Chapter Overview

In this Appendix, performing an eigenvalue buckling analysis in Mechanical will be covered.

Mechanical enables you to link the Eigenvalue Buckling analysis to a *nonlinear* Static Structural analysis that can include all types of nonlinearities. This will not be covered in this section. We will focused on Linear buckling.

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A. Background on Buckling

Many structures require an evaluation of their structural stability. Thin columns, compression members, and vacuum tanks are all examples of structures where stability considerations are important.

At the onset of instability (buckling) a structure will have a very large change in displacement \( \Delta x \) under essentially no change in the load (beyond a small load perturbation).
... Background on Buckling

Eigenvalue or linear buckling analysis predicts the theoretical buckling strength of an ideal linear elastic structure.

This method corresponds to the textbook approach of linear elastic buckling analysis.

• The eigenvalue buckling solution of a Euler column will match the classical Euler solution.

Imperfections and nonlinear behaviors prevent most real world structures from achieving their theoretical elastic buckling strength.

Linear buckling generally yields unconservative results by not accounting for these effects.

Although unconservative, linear buckling has the advantage of being computationally cheap compared to nonlinear buckling solutions.
For a linear buckling analysis, the eigenvalue problem below is solved to get the buckling load multiplier $\lambda_i$ and buckling modes $\psi_i$:

$$([K] + \lambda_i [S])\{\psi_i\} = 0$$

Assumptions:

- $[K]$ and $[S]$ are constant:
  - Linear elastic material behavior is assumed
  - Small deflection theory is used, and no nonlinearities included

It is important to remember these assumptions related to performing linear buckling analyses in Mechanical.
B. Buckling Analysis Procedure

A Static Structural analysis will need to be performed prior to (or in conjunction with) a buckling analysis.
Any type of geometry supported by Mechanical may be used in buckling analyses:

- Solid bodies
- Surface bodies (with appropriate thickness defined)
- Line bodies (with appropriate cross-sections defined)
  - Only buckling modes and displacement results are available for line bodies.
- Although Point Masses may be included in the model, only inertial loads affect point masses, so the applicability of this feature may be limited in buckling analyses

For material properties, *Young’s Modulus* and *Poisson’s Ratio* are required as a minimum
Contact regions are available in free vibration analyses, however, contact behavior will differ for the *nonlinear* contact types exactly as with modal analyses.

(see chapter 8 of the Mechanical Introduction course for further details).

<table>
<thead>
<tr>
<th>Contact Type</th>
<th>Linear Buckling Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initially Touching</td>
</tr>
<tr>
<td>Bonded</td>
<td>Bonded</td>
</tr>
<tr>
<td>No Separation</td>
<td>No Separation</td>
</tr>
<tr>
<td>Rough</td>
<td>Bonded</td>
</tr>
<tr>
<td>Frictionless</td>
<td>No Separation</td>
</tr>
</tbody>
</table>
At least one structural load, which causes buckling, should be applied to the model:

- *All* structural loads will be multiplied by the load multiplier ($\lambda$) to determine the buckling load (see below).
- Compression-only supports are not recommended.
- The structure should be fully constrained to prevent rigid-body motion.

\[ F \times \lambda = \text{Buckling Load} \]

In a buckling analysis all applied loads ($F$) are scaled by a multiplication factor ($\lambda$) until the critical (buckling) load is reached.
Special considerations must be given if constant and proportional loads are present.

- The user may iterate on the buckling solution, adjusting the variable loads until the load multiplier becomes 1.0 or nearly 1.0.
- Consider the example of a column with self weight \( W_o \) and an externally applied force \( A \).
- A solution can be reached by iterating while adjusting the value of \( A \) until \( \lambda = 1.0 \). This insures the self weight = actual weight or \( W_o \times \lambda = W_o \).
... Buckling Setup

Buckling analyses are always coupled to a structural analysis within the project schematic.

- The “Pre-Stress” object in the tree contains the results from a structural analysis.
- The Details view of the “Analysis Settings” under the Linear Buckling branch allows the user to specify the number of buckling modes to find.

In the details view, under solver controls, user can include negative load multiplier.
... Solving the Model

After setting up the model the buckling analysis can be solved along with the static structural analysis.

- A linear buckling analysis is **more computationally expensive** than a static analysis on the same model.
- The “Solution Information” branch provides detailed solution output.
After the solution is complete, the buckling modes can be reviewed:

- The Load Multiplier for each buckling mode is shown in the Details view as well as the graph and chart areas. The load multiplier times the applied loads represent the predicted buckling load.

\[ F_{\text{buckle}} = (F_{\text{applied}} \times \lambda) \]
... Reviewing Results

Interpreting the Load Multiplier ($\lambda$):

- The tower model below has been solved twice. In the first case a unit load is applied. In the second an expected load applied (see next page)
... Reviewing Results

Interpreting the Load Multiplier (\(\lambda\)):

\[
\text{BucklingLoad} = \lambda \times \text{Unit \_Load}
\]

\[
\implies \text{BucklingLoad} = \lambda
\]

Details of "1st Buckling Mode"

- **Scope**
  - Geometry: All Bodies

- **Results**
  - Load Multiplier: 29008

\[
\text{BucklingLoad} = \lambda \times \text{Actual \_Load}
\]

\[
\implies \frac{\text{BucklingLoad}}{\text{Actual \_Load}} = \lambda = \text{Safety \_Factor}
\]

Details of "1st Buckling Mode"

- **Scope**
  - Geometry: All Bodies

- **Results**
  - Load Multiplier: 1.0003
... Reviewing Results

The buckling load multipliers can be reviewed in the “Timeline” section of the results under the “Linear Buckling” analysis branch

- It is good practice to request more than one buckling mode to see if the structure may be able to buckle in more than one way under a given applied load.
Workshop Appendix A

- Workshop Appendix A - Buckling