and click Copy.

When ADINA Structures is finished, close all open dialog boxes. Set the Program Module drop-down list to Post-Processing (you can discard all changes), click the Open icon  and open porthole file prob50_down.

Post-processing

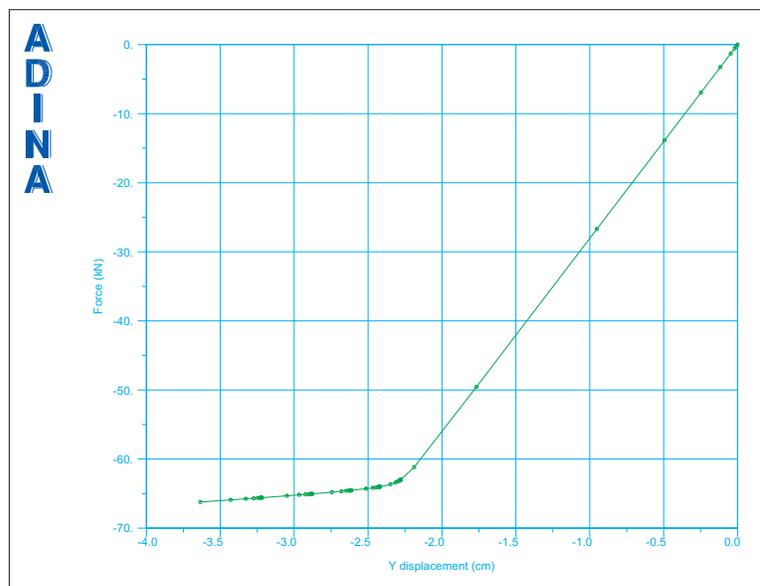
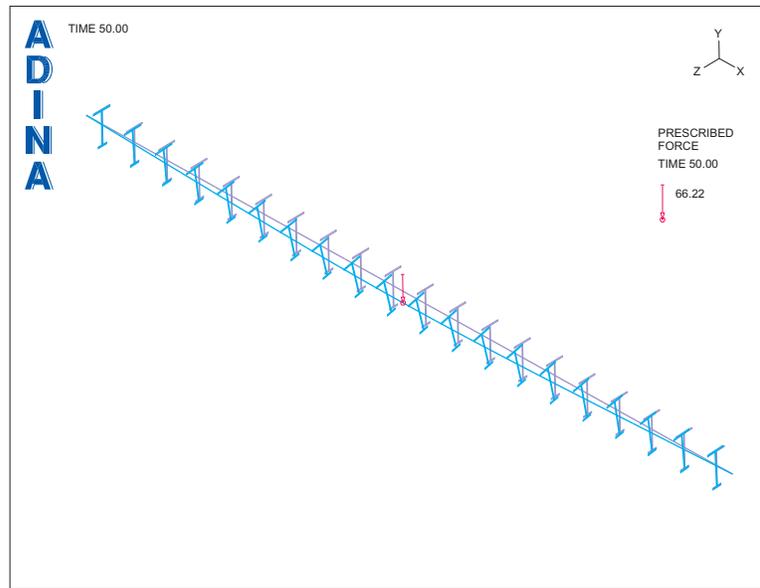
Click the Show Original Mesh icon , then click the Modify Mesh Plot icon , click the Element Depiction... button, click the Display Beam Cross-Section field, then click OK twice to close both dialog boxes. Click the Load Plot icon , then rotate the model until the graphics window looks something like the top figure on the next page.

The buckling mode appears to have been triggered by the load.

We want to plot the force-deflection curve. We have put the necessary commands in a batch file (prob50_1.p1o). Choose File→Open Batch, navigate to the working directory or folder, select the file prob50_1.p1o and click Open. The graphics window should look something like the bottom figure on the next page.

The model appears to buckle at a load of around -62 kN, which is in good agreement with the linearized buckling load estimate obtained above.

Problem 50: Post-buckling response of a slender beam



Post-buckling response, load applied upwards

Let's determine the post-buckling response, with the load applied upwards.

Set the Program Module drop-down list to ADINA Structures (you can discard all changes) and choose database file `prob50.idb` from the recent file list near the bottom of the File menu.

Click the Analysis Options icon , set the Displacement field to 0.01 and click OK.

Generating the ADINA Structures data file, running ADINA Structures, loading the porthole file

Click the Save icon  to save the database to file `prob50`. Click the Data File/Solution icon , set the file name to `prob50_up`, make sure that the Run Solution button is checked and click Save. The AUI opens a window in which you specify the mode shape file from the linearized buckling analysis. Enter mode shape file `prob50` and click Copy.

When ADINA Structures is finished, close all open dialog boxes. Set the Program Module drop-down list to Post-Processing (you can discard all changes), click the Open icon  and open porthole file `prob50_up`.

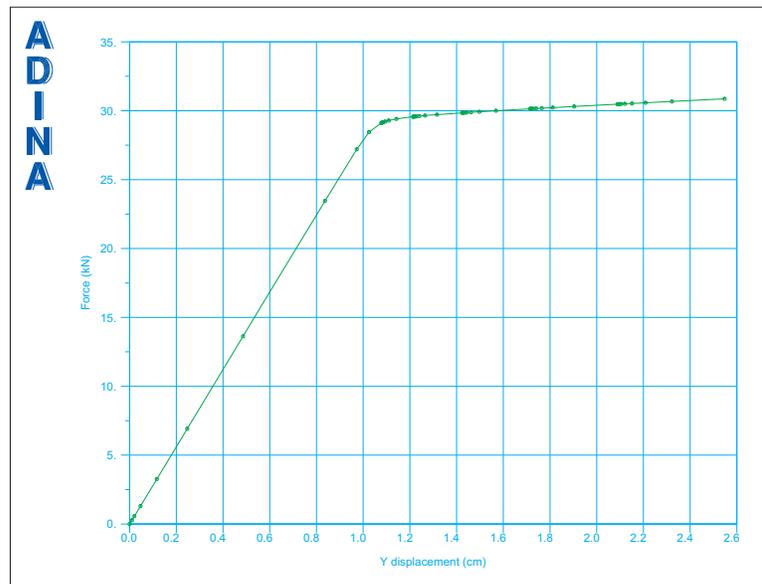
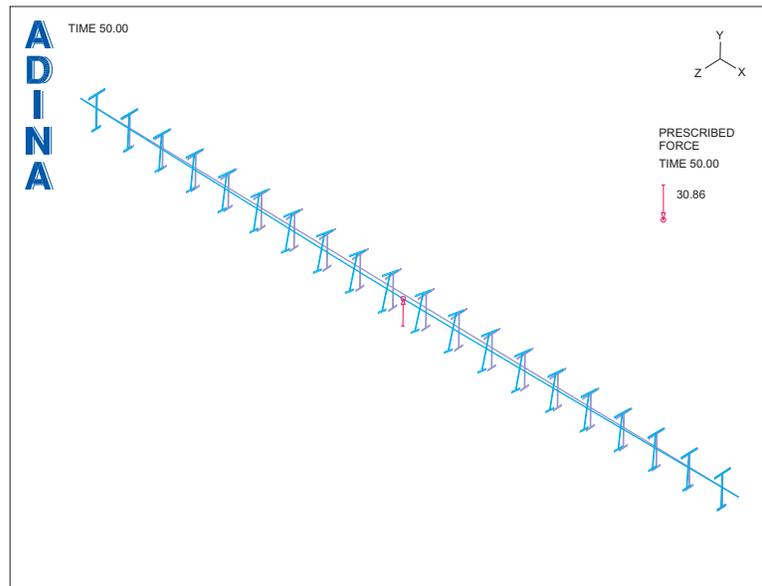
Post-processing

Click the Show Original Mesh icon , then click the Modify Mesh Plot icon , click the Element Depiction... button, click the Display Beam Cross-Section field, then click OK twice to close both dialog boxes. Click the Load Plot icon , then rotate the model until the graphics window looks something like the top figure on the next page.

Again the buckling mode appears to have been triggered.

We want to plot the force-deflection curve. We can use the same batch file that we used before. Choose File→Open Batch, navigate to the working directory or folder, select the file `prob50_1.p1o` and click Open. The graphics window should look something like the bottom figure on the next page.

Problem 50: Post-buckling response of a slender beam



This time the model appears to buckle at a load of about 29 kN, which is much lower than the linearized buckling load estimate obtained above.

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We would like to plot both force-deflection curves together. To do this, we will load both porthole files together, using the append feature.

Click the New icon  (you can discard all changes), then click the Open icon  and open porthole file prob50_down. Then choose File→Open Porthole, select file prob50_up, set the Operation to “Load/Merge (append option) into database” and click Open.

The Message Window shows some useful information. Notice the text

```
Loaded 50 time step solutions between times 1.00000E+00 and 5.00000E+01...
Porthole file ../prob50_down.por is completely loaded
....
Append mode: Reading of ADINA porthole file starts.
Append mode: largest time in database = 5.00000E+01
              largest load step in database = 50
Shift for time      = 5.10000E+01
Shift for load step =      51
...
Loaded 50 time step solutions between times 5.20000E+01 and 1.01000E+02...
Porthole file ../prob50_up.por is completely loaded
```

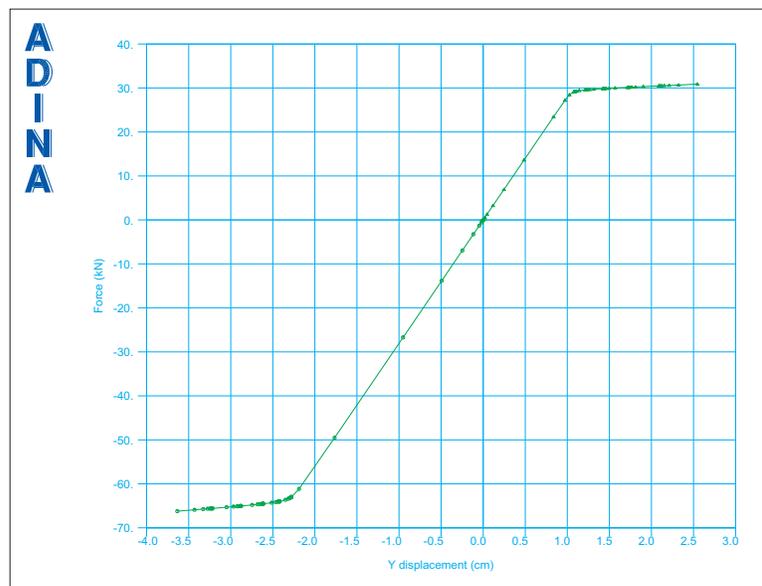
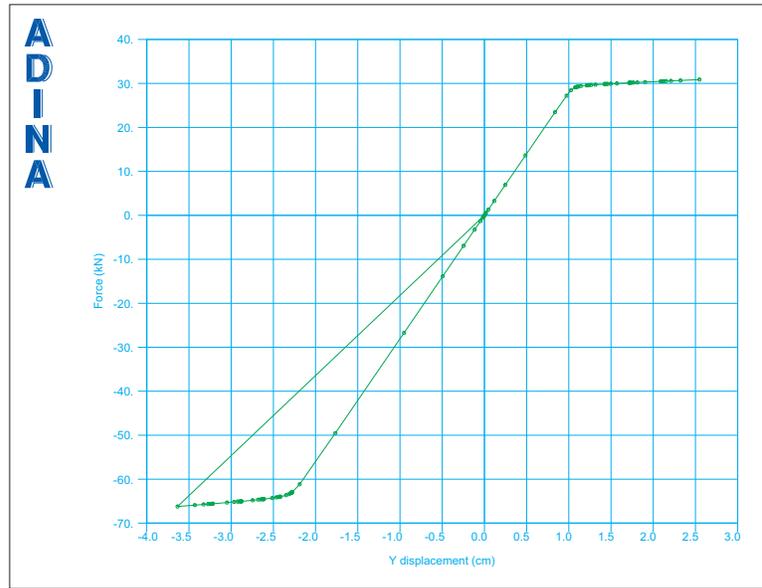
This text indicates that times 0 to 50 are associated with porthole file prob50_down, and time steps 51 to 101 are associated with porthole file prob50_up. The solutions for prob50_up are shifted in time by 51.0. For example, the plotted solution of time step 101 is actually time step 50 of the prob50_up analysis.

To plot the force-deflection curve, we can use the same batch file that we used before. Choose File→Open Batch, navigate to the working directory or folder, select the file prob50_1.pl0 and click Open. The graphics window should look something like the top figure on the next page.

Here there is an unsightly line connecting the most negative point with the origin. This line arises when connecting the results at time 50 (end of prob50_down) with the results at time 51 (start of prob50_up).

In order to avoid the unsightly line, we need to make two force-deflection curves in the same plot. We have put the commands in file prob50_2.pl0. Choose File→Open Batch, navigate to the working directory or folder, select the file prob50_2.pl0 and click Open. The graphics window should look something like the bottom figure on the next page.

Problem 50: Post-buckling response of a slender beam



Exiting the AUI: Choose File→Exit to exit the AUI. You can discard all changes.

Problem 50: Post-buckling response of a slender beam

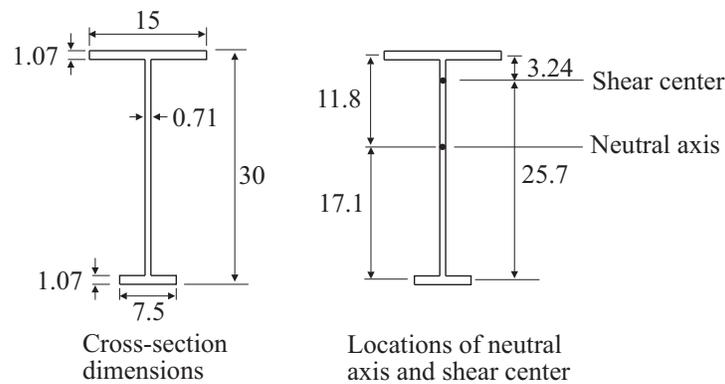
Additional notes

Wagner effect

The buckling load for load acting upwards is different than the buckling load for load acting downwards, due to the Wagner effect.

In the Wagner effect, any cross-sectional twisting causes the longitudinal stresses (from the axial and bending loads) to create a twisting moment, proportional to the amount of the twist. The contribution to the twisting moment from tensile longitudinal stresses is positive, the contribution to the twisting moment from compressive longitudinal stresses is negative. When the twisting moment is positive for positive twist, the buckling load is increased, when the twisting moment is negative for positive twist, the buckling load is decreased.

For this problem, the cross-section is redrawn here, to show the locations of the neutral axis and shear center (also known as the center of twist).



Because the top flange is so close to the shear center, the stresses in the top flange do not contribute as much to the Wagner effect twisting moment as do the stresses in the bottom flange.

When the load is applied upwards, the stresses in the top flange are tensile and the stresses in the bottom flange are compressive. Thus the twisting moment is negative for positive twist, and the Wagner effect tends to decrease the buckling load when the load is applied upwards.

Warping beam versus standard beam

It is important to distinguish between warping effects (which are present in all beams undergoing twisting, with the exception of beams of circular cross-section), and warping beam elements. The standard beam element includes warping effects, as does the warping beam element. The difference between the standard beam element and the warping beam element is that the warping beam element includes additional warping degrees of freedom.

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In the standard beam element, the twist per unit length is assumed constant in each element, therefore the warping effect is also constant in each element. Therefore, between adjacent elements, the amount of warping is different in general, in other words, the warping displacements are incompatible between adjacent elements.

In the warping beam element, the twist per unit length is not constant in each element, and the twist per unit length is compatible between adjacent elements. Therefore the warping displacements are also compatible between adjacent elements.

If the standard beam element is used to solve this problem, the buckling load for load applied upwards is underestimated, due to the incompatibility of warping displacements.

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