

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:

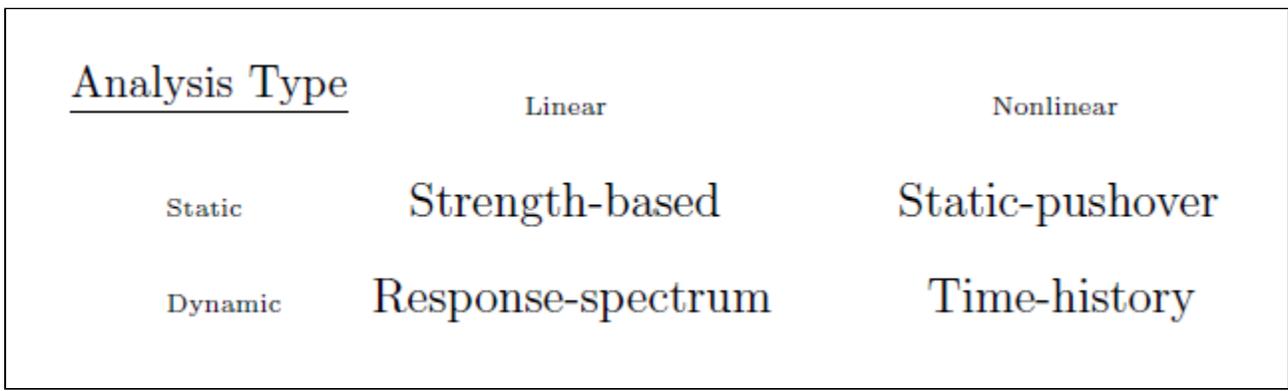


Figure 1 - Analysis methods

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