A theoretically exact approach based on nonlinear stiffness formulations is available in the literature. There are also a number of approximate methods to model these effects. The theoretically exact method involves the use of iterations for convergence and special non-linear solution algorithms to negotiate the non-linear part of the load-deflection curve. At each iteration, the nonlinear stiffness coefficients are evaluated. This tends to be time consuming.

On the other hand, the approximate methods are relatively easy to implement and use. Most approximate methods in the literature involve modifying the total stiffness matrix of the structure either by adding fictitious members of negative stiffness or subtracting what is known as a "geometric stiffness matrix".

The Geometric Stiffness Method [Wilson et al 1987], one of these approximate methods, has been used successfully within the assumptions of small deflections. RAM Frame has adopted the same algorithm for analyses involving P-Delta effects. The method basically involves modifying the stiffness matrix by subtracting what is called the "geometric stiffness matrix". This method will force P-Delta effects on both static and dynamic (Eigen value extraction) analyses. The softening effect of P-Delta analysis will result in additional story displacements, horizontal shears and overturning moments. The same softening effect will also result in lengthening of the periods of the structure. Note that the reactions components obtained from analysis where P-Delta effects are considered contain additional horizontal shears and overturning moments.

The details of the P-Delta method are given in the reference. However, certain modifications have been made in the implementation of the method in RAM Frame. For buildings with columns disconnected from the diaphragm, the P-Delta modifications are made only to the diaphragm stiffness. In some building floor type configurations, users may disconnect a significant number of columns from the diaphragm resulting in small overall diaphragm stiffness. P-Delta corrections may introduce singularity in the lateral stiffness corresponding to such diaphragms. RAM Frame detects such singularities and aborts the program. Users may then wish to combine the mass of such a diaphragm to the ones above or below it. Singularities could also occur in other types of buildings if P-Delta effects are high.

The P-delta correction to the stiffness is based on the specified story masses or applied dead\live loads. They must be specified in order for P-delta to be considered.

Two options are provided for how to calculate P-Delta effects (Figure 6-48)

- **Use Mass Loads :** This option uses building mass to calculate P-Delta effects. It is briefly related to mass associated with diaphragms (including member mass as well as any mass load defined with surface\line and point loads). This is the default method used in the program. RAM Frame provides users with an option for specifying factors for magnifying the P-Delta effects. To account for P-Delta effects due to live loads and/or factored loads, users may want to specify values larger than unity for the P-Delta factor. The program puts a maximum limit of 10.0 for the P-Delta factor. However, it needs to be remembered that the P-Delta modification scheme adopted in RAM Frame assumes small deflections in the building. Deflections within the range allowed by Code would generally be considered small
- **Use Gravity Loads :** Instead of using building mass, this option uses applied dead and live loads to calculate P-Delta effects. Note that different scale factors can be defined for dead and live load components. Live load reduction factors are also applied for live loads.

In either case, the program applies the same method to calculate P-Delta effects. The only difference is that the former uses building mass converted to building weights to be used in P-Delta calculations and the latter uses dead and live loads instead for P-Delta effects.

It should be also noted that P-Delta effects are not only considered for rigid diaphragms but they are also included for analysis with semirigid diaphragms (see Section 6.12.4.)

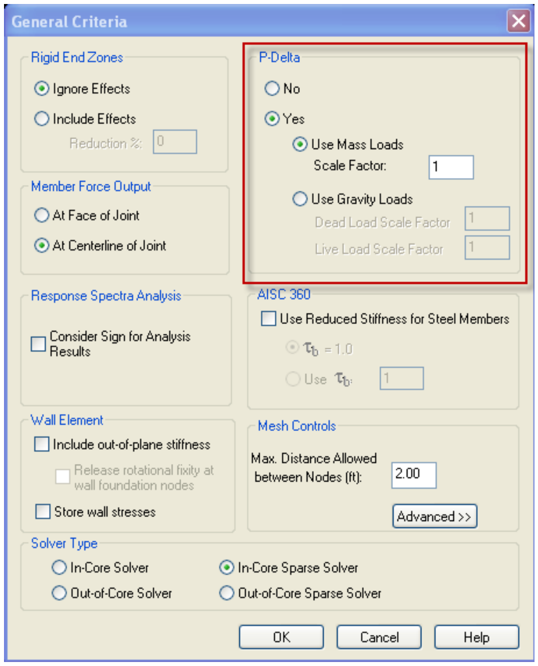

Figure 6-48 P-Delta Controls

6.14 Analysis with Tension-Only Members

Tension-only brace members are capable of resisting tensile forces but do not have resistance to compressive forces. They behave similar to regular frame members except they do not provide any stiffness in compression.

RAM Frame utilizes a nonlinear analysis algorithm to track tension-only members during solution of the structural model under applied lateral loads. The program applies the loads for a given load case to the structure and iteratively controls the stiffness of the tension-only members. In some cases, it is necessary to apply the loads incrementally in order for the analysis to converge to a solution. When this is necessary, the program incrementally increases the applied loads while it searches the correct equilibrium state. If the equilibrium state is not found, the loads are applied with smaller increments. The program automatically adjusts load increments as it processes lateral loads.

Further information on analysis with tension only members are provided in Section 3.3.8

It should be noted that only axial forces in the tension-only members are monitored during the iterative analysis. In other words, bending stiffness of tension-only members still exists if the member’s ends are not released (or fixed) and it is not changed during the iterative process.