Engineering Needs for Existing Buildings
Observed Technical Needs – Research Perspective
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1) **Nonlinear Structural Analysis and Assessment:** The introduction of nonlinear static pushover analysis in the late 1990's was a major step forward to assess the seismic performance of existing buildings. Over the past few years, nonlinear dynamic analysis has become possible and has the advantage of overcoming some of the inherent limitations of static nonlinear analysis. However, in spite of the advancements made in our understanding of structural behavior, nonlinear analysis models, and computational technologies, there are still significant limitations in our ability to model the nonlinear response of buildings. The challenges for existing (versus new) buildings are particularly challenging due to the potential for various modes of strength and stiffness deterioration.

   Improved modeling capabilities and validation are needed for a wide variety of models for different structural materials and systems. Depending on the situation, the improved models may range from phenomenological nonlinear spring models to more fundamental continuum finite element models. To facilitate development and reliable use of improved models, an important need is to develop more streamlined procedures and processes for validating nonlinear cyclic models and dynamic analyses against test data, theory and detailed simulations. To the extent possible, validation through testing of existing structures (ones slated for demolition) should be pursued. Validation could also shed important light on modeling aspects such as loading rate and loading protocol effects, which are known to influence response but are not well acknowledged in current models.

   Included below is a list of specific structural components where modeling improvements are needed. A few common needs across all system types and materials are the need for analyses that can incorporate nonlinear response of "force-controlled" components, such that the effects of their failure can be more accurately assessed (in contrast to current practice that relies on judgment to assess the consequences to failure of force-controlled components).

   Considering both the limitations of current modeling technologies and the needs for practice, the high priority modeling needs include validated models to capture the response of:
   - non-ductile concrete components including (in rough order of priority): (a) beam-column columns under the effects of biaxial bending, axial load, and biaxial shear and torsion, (b) concrete walls – both slender and squat, subjected to shear, bending and axial load effects, (c) masonry infill walls, including local interaction with the surrounding frame, (d) splices in beams and columns, (e) beam-column joints, and (f) slab-column connections.
   - Non-conforming steel building components including: (a) beam-columns susceptible to torsional-flexural buckling and/or local flange/web buckling, (b) brace and moment frame connections, including localized deformations and fracture, and (c) braces.

- Masonry walls including in-plane and out-of-plane response and interaction with flexible diaphragms and diaphragm connections.
- Wood walls and diaphragms, including models to simulate the response of architectural finishes and partition walls.

Note – simulation needs related to soil-structure interaction are included in a separate item.

2) Improved Guidelines and Criteria for Building Assessment: FEMA 273 and subsequent updates and improvements in ASCE 41 are vital resources for assessment of buildings. These documents were instrumental to facilitating use of nonlinear static analysis by providing clear procedures, model parameters and acceptance criteria. However, the current framework has many limitations and simplifying assumptions that can lead to inaccurate assessments. Many engineers have also expressed concerns that assessments done using ASCE 41 tend to be overly conservative since the procedures are limited in their ability to capture the dynamic nonlinear response of the structure.

Therefore, there is a need for a major overhaul of ASCE 41 that would address some of the following aspects:

- Improvements to make more effective use of nonlinear dynamic analysis (in contrast to current focus on nonlinear static analysis). A key aspect of this would be extension of the generalized force-deformation models to explicitly reflect cyclic loading effects.
- Explicit consideration of modeling uncertainties, by providing both central values (means or medians) and dispersions of model parameters. Related to this is quantifying the influence of these modeling uncertainties on performance assessments.
- More realistic characterization of structural response. In particular, the strict distinctions between “deformation-controlled” and “force-controlled” components should be relaxed to recognize the actual nonlinear response of indeterminate structures. This also suggests that model parameters should be described by equations rather than by strict separation into categories (e.g., the current distinctions between “conforming” and “non-conforming” are fairly course and do not capture important ranges of behavior within each category).
- Improved clarity and procedures for relating local strain measures to overall component deformations. This would facilitate the utilization of more fundamental analysis methods to simulate response that cannot be accurately captured with existing macro-models.

3) Benchmarking and Calibration of Performance Acceptance Criteria: Related to the previous point, one of the major limitations of ASCE 41 is the relationship between local component criteria (e.g., hinge rotations) and global performance criteria (e.g., IO, LS and CP). With the availability of FEMA P695 and P58 methodologies to assess collapse and other performance targets, it would be extremely valuable to benchmark the ASCE 41 performance criteria against more realistic models. After benchmarking the performance (i.e., understanding the risk of collapse associated with the CP criteria in ASCE 41), then the ASCE 41 procedures could be improved and calibrated to provide more consistent and transparent performance measures. This assessment could also relate the performance associated with these limits in ASCE 41 to the performance of new buildings that conform to ASCE 7.

4) Liquefaction and Large Ground Deformations: Recent earthquakes in New Zealand and Japan have demonstrated the devastating consequences of large ground deformations and liquefaction. Improvements in our ability to assess and mitigate the effects of ground movement are needed in the following areas:

- Criteria to evaluate liquefaction triggering and prediction of ground deformations under buildings, considering overbearing pressures. The presence of the building introduces additional dynamic stresses from the SSI that affects the demands for liquefaction. In addition, the static building loads (overburden and shear) affect the soil's resistance to liquefaction. So there are several embedded problems here that are tricky to sort through.

- Improved understanding of the influence of liquefaction and ground deformations on buildings and techniques to mitigate these effects through ground improvement, foundation retrofit, or other means.

- Guidance for evaluating piles with non-ductile reinforcing that go through soil layers of different stiffness and strength and lead to potentially large curvatures.

5) Soil Structure Interaction: Development of capabilities for nonlinear SSI including incoherence ground motions in nonlinear response history analysis. This pertains to cases where the building site and foundation are explicitly modeled with elements that represent the spatial variation in soil properties, soil-structure contact, and ground motions. Such models would enable consideration of:

- Foundation sliding and rocking effects. In short low-rise structures, these effects can be beneficial by reducing motions in the structure. In taller structures, the effects can be varied, depending on the specific circumstances.
- Modeling incoherence in ground motions both through the depth and over the plan area of the building foundation. Information is needed to first characterize this incoherence and then to develop computational methods and implementations for inputting incoherent ground motions into the soil-foundation-structure system.
- Related to modeling of foundations is the need for a more rational and consistent framework for seismic earth pressures on retaining walls under conditions of principally kinematic and inertial loading. The existing models for wall pressures rely on mobilization of shear strength, which may be unrealistic since most of the seismic increments occur at stress levels well below those required for shear strength mobilization. Consequently, pressures arise from relative movement between wall and soil that require a different basis for modeling.

6) Broader Issues in Awareness and Decision Making for Existing Buildings

- Post earthquake occupancy issues for existing buildings, considering exogenous constraints. This could include availability of power and water to the building, closure of buildings due to adjacent safety risks (e.g., Christchurch CBD), etc.
- Building rating systems (a la LEED) to help tenants and others drive seismic safety increases via market forces by informing them of the safety of the buildings they occupy.

- Pre-analysis of instrumented buildings, so that sensor data can be used to make rapid tagging decisions. In concept this is straightforward, but work should be done to (a) investigate the reliability of such assessments, and (b) develop a best-practices or guideline document on how to develop effective instrumentation programs and pre-analyses to facilitate rapid post-earthquake assessment.