Advanced Seismic Systems and Code Evolution

By Jerod G. Johnson, Ph.D., S.E.

The past decades have seen major progress toward the broad utilization of advanced nonlinear analysis methods for seismic design. Many of us have witnessed continual development and evolution of the modern standard for nonlinear seismic design – ASCE 41, now titled *Seismic Evaluation and Retrofit of Existing Buildings*. Its precursors include FEMA 273 and FEMA 356, not to mention countless others (e.g., ATC 40) that emerged even earlier in an effort to address the vast inventory of infrastructure that cannot satisfactorily qualify under standards for new construction.

It has been interesting to witness the evolution of modern methodologies as they have progressed from "White Papers" to "Guidelines" and then to "Pre-Standards" and finally full-fledged "Standards". Countless individuals have contributed untold hours and shared vast amounts of experience and knowledge to bring us modern seismic rehabilitation requirements. These efforts have led to a clearly pragmatic approach for dealing with the threat of earthquakes.

The use of basic nonlinear analysis methods can even demonstrate the frailties of some of the most prolific seismic-force-resisting systems found in modern infrastructure. As an example, consider a concentric braced frame. What are the consequences of braces buckling in compression? It is an interesting rhetorical question and has led some to believe that if the concentric braced frame were to be introduced as a new product today for regions of high seismicity, it would be an uphill battle to win approval. However, its successful use over many decades has yielded a grandfathering of sorts, accompanied by some adaptations; very large beams (to account for unbalanced brace forces) in chevron or "V" configurations come to mind.

The widespread adaptation and use of nonlinear analysis methods have shed light on behaviors that, in worst cases, have been ignored, in better cases are only misunderstood, and in the best cases are handled head-on by the structural engineer. We often deal with irregular behaviors and geometries, and go to painstaking efforts to qualify our projects as "regular" so as to be acceptable following the prescriptive code standards. However, nonlinear analysis methods (static pushover) can demonstrate that even a perfectly symmetrical, conventionally braced frame structure will develop an extreme torsional irregularity when considering the prescribed 5% accidental eccentricity. This is because the likelihood of complementary braces on opposing sides buckling simultaneously is extremely low.

How do we address the consequences of this behavior? One valid, yet economically impractical approach is to design structures to remain elastic (R=1). Good luck explaining to your clients why your design is four times the cost of your competitor's! Such an approach may seem extreme, but has actually appeared among published opinion statements regarding future seismic code development. The more pragmatic way forward is to embrace and design systems that are better prepared to handle the nonlinearity and mitigate its global effects on the structure.

Such systems are already recognized in the code, but in an indirect manner. Simply observe the highest prescribed R factors to identify the systems with superior nonlinear performance. Among these, buckling restrained braced frames have emerged as a solution preferred by many. Other steel systems include special moment frames, eccentric braced frames and steel plate shear walls. Each of these systems has a demonstrated ability for well-balanced and primarily symmetric hysteretic behavior. In essence, frames using these systems can experience repeated cycles of elasto-plastic deformation while maintaining their ability to support gravity loads. In so doing, they dissipate energy in a stable, controlled and targeted manner.

The emergence and utilization of nonlinear analysis methods afford engineers the tools to address seismic design in this manner. While conventional approaches are still valid, the increasing ease of use for nonlinear methods make the application of the R factor to the global structure seem increasingly less reliable, perhaps even less practical. Even so, reconnaissance efforts following major events suggest that satisfactory performance can be realized using traditional methods, which have served us well.

It seems somewhat ironic, though, to see virtually all modern structural analysis software, coupled with amazingly powerful desktop computers, automatically develop the prescribed pseudo-static seismic forces in virtually the same manner as hand calculations and slide rules from many years ago. The tools that we use have powers and capabilities for seismic analyses far beyond most of the analytical tasks to which we apply them. Seems a bit like swatting flies with a sledge hammer!

What will the future hold? Nonlinear methods have a demonstrated ability to provide a more reliable outcome and the means for meeting specific seismic performance objectives. Will direct nonlinear analysis methods replace the current simplified and indirect methods? Time will tell.

Clarification

The author's article, *Development Length: More Complexity or Saving Grace?* (STRUCTURE, December 2013), concluded by stating, "Furthermore, ACI 318 section 12.2.5 allows for reduction of development length and lap splice in direct proportion to the amount of excess reinforcement provided. Owing to the discreteness of bar sizes, excess reinforcement can usually be quantified such that embedment and lap splicing requirements can be rationally adjusted accordingly." While this is correct for development length and embedment, an alert reader pointed out that such a reduction is now explicitly prohibited for lap splice length by ACI 318 section 12.15.1. Consequently, option (b) presented earlier in the text is not actually a viable alternative, unless the requirements of ACI 318 section 12.15.2 can be satisfied, which would allow the lap splices to be Class A rather than Class B.▪

*Jerod G. Johnson, Ph.D., S.E. (**jjohnson@reaveley.com**), is a principal with Reaveley Engineers + Associates in Salt Lake City, Utah.*