

Progressive collapse analysis

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How is a progressive-collapse analysis performed in which a column is removed to evaluate dynamic response?

Answer: Progressive collapse may be modeled using [SAP2000](#) or [ETABS](#) in the sense that certain members may be removed to study the effect on the structure. Progressive collapse and dynamic effects may be evaluated using [time-history](#) analysis as follows:

1. Create a model (Model A) which contains the entire structure, including the column to be removed. Analyze this model to obtain the internal forces of the column which will be removed.
2. Create another model (Model B) in which the column is removed. Apply the column end forces, obtained during the analysis of Model A, to simulate the presence of the removed column.
3. Simulate the removal of the column by running a time-history analysis in which these equivalent column loads are reduced to zero over a short period of time. This is done by applying a ramp [time function](#) in which loads opposite to those of the equivalent column loads are scaled from zero to the full value. The duration of this event should match the time in which the column is removed.

Dead load may be applied through either of the following two approaches:

- Apply the dead load together with the equivalent column load in a nonlinear-static [load case](#). Then the time-history load case, in which the column is removed using a time function, should start at the end of this nonlinear-static load case.
- Use a single time-history load case to apply the dead load and the equivalent column load using one time function which gradually ramps these loads to their full values. The column removal load may then be applied through a separate time function which has a later arrival time.

This process enables observation of the dynamic effects which are associated with the removal of a structural member. Note that this is an idealized computational process which will not capture such effect as the impact of material collapsing onto the remaining structure.

The following are a number of points to consider.

First, some points on analysis.

1. In a response history analysis, the displacement-velocity-acceleration relationships are defined by the step-by-step integration method. The most common is the "constant average acceleration" method (also known as the "trapezoidal rule" or "Newmark beta=1/4 method"). The relationships are not simply $d(\text{displ})/dt = \text{veloc}$ and $d(\text{veloc})/dt = \text{accn}$. If you look at the velocities in the text file that you sent, you will see that the average values are OK, but they oscillate. This is probably because the text files are for a time step of 0.02 seconds, which is too long. I would expect the velocities to vary more smoothly for the shorter time step that you considered (0.001 sec).
2. The calculated accelerations can be very sensitive, and may oscillate wildly.
3. The amount of damping that you assumed may be much too large. You may have used the same Rayleigh damping properties that you would use for a dynamic earthquake analysis. If so, those properties will be based on the long period vibration modes for lateral motion. The periods for vertical vibration, when a column is suddenly removed, are much shorter, so those modes may be very heavily damped. If you use Rayleigh damping, the properties should be based on the dominant vertical periods of vibration with a removed column.
4. Incidentally, 5% damping is probably too large, for earthquake analysis as well as progressive collapse. For a tall building, a more reasonable value for earthquake analysis is 2%. For progressive collapse I suggest no more than 1% (based on vertical vibration periods), or even zero.

Second, some suggestions for running analyses.

1. Before doing any analysis, be clear on the purpose. For many structures, the purpose of the analysis is to show that if one column is suddenly removed, there is at most a small amount of damage. This is relatively easy, and may require only linear static analysis. For some structures actual collapse may be a concern. In this case the analysis is much more complex. Also, the calculated response is likely to be so sensitive to the modeling assumptions that the analysis may be little more than an academic exercise. The attached paper by Graham Powell can provide some guidance.
2. Before running a dynamic analysis, start with a static analysis (remove the column, analyze for static gravity loads plus static loads equal to the column forces (upwards load), then add static downwards load equal to two times the column forces). Use this to get an upper bound estimate of the vertical deflection (the factor of two is the dynamic amplification factor for an undamped elastic structure when the column is suddenly removed), and also to see if there is any substantial inelastic behavior.
3. If a dynamic analysis is needed, it is probably a good idea to start with an elastic analysis. For zero damping the results should be close to those for a static analysis with an impact factor of 2.0. Be sure to use a time step that is short enough to capture the vertical vibrations, which are likely to have short periods. The analysis results may be sensitive to the assumed distribution of vertical masses, and to the assumed damping. Since there is only one substantial displacement cycle when a column is suddenly removed, it can be argued that there is less effective damping than for earthquake response, with many cycles. For damping, be very careful with the beta-K part of Rayleigh damping. It may be wise to specify only alpha-M damping, or to assume zero damping.

4. If an elastic analysis indicates that there may be significant inelastic behavior, run an inelastic static analysis. If the amount of inelastic behavior is small, this should run OK. Among other things, look at the energy balance (of the type considered in the attached paper).
5. If an inelastic dynamic analysis is still needed, then run one, but be aware that the calculated response is likely to be very sensitive to modeling assumptions such as strengths, strain hardening ratios, damping, mass distribution, and whether the catenary effect is considered.

References

- Powell, Graham. [Collapse Analysis Made Easy \(More Or Less\)](#)
- Smilowitz, R. [Analytical Tools for Progressive-Collapse Analysis](#). Weidlinger Associates.
- Agnew, E., Marjanishvili, S. (2006). [Dynamic Analysis Procedure for Progressive Collapse](#). *Structure Magazine*, 24-27.