**MEEN 673** **Spring Semester 2023**

# Nonlinear Finite Element Analysis

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## ASSIGNMENT No. 5
## First-Order Shear Deformation Theory of Plates from Chapter 7 of the book

**Date: 9 Mar. 2023** **Due: 6pm, 24th March 2023**

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You are required to develop a geometrically nonlinear finite element analysis computer program based on *Newton iterative technique* to analyze static bending of linear elastic plates using the *first-order shear deformation plate theory* (FSDT; Chapter 7 of the text book). Use the following definitions of plate extensional ($A_{ij}$) and bending ($D_{ij}$) stiffnesses in terms of the engineering constants:

$$A_{11} = \frac{E_1 h}{1 - \nu_{12}\nu_{21}}\ , \quad A_{12} = \nu_{21} A_{11}\ , \quad A_{22} = A_{11}\,(E_2/E_1)\ , \quad \nu_{21}E_1 = \nu_{12}E_2$$

$$D_{11} = A_{11}(h^2/12)\ , \quad D_{12} = \nu_{21} D_{11}\ , \quad D_{22} = D_{11}(E_2/E_1)$$

$$A_{66} = G_{12}h,\ A_{44} = K_s G_{23} h, \quad A_{55} = K_s G_{13} h, \quad D_{66} = G_{12}(h^3/12), \quad K_s = 5/6$$

where $K_s$ is the shear correction factor and $h$ is the total thickness of the plate.

Use the developed computer program to solve two plate problems: (1) simply-supported square plate (SS-3) and (2) clamped square plate, both subjected to uniformly distributed transverse load $q = q_0 =$ constant. The geometric and material parameters to be used are $a = 10$ in., $h = 1$ in., $E_1 = 7.8 \times 10^6$ psi, $E_2 = 2.6 \times 10^6$ psi, $\nu_{12}$=0.25, $G_{12} = G_{13} = G_{23} = 1.3 \times 10^6$ psi. Use $8 \times 8$ and $4 \times 4$ uniform meshes of linear and equivalent meshes of nine-node quadratic rectangular elements in a quadrant of the plate to analyze the problems. Use load steps such that the *load parameter* $\Delta P \equiv \Delta q_0 a^4/E_2 h^4$ is equal to 5, and use 32 load steps to obtain the nonlinear response. Plot (a) load vs. center deflection ($P$ versus $w/h$), and (b) load vs. maximum stress ($\sigma_{xx}$ and $\sigma_{xy}$). Part (b) requires you to have a postprocessor in which you will compute membrane, bending, and total strains and stresses. Use a convergence tolerance of $\varepsilon = 10^{-3}$ and a reasonable value of $ITMAX$. Note that the stress calculation requires including a subroutine STRESS (you must create it); you may use either one-point integration (irrespective of linear or quadratic element) or reduced integration rules (i.e., $1 \times 1$ for linear and $2 \times 2$ for quadratic elements) to compute $\sigma_{xx}$, $\sigma_{yy}$, $\sigma_{xy}$, $\sigma_{xz}$, and $\sigma_{yz}$.

Note: As a part of this programming assignments, you must derive **the part of the tangent stiffness coefficient** $T_{ij}^{33}$ that is being added to $K_{ij}^{33}$. This may not be available in the book.

You must submit the following items in zip folder by e-mail to ecampus. (1) Pusedo code, (2) a copy of the computer program that you have developed, (3) input for the problems, and (4) plots/tables of the numerical results obtained for each of the problems. The grader will sent you template for the assignment.

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**Advance Notice:** Test # 2 is also two-part test. Part 1 is an in-class test on 30th March from 11am till 12:30pm; and Part 2 is a take-home, to be given on 30th March 2022 at 12:30 pm, and it is due by 6pm on March 31st. It includes material covered from Chapters 6 on 2D (steady and unsteady) and 7 (plate bending) and Programs 3, 4, and 5. You are required to submit the solution to Part 2 of Test2 in one file via my email to the grader with a copy to the instructor. Please include all required information for grading (note that the source codes are not to be submitted).

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