Nonlinear buckling

Nonlinear buckling may be evaluated in SAP2000 using Nonlinear static analysis. This procedure takes an iterative approach while implementing P-Delta and Large-Displacement effect. Structural response is shown by plotting selected joint displacements against load application. A softening behavior may be observed in this plot, indicating the onset of buckling, and the condition of instability which follows.

Modeling tips

- **Symmetric structures.** When analyzing symmetrical structures, a geometric or loading imperfection should be introduced to initiate buckling.
- **Subdivision.** Structural objects should be subdivided into lengths small enough to capture geometric nonlinearity. Four to eight frame or shell objects are typically necessary per span.
- **Convergence.** In the load-case definition, multiple output steps should be requested to improve convergence, and to better indicate buckling response. Convergence tolerance may need to be tightened, possibly to the order of 1e-6.
- **Displacement control.** If a structure loses load-carrying capacity, displacement control should be implemented, rather than load control. This refers to the load-case control definition, and not how the load is actually applied.
- **Extreme conditions.** When instability is severe, nonlinear static analysis should be converted to direct-integration time-history analysis.

Difference between Linear and Nonlinear buckling

- **Linear (Eigenvalue) analysis.** During Linear buckling analysis, perturbations are applied to the undeformed structural configuration. A specified set of loads are observed for which deflections could induce instability under P-Delta effect. Linear buckling analysis produces a set of buckling factors and corresponding mode shapes. When loading is multiplied by these buckling factors, the resultant scaled loading conditions represent those which induce buckling. Similarly, the mode shapes are normalized displacement sets which indicate the configuration of the buckled structure.

- **Nonlinear analysis.** During Nonlinear-static buckling analysis, the total load is applied incrementally. Stiffness and response are evaluated at each increment. Between each displacement step, stiffness may change due to the following effects:
  - **P-Delta effect.** which involves large tensile or compressive stresses on transverse bending and shear behavior.
  - **Large-Displacement effect.** in which deformed configuration is considered when assembling the equilibrium equations.
  - **Nonlinear material behavior.** in which performance incorporates inelastic response. SAP2000 implements material nonlinearity using frame hinges and nonlinear layered-shell objects.

- **Comparison.** Because Nonlinear-static buckling analysis considers material nonlinearity while generating buckling response, results are often more realistic than those of Linear buckling analysis. The results of Nonlinear-static analysis are indicated by a plot of deformed configuration against load application. This plot displays the softening behavior which indicates the onset of buckling.

The *CSI Analysis Reference Manual* is an excellent resource for information on buckling. We recommended the following chapters:

- Analysis Cases > Linear Buckling Analysis, page 315
- Geometric Nonlinearity > Overview, page 365
- Geometric Nonlinearity > P-Delta Effect, page 369

See Also

- *Eigenvalue vs. Nonlinear buckling analysis* article