Nonlinear

Nonlinear structural behavior may be associated with either geometric or material response, each described as follows:

- **Geometric nonlinearity** concerns the P-Delta effects associated with application of external loading upon the displaced configuration of a structure.
- **Material nonlinearity** concerns inelastic structural response in which the behavior of a component, system, or connection deviates from the initial stiffness tangent characteristic of linear-elastic behavior.

Linear vs. nonlinear analysis

Nonlinear analysis methods are best applied when either geometric or material nonlinearity is considered during structural modeling and analysis. If only elastic material behavior is considered, linear analysis methods should suffice, though P-Delta formulation may still be applied. Linear and nonlinear methods may be static or dynamic. A few of the traditional analysis methods, and the relations between their attributes, are presented in Figure 1:

Analysis Type	Linear	Nonlinear
Static	Strength-based	Static-pushover
Dynamic	Response-spectrum	Time-history

Figure 1 - Analysis methods

Each of these analysis methods has benefits and limitations. An overview of each method is as follows:

- **Strength-based** analysis is a static-linear procedure in which structural components are specified such that their elastic capacities exceed the demands of loading conditions. Strength-based demand-capacity (D-C) ratios indicate the adequacy of each component. Since only the elastic stiffness properties are applied to the analytical model, strength-based analysis is the most simplified and least time-consuming analysis method.
- **Static-pushover** analysis is a static-nonlinear procedure in which a structural system is subjected to a monotonic load which increases iteratively, through an ultimate condition, to indicate a range of elastic and inelastic performance. As a function of both strength and deformation, the resultant nonlinear force-deformation (F-D) relationship provides insight into ductility and limit-state behavior. Deformation parameters may be translational or rotational. Pushover is most suitable for systems in which the fundamental mode dominates behavior. When higher-order modes contribute, as with taller buildings, dynamic analysis is most effective.
- **Response-spectrum** analysis is a dynamic-linear method in which maximum structural response is plotted as a function of structural period for a given time-history record and level of damping. For a set of structural mode shapes and corresponding natural frequencies, the linear superposition of SDOF systems represents response. Response measures may be in terms of peak Acceleration, velocity, or displacement relative to the ground or the structure. Structures must remain essentially elastic since response-spectrum analysis is dependent upon the superposition of gravity and lateral effects. Results may be enveloped to form a smooth design spectrum.
- **Time-history** analysis is a dynamic-nonlinear technique which may involve either the FNA or the direct-integration method. FNA is a modal application, whereas with direct integration, the equations of motion are integrated at a series of time steps to characterize dynamic response and inelastic behavior. Loading is time-dependent, and therefore suitable for the application of a ground-motion record. Time-history analysis may account for both material nonlinearity and P-Delta effects.

Analysis objective

Engineers may use any of these analysis methods to:

- Characterize and gain insight into structural behavior.
- Generate information useful to the design decision-making process.

Capacity Design

Nonlinear modeling and analysis is fundamental to Capacity Design.

Articles

Tutorials

Title	Description	Program
Pushover analysis first steps	Guidelines for performing pushover analysis.	SAP2000

Test Problems

Title	Description	Program
P-Delta effect for a cantilevered column	Calculation and verification of the P-Delta effects of a cantilevered column.	SAP2000