Nonlinear Regimes That Challenges us in Finite Element Analysis

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Pedro V. Marcal,
pedrovmarcal@gmail.com

We start with the basic premise that we can approximate the behavior as a series of incremental straight lines.

1. Start with ensuring linear accuracy [1,2,3,4]
2. This is governed by incremental equations in elastic plastic stress-strain relations [D], [5,6,7]
3. Similarly we can generate the incremental strain-displacement function \(de=[B(x,u)](du)\), [8,9]
4. General expressions lead to general algorithms, then to general purpose programs[10]
5. It is surprising how unstable these equations can become near their transitional and/or maximum behaviors. In elastic-plastic behavior by calculating a mean stiffness, we may take larger incremental steps.[5] By using the nonlinear equations given by the principle of Virtual Work, we can add Residuals to the right hand side for additional corrections.[10] Sometimes projecting past the point of instability, we may continue our downward load displacement by interpolating to a higher order around the peak.[11]
6. Industry demanded and used these latest development.instead of expert analyst requiring Ph. D., Their design practices and the Codes (eg. Nuclear Codes) required that the bulk of the analysis could be handed to lower level support staff. The development of an expert system, named Stress Analysis CONsultant (SACON) [12]and follow on by Kawasaki Heavy Industry [13]. The latter program claimed that high school level technical trainees were able to carry out nonlinear component analysis.
7. At the same time , we were able to make progresson finite element theory and compare it with experiments [14,15,16,17,18]
8. Linear approximations to Failure by Eigenvalue extraction,
   Vibration \(\omega^2[M]-[K])[u]=0\) (1)
   [17,18,19,20]
   Buckling \(( [K(lin)]- \lambda[K(u)])[u]=0\) (2)
   [15]
   Useful for understanding behavior.
   From linearized approx..
   \(\Delta(W(lin)-W( geometry includes crack extension \delta a )\)
   Gives Griffith or J integral \(\frac{\delta W}{\delta a}\)
   It is interesting to speculate that the mean stiffness of the stress-strain relation [1] can give a better estimate. It gives the writer a better physical intuition.
   What happens when there is dynamics? Marcal and Yamagata[23] showed how to include it by considering D’Alembert Forces and using vibration modes.
   We can also accumulate the dynamic forces and let it create additional paths of cracking.[24] (crazy cracking!)
Collaboration with Dr. Fong and others at NIST. Learnt that data is not complete without probability.[25]

Can we extend it to Fluid mechanics? Marcal tried balancing work rate loads for no turbulence and turbulence starting at a single element, assumed to be highest viscous stress.[26]

10. We consider phase changes in the material and track the nonlinear material behavior. Such an important behavior describes the welding problem[27] and now the closely related sintering [28] 3D printing process. Some lessons to remember from welding, time scales of cooling are much longer than the instantaneous tracking of the nonlinear behavior function. Simplifying assumptions of lumping a series of incremental steps of heating will not affect the macro behavior. Its probably OK to neglect creep.

11. There is a class of problems that depends on combining materials, mostly as fiber reinforcement. It appears to be widely adopted in Nature for our biological systems. In reinforced concrete, the inclusion of reinforcing bars is simple [29] yet the concrete cracking complicates matters. The generalization of the process for polymer reinforced fiber composites[30] showed good results when compared with experiment.

12. To conclude, we consider the optimal design of structures. We can achieve this by devising materials that are function of the cost[31]. Another way is to use nonlinear programming [32]. we mention a new theory of optimization. Q-delayed learning[33] which according to dynamic programming yields an optimum for a series of steps each of which is a local optimum for a particular objective.in [34], the writer developed a simple program, QFEM.py to modify the nodal coordinates for a series of different loading regimes and obtained an optimal design.

References


