P-Delta and Minimum Base Shear

In the context of the topic for next Friday's conference call, here are some questions and speculations:

1. AB-83 asks for a code "conformance" check, and the question is whether to use the min. base shear requirement (Eq. 30-7) in the drift check. The first question is – how is this being handled now for code conforming structures? I suppose it should be the same for a prescriptive design and alternative design?
2. It would be great to see it spelled out what the purpose of the min. base shear eq. is. Is it to account for ground motion uncertainties (that's the way I read it in the information sent around by Charlie Kircher), or for modeling uncertainties, or both?
3. If it is to account mostly for ground motion uncertainties, then it should apply for strength and stiffness design, presuming there is agreement that there is good justification to the drift limit of, whatever (1.5% or 2%).
4. If it is to account for modeling uncertainties (i.e., our inability to predict behavior with confidence), then one could pass the buck to level 3 (stability analysis under MCE). This presumes that there is a consistent way to incorporate modeling uncertainties into the stability analysis (and that the answer obtained from a response history analysis is close to a good answer). And that's where the TBI effort becomes critical.
5. It would be most desirable, but probably unrealistic, to shelve the answer to the question asked until the TBI effort is completed. If this cannot be done, it might be advisable to take some precautionary measure to safeguard against unforeseen collapse potential due to P-delta misunderstanding. Fully trusting everyone's nonlinear analysis or masking the problem with a mysterious min. base shear may not be the right way. Here are my arguments why.

Yes, P-delta is one of the culprits than makes tall and flexible buildings go south. Clearly, sidesway collapse is not the only collapse mode, but if it happens it happens ONLY because of P-delta. Sidesway collapse, by definition, means that "second order" effects (P times delta) can no longer be resisted by the structural system.

But, unfortunately, P-delta is **very sensitive** to yielding mechanisms (which differ a lot among moment frames and are very different for wall structures than for moment frames), to the effective post-yield stiffness, and to deterioration in strength and stiffness. (A few examples are given at the end).

As the name says, P **and** delta count, but not the delta predicted from elastic analysis. A rigid the job drift limit based on elastic analysis results multiplied by a C_d factor is not going to solve the problem. Also, as long as collapse safety is the issue (is it?), why is it relevant to keep the drift in the upper stories, where the P is small, below a rigid limit (unless there is clear deterioration)? There must be a better way to account for all this than a minimum base shear and an associated rigid drift limit (again, unless ground motion uncertainties are the reason for the min. base shear).

But more explicit attention needs to be paid in the AB-83 to make sure that P-delta is well accounted for in the level 3 stability analysis. This may not be the topic of next Friday's discussion, but in my opinion the issues are closely related.

P-Delta -- Importance and Sensitivity

The following summary is based on moment frame structures (except for Fig. 5). Most tall buildings are NOT moment frames, but the concepts should be applicable. The figures are taken from

Adam, C., Ibarra, L.F., and Krawinkler, H., "Evaluation of P-Delta Effects in Non-Deteriorating MDOF Structures from Equivalent SDOF Systems," *Proceedings of the 13th World Conference on Earthquake Engineering*, Paper #3407, Vancouver, Canada, August 1-6, 2004.

Ibarra, L.F., and Krawinkler, H., "Global Collapse of Frame Structures Under Seismic Excitations," *John A. Blume Earthquake Engineering Center Report No. TR 152,* Department of Civil Engineering, Stanford University, 2005, and PEER Report 2005/06, Sept. 2005.

Zareian, F, "Simplified Performance-Based Earthquake Engineering", *Ph.D Dissertation,* 2006; Stanford University, Stanford California

1. Sensitivity to yield ("collapse") mechanism.

Even disregarding deterioration, P-delta changes the so-called collapse mechanism and causes concentration of plastic hinging in the lower stories where P is large. Typical deflection profiles without and with P-delta are shown in Fig. 1. The consequence is that the effective post-yield stiffness changes drastically because of P-delta see Fig. 2.

2. The meaning of the stability coefficient θ.

Codes define a stability coefficient, θ, which is defined as something like $P\delta/(Vh)$. This coefficient defines the importance of P-delta in the elastic range, but may be VERY misleading in the inelastic range, see Figure 3.

3. Sensitivity to post-yield stiffness.

Depending on the "collapse" mechanism and on the assumed post-yield hardening stiffness of the components, the effective structure post-yield stiffness (see Figs. 2 and 3) may vary by a large amount, and the collapse capacity will vary correspondingly.

4. Sensitivity to deterioration

Yes, deterioration in strength and stiffness will amplify P-delta effects and will reduce the collapse capacity. A structure (or more appropriately its analytical model) will never collapse in a sidesway mode if there is no P-delta effect and no deterioration. The effect of P-delta for deteriorating systems is illustrated in Fig. 4. And it is huge, particularly for long-period frame structures!

5. Frames versus Walls

For wall structures that develop a plastic hinge at the base the P-delta effect likely is not a dominant issue because the story drift at the base is not large. A side-by-side comparison between a frame and a wall structure (but only 8 stories) is shown in Fig. 5. The picture may change drastically if the wall fails in a shear mode.

The conclusion is that the importance of P-delta depends on many parameters, and the development of a simple recipe to account for all these parameters may not be easy. Again, the TBI needs to address this.
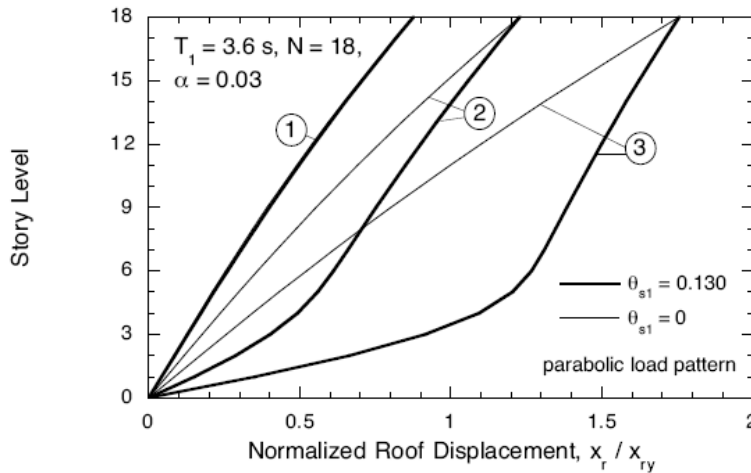

Fig. 1. Pushover deflection profiles for N = 18, T1 = 3.6 sec. frame structure (1) = elastic, (2) and (3) = inelastic. Thin line = no P-Delta, thick line = with P-delta
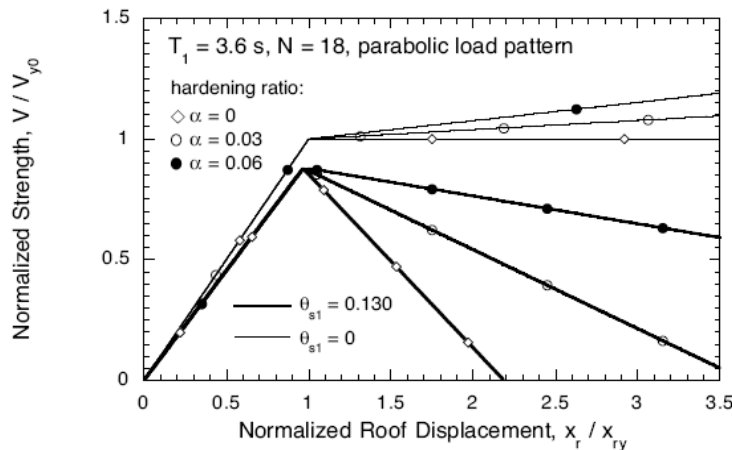

Fig. 2. Pushover base shear – roof drift curves for N = 18, T1 = 3.6 sec. frame structure Thin lines = no P-Delta, thick lines = with P-delta

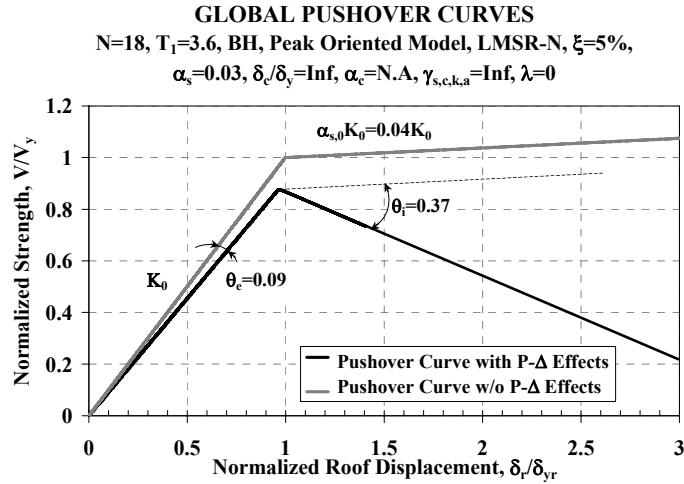**GLOBAL PUSHOVER CURVES**
N=18, T_1=3.6, BH, Peak Oriented Model, LMSR-N, ξ=5%,
α_s=0.03, δ_c/δ_y=Inf, α_c=N.A, $\gamma_{s,c,k,a}$=Inf, λ=0

Fig. 3. Elastic and Inelastic Stability Coefficients Obtained from Global Pushover Curves, Non-Deteriorating Frame 1836

EFFECT OF P-Δ ON MEDIAN $[S_{a,c}(T_1)/g]/\gamma$
N=Var, T_1=Var, BH, Peak Oriented Model, LMSR-N,
ξ=5%, α_s=0.03, δ_c/δ_y=4, α_c=-0.10, $\gamma_{s,c,k,a}$=Inf, λ=0
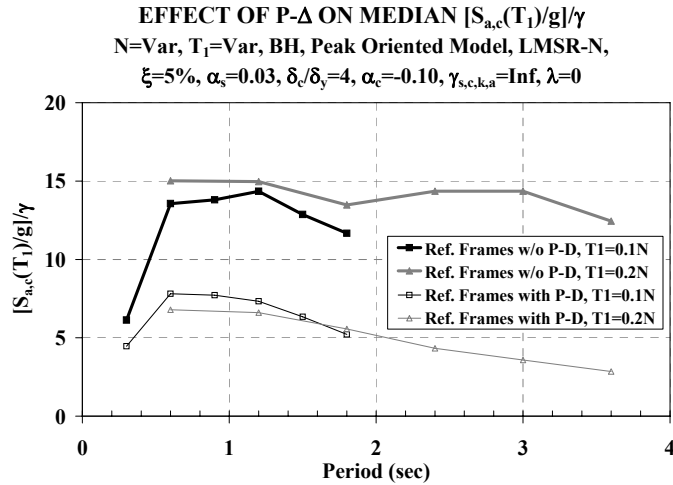

Fig. 4. Effect of P-Delta on Median Collapse Capacity of Reference Moment Frames ($[S_{a,c}(T_1)/g]/\gamma$ is the median R_μ factor at collapse)
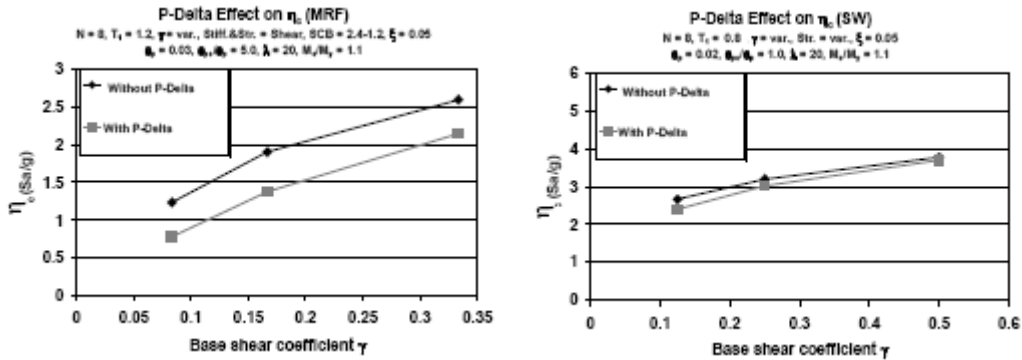

Fig. 5. Effect of P-Delta on Median Collapse Capacity of an 8-Story Moment Frame and Shear Wall Structures