Elastic softening due to fiber hinges in older versions of SAP2000, CSiBridge, and ETABS

The information on this page applies only to SAP2000 and CSiBridge versions 18.0.1 and prior, and to ETABS versions 15.2.1 and prior.

The following enhancement has been implemented for SAP2000 and CSiBridge v18.1.0, and for ETABS v16.0.0:

The behavior of fiber PMM hinges has been enhanced to remove double-counting of the elastic flexibility in frame members. The elastic flexibility of the frame section now will be set to zero for a tributary length of the member equal to the hinge length of the fiber hinge, so that all elastic flexibility over that length is represented only by the fibers in the hinge. For bending behavior this works best when the hinge is located at the center of its tributary hinge length (axial behavior is not affected significantly by location). The tributary hinge lengths will be shifted as necessary so that they do not overlap the ends of the member or end offsets, and so that they do not overlap each other in the case of multiple hinges. In some cases this may mean that the hinge is not centered in the tributary hinge length, particularly for hinges at the ends of the member. In this latter case better results will be obtained if the hinges are located a half hinge length from the end. For hinge lengths that exceed the length of the element, adjacent elements will not be adjusted and some double counting of elastic flexibility will remain in the model due to the adjacent elements. For this reason it is not recommended to use object or element discretizations that are smaller than the hinge lengths. When frame hinge overwrites are assigned to automatically subdivide at hinge locations, this discretization will now be limited at fiber hinges to be no smaller than the hinge length, provided that no other specified discretization is applied near the hinge. Overall this enhancement will tend to affect the results for all models that use fiber hinges when compared with previous versions of the software, although the effect will be limited in most models where the hinges do not dominate the model. Affected models will tend to be stiffer. Only fiber PMM hinges are affected by this enhancement. For ETABS, hinges modeled using link elements are not affected as there was (and still is) no double-counting of elastic flexibility in this case.

Is it possible to implement fiber hinges without introducing softening?

Extended Question: Fiber hinges seem to introduce artificial flexibility to the model, though hinges are a plastic mechanism which should not influence elastic behavior. Is it possible to implement fiber hinges without introducing softening?

Answer: This softening behavior may be attributed to calculation of the fiber-hinge response curve, which proceeds directly from the axial response of individual section fibers. During linear response, fiber elasticity is added to element elasticity, causing softening. To avoid elastic softening, users should divide frame members at hinge locations such that a smaller segment is positioned along the hinge length. A large area property modifier should then be assigned to small sections, using the Assign > Frame > Property Modifiers menu.

Below is a detailed description of how the program determines the flexibility of the element with hinge:

The issue here is that the flexibility of the fiber hinge is added to the elastic flexibility of the frame member containing the hinge. It may be better viewed as the modulus of elasticity being modified rather than the moment of inertia. Over the length of the hinge, the effective modulus $E_{eff}$ can be computed from $\frac{1}{E_{eff}} = \frac{1}{E_f} + \frac{1}{E_h}$, where $E_f$ is the modulus of the frame element, and $E_h$ is the modulus of the hinge. For a fully-steel hinge at zero stress, $E_h = E_f$, so that $E_{eff} = \frac{E_f}{2} = \frac{E_h}{2}$. For reinforced concrete, the averaged value of $E_h$ may be different from $E_f$.

By setting the axial and bending section property modifiers to a large value over the length of the hinge, $E_f$ becomes very large and $E_{eff} = E_h$, or nearly so. This is the recommended approach.

The value of $E_h$ used for modal analysis, or any linear analysis, depends upon whether the linear load case starts from zero initial conditions or uses the stiffness from a previous nonlinear case. From zero, the initial elastic stiffness of each fiber is used. If the fiber has different initial tension and compression stiffness, such as for concrete, the average stiffness is used. From a previous nonlinear load case, the actual stiffness $E$ of each fiber at the end of the load case is used. The approach most often appropriate is to run a nonlinear gravity load case and use the stiffness at the end of that load case to compute the modes.