ATTACHMENT 1

Demand Procedure

The following procedure, utilizing the superposition principle, illustrates one method that can be used to compute superstructure moment and shear demands at the extreme seismic limit state. This limit state is reached when all potential plastic hinges have formed in the supports below the joint regions, and considers the effects of dead, secondary prestress, and seismic loadings. This procedure considers each of the three load cases on a stand alone basis, and the final limit state results are obtained by the superposition of the individual load cases, and must sum to a state of equilibrium.

Prior to the seismic load application, the column members are "pre-loaded" with moments due to unbalanced dead loads and secondary prestress effects. At the extreme seismic limit state, the "earthquake moment" applied to the superstructure from the support may be greater or less than the overstrength moment capacity of the column or pier, depending on the direction of these "pre-load" moments and the direction of earthquake motion under consideration. Consequently, when the three load cases are superimposed, the column members will reach, but not exceed, the overstrength moment capacity at potential plastic hinge locations.

Although the procedure illustrated below applies to superstructure demands in the longitudinal direction, these concepts can also be applied to the transverse direction. Since moments and shears are related, the shear demands at the extreme seismic limit-state can also be found using this procedure.

In order to provide clarity and consistency to the equations, moments and shears shown in all free-body diagrams within this procedure correspond to their positive sign convention (CCW for bending moments). These diagrams do not reflect the actual direction of the forces under any specific loading condition. Caution must be taken to ensure the correct sign is applied to each force variable during the superposition process.

Step 1: Determine Dead Load Moments and Shears

Several methods of frame analysis can be performed to obtain moments M^{L}_{dl} and M^{R}_{dl} in the superstructure, and M^{col}_{dl} in the columns. Moment equilibrium must be satisfied at the c.g. of the superstructure/support joint (i.e. $M^{L@cg}_{dl} + M^{R@cg}_{dl} + M^{col@cg}_{dl} = 0$). Typically, the overall superstructure moment and shear forces are distributed uniformly to each girder, and substructure moments and shears are distributed equally to each column. Moments and shears due to dead loads are shown in Figure 1.

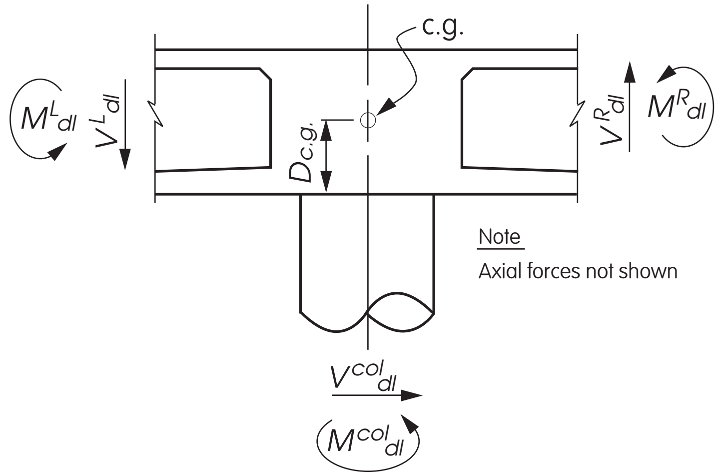

Figure 1 - Longitudinal Dead Load Moments and Shears

Step 2: Determine Prestress Secondary Moments and Shears

Secondary prestress moments and shears in the superstructure and columns can be obtained by several structural analysis techniques. Hand methods or computer programs capable of incorporating prestress effects are acceptable. These moments are denoted as $M^L_{p/s}$, $M^R_{p/s}$ and $M^{col}_{p/s}$ in the superstructure and columns, respectively. Equilibrium must be satisfied at the c.g. of the superstructure/support joint (i.e. $M^{L@cg}_{p/s} + M^{R@cg}_{p/s} + M^{col@cg}_{p/s} = 0$). Moments and shears due to prestress effects are shown in Figure 2. Moment and shear forces are distributed to the girders and columns as described in Step 1. Prestress forces should be considered only when the result is an increase in overall superstructure demand.

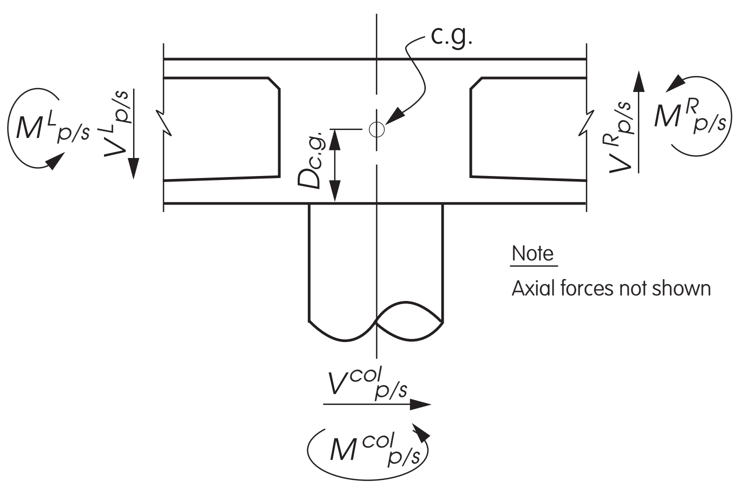

Figure 2 - Longitudinal Prestress Secondary Moments and Shears

Step 3: Determine Earthquake Moments and Shears

The purpose of this step is to determine the forces in the superstructure induced by seismic loading. All potential plastic hinges must form in the columns due to the combination of dead, prestress secondary, and seismic loads. Therefore, the maximum seismic load to which a structure can be subjected is a lateral load when combined with the moments and shears due to dead load and prestress load would induce column forces equal to their overstrength capacities. The moments and shears induced by the seismic load in the columns are then distributed to the adjacent superstructure members.

(a) Determine the Moments and Shears Due to the Seismic Loading Required to Ensure that Potential Plastic Hinges have Formed in all the Columns of the Framing System

To form a plastic hinge in the column, the seismic load must produce a moment at the potential plastic hinge location of such a magnitude that, when combined with the dead load and prestress moments, the column will reach overstrength plastic moment capacity, M^{col}_{o}.

Let the moment at the top of the column (at soffit interface) generated by the seismic force be denoted at $M^{col@soffit}_{eq}$. Utilizing the superposition principle, $M^{col@soffit}_{o} = M^{col@soffit}_{eq} + M^{col@soffit}_{dl} + M^{col@soffit}_{p/s}$. The earthquake moments can then be calculated as $M^{col@soffit}_{eq} = M^{col@soffit}_{o} - M^{col@soffit}_{dl} + M^{col@soffit}_{p/s}$. Moments and shears for this load case are shown in Figure 3.

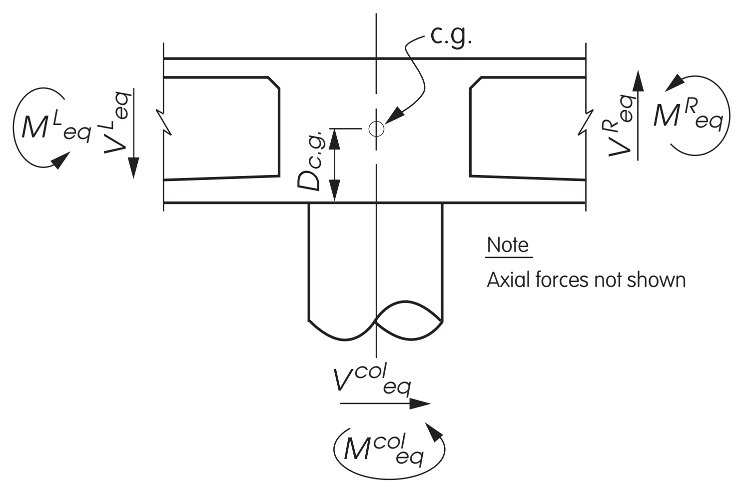

Figure 3 - Longitudinal Earthquake Moments and Shears

(b) Determine the Earthquake Moments and Shears in the Superstructure

The moments and shears determined previously in (a) are then transferred to superstructure members. Several analysis techniques can be used to distribute the column earthquake moment and shear demands to the superstructure. If a moment distribution or a frame analysis method is used, the superstructure can be modeled as a continuous beam. A moment of magnitude equal to $M^{col@soffit}_{eq} + V^{col@soffit}_{eq} * D_{c.g.}$ associated with each column can be applied at each superstructure/support joint, then distributed to obtain the moments and shears in the superstructure.

Static non-linear "Push-over" frame analysis programs, such as wFRAME[7], can be used to distribute the earthquake moments and shears into the superstructure in lieu of the method described above.

Step 4: Compute the Moment and Shear Demand at the Section Being Investigated

The limiting seismic moment and shear demand in the superstructure is the summation of all the moments and shears computed in Steps 1 through 3. The respective direction of bending moment and the effective section width must be taken into account. The superstructure demand moments are defined as $M^L_D = M^L_{dl} + M^L_{p/s}* + M^L_{eq}$. and $M^R_D = M^R_{dl} + M^R_{p/s}* + M^R_{eq}$. for the left and right sides, respectively. Dead load and prestress moment demands in the superstructure are proportioned based on the number of girders within the effective section width. The earthquake moment induced by the column generates demand within that same effective section width. A summary of moments and shears due to dead, prestress, and seismic loads are illustrated in Figure 4, shown in the positive sign convention.

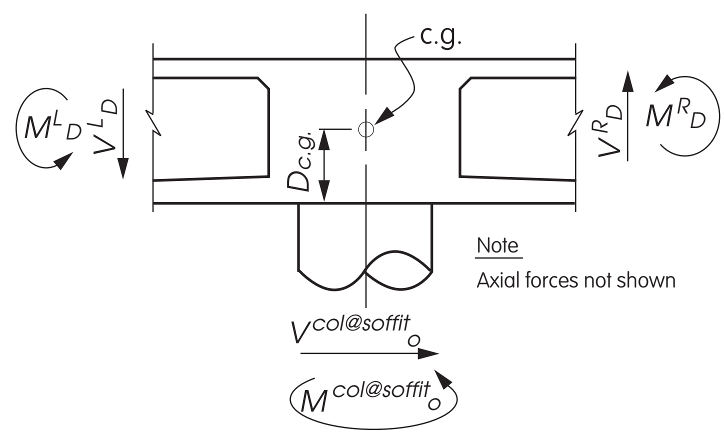

Figure 4 - Longitudinal Free Body Diagram of Joint Forces