Structural Analysis

discussing problems, solutions, idiosyncrasies, and applications of various analysis methods

Challenging Issues When Conducting Nonlinear Seismic Analysis

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It is no mystery that there are still uncertainties and lack of guidance when conducting nonlinear seismic analysis of structures. The challenge remains that the modeling, type of nonlinearities, and parameters required for analysis oftentimes vary from project-to-project and person-to-person depending on the assumptions that are made in light of limited guidance. This article summarizes key points and relevant discourse from a panel session as a means of sharing information, advancing the practice, and closing the gap between research/development and practice associated with conducting nonlinear seismic analysis.

Motivation

From the 2012 survey results compiled by the ASCE Subcommittee on Emerging Analysis Methods in Earthquake Engineering and published in *Nonlinear Analysis in Modern Earthquake Engineering Practice* (STRUCTURE, March 2014), four (4) major barriers for entry into nonlinear analysis were identified: 1) high complexity, 2) time consumption, 3) lack of clear guidance, and 4) communicating the benefit of advanced analyses to owners. The Subcommittee was led to charter more discussions and means to "close the gap" between research/development and practice about nonlinear seismic analysis. To further this effort, a panel discussion consisting of academics and practitioners was held at the 2015 *Structures Congress* in Portland, Oregon. Critical issues and challenges to date were discussed, and viewpoints were shared. This article summarizes some of the highlights from the session that may prove useful for structural engineers who are confronted with the challenge of conducting nonlinear seismic analysis, where several initial questions arise:

- Does this design warrant advanced nonlinear analysis?
- Who will pay for it?
- Will the project finish on time due to the extended amount of time required to do such a complicated analysis?
- Is there confidence in the results produced based on assumptions made?

As structural engineers, we have a huge responsibility to society and the profession based on the designs we produce. As if that's not a big enough charge, we know that these undertakings can be daunting at best.

Panel Discussion

During the 2015 SEI/ASCE *Structures Congress*, seven (7) panelists from academia and industry gathered together to discuss some of the challenging issues facing the profession, such as modeling of nonlinear structural components, capturing geometric nonlinearities in response, pushover analysis, time history analysis, selection of ground motions, and how much modeling detail is enough to get reasonable results. The panelists, ranging in specific expertise centered on seismic analysis and design, were:

- Ibrahim "Ibbi" Almufti, S.E., P.E., LEED AP, Associate at Arup
- Finley Charney, Ph.D., P.E., Professor at Virginia Tech
- Amir Gilani, Ph.D., S.E., Structural Specialist at Miyamoto International, Inc.
- Walterio A. Lopez, S.E., Principal at Rutherford & Chekene
- Weichang Pang, Ph.D., Associate Professor at Clemson University
- Rafael Sabelli, S.E., Director of Seismic Design at Walter P Moore
- James Daniel Dolan, Ph.D., Professor at Washington State University

The general consensus for eight (8) major areas are summarized herein based on the following categories: 1) when to conduct nonlinear analysis, 2) the challenges, 3) justification to owners, 4) challenges for structural software industry, 5) nonlinear analysis validation, 6) need for more guidance, 7) pushover analysis and 8) "the future."

When to Conduct Nonlinear Analysis

All panelists unanimously pointed out that nonlinear analysis should be applied in situations where the building type is not regular or assumptions of code-based linear analysis are not valid anymore. Everyone also agreed that analysis for retrofitting or presence of certain lateral-force resisting systems like viscous dampers, isolators, or any new type of lateral-force resisting system warrants nonlinear analysis.

The Challenges

The primary point emphasized was the need to interpret results from advanced analysis, which requires experience and peer reviews. "The added cost and likely peer review time and expenses associated with nonlinear procedures may be a barrier of entry [Gilani]." This begged the next concern for determining when advanced analysis is even deemed necessary, especially given the processing time, time needed to interpret results and cost to do such analyses. The second challenge identified was the scaling of ground motions. All of these challenges were also identified from the 2012 survey, but rose as the top two challenges agreed among the panelists.

Justification to Owners

Justification to owners is one of the starting points before an engineer can proceed to do nonlinear

seismic analysis in cases where it is not warranted. Each panelist had a slightly different perspective based on their experience and understanding. Almufti and Pang pointed out that simulated financial losses and downtime after a seismic event could be one of the motivation for the owners. Lopez indicated nonlinear analysis could provide potential savings in material/schedule/etc. over the code prescribed linear procedures. Charney noted that justification may not be likely if the same building can be designed by satisfying all the code requirements. Sabelli and Gilani indicated that a lack of reliability of linear methods in certain situations could be the driving factor. Sabelli also indicated economy and design creativity for unconventional systems as justification for performing nonlinear analysis. Overall, everybody agreed that nonlinear procedures are time consuming and computationally demanding, and also require an added cost of peer review.

Challenges for Structural Software Industry

The general consensus to this question was that software must provide tools for efficient data management, post-processing and reduction in run time for nonlinear time history analysis.

Nonlinear Analysis Validation

This is the confidence building step which every engineer "must" go through during the nonlinear analysis. Unfortunately, there are no standard guidelines which one can follow, but only a set of "rules of thumb" derived from experience and fundamentals of structural analysis. One can start from viewing results like mode shapes, vibration periods [Pang, Charney], running sensitivity studies by varying time steps, changes in phenomenological definitions, hinge properties etc. [Gilani], validation of component behavior by comparing analytical and experimental results, matching initial conditions like dead and live load in columns [Lopez]. Gilani pointed out that it is due to the difficulty of such validation that the code requires peer review of design based on nonlinear analysis.

More Guidance

One new topic that surfaced from the discussion was the need for data management given the large amount of data produced when conducting advanced analyses. This is important to recognize, as it goes hand-in-hand with the need to interpret results. Moreover, further guidance was needed for validating models, assuming that the modeling results are reliable, while supporting documents from FEMA P-695 and ASCE 7/41 help with selection and scaling of ground motions [Pang]. Similarly, when following ASCE 7 Chapter 16 "where the system is to be modeled in 3D, subjected to 11 pairs of ground motions, and in cases where accidental torsion must be analyzed, this can increase to 44 pairs of ground motions with the use of scenario spectra as the target for ground motion scaling, which can increase the required analysis by another factor of 2, 3 or 4…the time required to perform this analysis can be measured in hours or days for a single analysis for complex systems [Charney]." As such, future additions and enhancements to ASCE 7-16 and ASCE-41 may (or may not!) be welcomed continuous improvement to aid advanced analyses.

Pushover Analysis

"To do pushover analysis or not, that is the question!" The general impression from the

panelists was that a pushover analysis should not be used as the sole measure and not be needed if one is performing a nonlinear time history analysis. It was noted that pushover analysis is less useful for drift or ductility demand, but rather to help proportion the structure to activate any intended ductile mechanism [Sabelli]. Furthermore, "pushover analysis is probably not appropriate for multi-mode buildings [Almufti]." Pushover analysis was also noted as "not being useful… do a response history, as collapse mechanisms are frequently misidentified, even for short buildings [Lopez]."

The Future

Given recent discussions and even votes, the need for more education and training on advanced topics like nonlinear analysis cannot be overstated. Education, training, workshops, continuing education units, and other types of professional development are paramount. Training in school and other "proper training of engineers', as noted by Graham Powell's two articles in the November and December 2008 issues of STRUCTURE magazine, were reiterated by Lopez. Coupled with more knowledge would be the need for "better post-processing tools as well as acceptance criteria for structural elements in new construction, since ASCE-41 is not intended for new construction [Lopez]." While a fruitful discussion and exchange of information from experienced advanced analyses users took place, there is still more work to do to streamline this process and educate future engineers on advanced nonlinear analysis procedures. So the question still remains, do we "pay now or pay later?" For a complete listing of the panelists' responses, please visit **www.cece.ucf.edu/people/kmackie/SEI-SEC/Panelist.html**.

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