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Continuing Education Course #422
Structural Nonlinearity
Part 3 - Analyzing Nonlinearity

1. Most joints between members and most support joints of a structure should be modeled as having what, for the purposes of nonlinear analysis?
 - a. unidirectional response
 - b. reserve strength
 - c. partial moment/rotation fixity
 - d. planar response

2. Why should 3D structures not be nonlinearly analyzed using one or more planar/2D idealizations?
 - a. any eccentricity in applied lateral loads or any asymmetric framing will engage 3D response
 - b. nonlinear structural analysis software packages typically won't accept or analyze 2D structures
 - c. 2D nonlinear analysis only uses 1D-line (beam, truss) elements and 3D nonlinear analysis only uses 2D-area or 3D-volume (plate or brick) finite elements
 - d. because seismic accelerations can act three-dimensionally

3. Which of the follow substructures may need to be modeled along with the dedicated structural framing for nonlinear analysis of a building?
 - a. Roof-mounted antennae
 - b. Wall-mounted awnings
 - c. Full-height partition walls without deflection gaps overtop
 - d. Architectural metals bridging multiple frame members, like stairs or continuous facade members
 - e. C & D
 - f. A & D

4. Why should nonlinear analyses be performed using ultimate, or LRFD, level loads?
 - a. nonlinear analyses were not developed until after LRFD had overtaken ASD in many codes and standards
 - b. software that can perform nonlinear analyses is developed outside USA, where LRFD is more prevalent
 - c. the behavior at ultimate loads (overloading) is the concern, and nonlinear results based on ASD-level loads cannot be scaled up
 - d. omega factors (> 1.0) cause divide-by-zero errors in software while phi factors (< 1.0) do not

5. An interesting facet of sequential/staged analyses (e.g. analyzing structures that add/remove members or supports over time) is:
 - a. considering how to accommodate structural distortion that occurs prior to changes being made
 - b. that seconds and minutes are used in both Imperial and Metric units systems, precluding the need for conversions
 - c. if the time duration is measured in minutes, hours, days, or years instead of seconds then kinematics can be used in lieu of structural dynamics
 - d. that problems that could occur during changes being made to the structure are the contractor's responsibility

6. What should be tracked and recorded while performing analyses over time that have several time states, like the closing of a gap support?
- a. joint forces and some internal member forces for each time state
 - b. possibly distortions (displacements, rotations, deflections, slopes) at joints or locations along members
 - c. the direction of each force or movement, as well as the magnitude
 - d. all of the above
7. The Wood (Rankine-Merchant) method
- a. pertains to retained soils and does not apply to structural analysis
 - b. pertains to timber material science and does not apply to structural analysis
 - c. can be used to perform rudimentary materially nonlinear frame analysis
 - d. is used to determine interpolated values when following along a curve
8. Curved members are usually analyzed by:
- a. rigorous derivations of bending, torsion, and radial stresses for each curve profile
 - b. discretizing the member into sub-members and performing a linear analysis, even though it is an approximation
 - c. ignoring the curve and using a straight sloped and/or angled member that connects the endpoints of the curved member (chord) in structural models, and using the results from a linear analysis
 - d. applying curvature modification factors to the results obtained using the method in C, above
9. Members under gravity loads that are curved in plan are expected to undergo _____, while members under gravity loads that are curved in elevation are expected to develop _____.
- a. full yielding | plastic hinges
 - b. torsion | longitudinal axial forces
 - c. large deflections | radial stresses
 - d. creep | kinematics
10. If axial-compression carrying columns are to be analyzed for $P-\delta$ effects using 2nd-order structural analysis software, then:
- a. they must be modeled using 3D-volume brick finite elements
 - b. they should be discretized into two to eight beam-type sub-members
 - c. they should be braced for accidental diaphragm torsion
 - d. 3rd-order software should be used instead since 2nd-order analysis cannot solve for P-delta effects
11. Which of the following conditions does not tend to demand nonlinear dynamic analyses in lieu of nonlinear static analyses?
- a. building structures 4-stories in height or shorter
 - b. structural systems that exhibit multi-mode dynamic response
 - c. harmonic loading from an unbalanced machine on the structural system
 - d. base-isolation of structures
 - e. cyclic stress reversals due to wind vortex shedding
12. Most material standards (AISC, ACI, etc):
- a. require that 2nd-order analysis be performed for structures where geometric nonlinearity could be influential
 - b. defer to local jurisdictions to declare when nonlinear analyses are required
 - c. regard nonlinearity as novel and negligible
 - d. require simulation or 3rd-order analysis for structures with height-to-width ratios greater than four
13. When should a linear analysis be run initially, prior to adding nonlinearity and nonlinearly analyzing?
- a. when more than four phase-type nonlinearities are to be included in nonlinear analyses
 - b. it is always recommended

- c. when time and the project budget allows
- d. when the user is new to nonlinear analysis and still learning
14. How should member fabrication and erection tolerances be considered in nonlinear analyses?
- a. by not including them and stating in design documents that published tolerances are to be disregarded and set to zero
- b. by including them, and picking the orientation of tolerances that results in the lightest and cheapest members
- c. by including them, and determining the most influential orientation by rational analysis or by trying each orientation individually
- d. by not including them, as material standards (AISC, ACI, AISI, etc) provide for tolerances in the constants they've listed in their published formulae
15. Which of the following is not a reason that a 2nd-order (or simulation or 3rd-order) analysis would run many iterations but then diverge or never converge?
- a. not specifying the minimum member section properties needed for analysis
- b. contain a member that is approaching its global buckling capacity
- c. the structural system is generally too flexible
- d. the software has not been configured in a way to exit the solver
16. Why might 2nd-order/simulation/3rd-order structural analysis software not initiate or return an error on the first couple of analysis iterations?
- a. the model contains cables or fabric elements that have not been pre-analyzed to determine dead load geometry
- b. the software has not been configured in a way to exit the solver
- c. the model contains components that are moving rigidly without any provision for stabilization
- d. A & C
- e. A & B
17. Soft springs:
- a. are freely recommended for use in stabilizing a structure, or to create or dampen a degree-of-freedom
- b. should be used prior to trying other solvers, convergence settings, load ramping, etc. if needing to address excessive structural movement
- c. are dangerous if they are added to a structural model to dampen movement and hide an instability
- d. do not affect structural response enough to cause any issues
18. A building structure that contains nonlinearities is to be designed, and newly purchased software is going to be used to perform the analysis. Which of the following provides for adequate quality assurance and quality control?
- a. C & D
- b. E & F
- c. the nonlinear results are to be checked against a separate model created using the firm's old nonlinear analysis software
- d. senior staff required that the software company deliver the new software alongside several files of pre-modeled benchmark problems for all the types of nonlinearity that the firm encounters
- e. the building structure is modeled linearly, analyzed linearly, and then the linear results are compared to the nonlinear results showing that differences in results seem reasonable
- f. the software company says in their brochure for the nonlinear analysis software that the types of nonlinearity contained in the building structure being designed can be solved by the software
19. Modeling columns as "kinked" with two sub-members and the mid-height joint laterally offset, or adding lateral displacements (as a load) to a roof diaphragm in addition to lateral wind load and gravity axial compression, then running a 1st-order linear analysis is:
- a. a clever way to avoid performing nonlinear analyses for P-delta effects in any situation
- b. a crude linear idealization that could, at best, be used to roughly check nonlinear analysis results

- c. also called "moment magnification"
- d. only acceptable as a P-delta effects replacement for agricultural, storage, or other similar structures with low risk to human life
20. If a structural system is designed to be stiff enough in comparison to thresholds published in material standards, then what can often be avoided?
- a. needing finite element analysis software
- b. including geometrically nonlinear P-delta effects in structural analyses
- c. checking of nonlinear analysis results
- d. torsional warping
21. If a member in a structural system is analyzed linearly and is found to deflect more than about half the member depth, and/or if the member rotates or slopes more than approximately 10 degrees, then:
- a. soft springs are required to help dampen the structural movement
- b. simulation-type analysis is required
- c. the member has yielded
- d. small-deflection beam theory is no longer applicable, and the member must be analyzed using moderately large or large deflection beam theory
- e. materials with a higher modulus of elasticity should be specified
22. Sometimes post-yielding materially nonlinear analysis seems to be warranted, yet could be avoided by what?
- a. explicitly specifying members and materials strong enough to remain elastic and preclude yielding
- b. using linear analysis to determine the location of the onset of yielding
- c. using 3rd-order analysis
- d. A & B
- e. B & C
23. What are the design forces for the Example 1: Gap Support beam at location $x = 15$ ft (4.6 m)?
- a. 29.8 k shear, 68.8 k-ft moment (132 kN shear, 93.2 kN-m moment)
- b. 34.8 k shear, 68.8 k-ft moment (155 kN shear, 93.2 kN-m moment)
- c. 34.8 k shear, 68.8 k-ft positive moment, 119 k-ft negative moment (155 kN shear, 93.2 kN-m positive moment, 161 kN-m negative moment)
- d. 34.8 k shear, 188 k-ft positive moment, 119 k-ft negative moment (155 kN shear, 254 kN-m positive moment, 161 kN-m negative moment)
- e. 34.8 k shear, 188 k-ft moment (155 kN shear, 254 kN-m moment)
24. When using discretization to analyze nonprismatic members, less sub-members are needed to accurately analyze geometric nonlinearity and stability than to accurately analyze for stiffness (deflection/slope and distribution of forces to adjoining structure)
- a. True
- b. False
25. "Shortcuts" for nonlinear analysis can be summarized as:
- a. nonlinearity does not often conform to or exhibit behavior that can be described with a rule-of-thumb or circumvented by a shortcut
- b. proprietary secrets of leading structural engineering firms
- c. widely available and computable, but more involved and time-consuming than just performing nonlinear analysis
- d. existing but avoided in engineering practice to allow structural software companies to innovate
26. Instantaneously changeable structural systems:
- a. must be undergo structural movement to be able to be analyzed
- b. are often referred to as internally, statically unstable

- c. initially offer no structural resistance to displacement or rotation in a certain direction, and then develops resistance upon finite displacement or rotation in that direction
- d. all of the above

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