Damping of stiff elements with inelastic softening

During nonlinear direct-integration time-history analysis, special consideration may be necessary for modeling the stiffness-proportional **damping of stiff elements** which experience **inelastic softening**. As explained in the CSI *Analysis Reference Manual* (Viscous Proportional Damping, page 79), the damping matrix for element j is computed as:

$$C_j = c_M M_j + c_K K_j$$

Here, c_M and c_K are the mass and stiffness-proportional damping coefficients, M_j is the mass matrix, and K_j is the initial stiffness matrix. Dynamic equilibrium is then computed as the sum of stiffness forces, damping forces, inertial forces, and applied loading.

During analysis, nonlinear objects may yield and then undergo significant softening. If softening causes significant deformational velocity, significant damping forces may also result in objects which are initially stiff. While in equilibrium with other forces which occur at a joint connected to the stiff object, these damping forces may cause a jump in stiffness forces between the softening object and its interconnecting objects. Such a condition may occur in a concrete column modeled using multiple elements which contain hinges. When the initially stiff column is subjected to cyclic bending, cracking and the ratcheting of yielding tensile rebar will soften response. Axial velocity and excessive $c_K K_j$ damping contribution may then generate large differences in the axial force between adjacent elements within the subdivided column. While this jump in axial force does satisfy dynamic equilibrium, such behavior may not be desirable, and additional measures may need to be taken to achieve proper response.

Adjust stiffness-proportional damping

Problems associated with inelastic softening may be solved by transferring stiffness from the load case, general to the entire structure, to the material of individual objects which are affected by softening. This is done as follows:

1. In the time-history load case, leave the c_M value, but change c_K to zero.
2. For all materials, set c_K to the value originally used in the load case. This is done using interactive database editing under VisStiff > Material Properties 06 - Material Damping. Properties may also be managed through Define > Materials > Advanced Properties.
3. Copy the material of softening objects, scale c_K by a value between 10^{-2} and 10^{-3}, then apply this material locally to the affected objects.

Since material damping sums with that specified in load cases, this procedure reduces stiffness-proportional damping only in affected objects, without affecting the rest of the model. Nonlinear material behavior will then account for energy dissipation.

Convergence

If reduced damping creates convergence problems, users should apply Hilber-Hughes-Taylor (HHT) integration to the load case using a small negative HHT-alpha value. The prescriptive range is 0 to $-^1/_3$, while a value of $-^1/_{24}$ or $-^1/_{12}$ should improve the rate of convergence without significantly affecting the accuracy of results. Additional details and descriptions may be found in the CSI *Analysis Reference Manual* (Nonlinear Direct-Integration Time-History Analysis > Damping, page 415).

See Also

- **Direct integration** – Direct-integration time-history analysis