Nonlinear Finite Element Analysis

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ASSIGNMENT No. 2
(PROGRAM No. 2)

(Tests the understanding of material from Chapter 5 on Beams)

Date: 2 Feb 2023 **Due: 6pm on 10 Feb (Friday) 2023**

Use **Program 1** from **Assignment 1** to develop the *nonlinear* analysis capability to analyze straight beams using the Euler-Bernoulli and Timoshenko beam theories with the von Kármán nonlinearity (see Chapter 5 of the textbook). **Be sure to keep a copy of Program 1 file safe in your computer before you modify it to develop Program 2.** Your program should have the **direct iteration** and **Newton's iteration** solution options. You may *validate* your program using the (a) hinged-hinged (roller supported) beam, (b) pinned-pinned, and (c) clamped-clamped beam problems of **Examples 5.2.1** and **5.2.2** of Chapter 5. Once you are sure that the program is working, solve **Problems 5.11** and **5.12** of the textbook.

Helpful reminder: All nonlinear terms in both theories and shear terms in the TBT must be included in the reduced integration loop while all other terms should be included in the full integration loop (see Box 5.2.2 on page 234 and Box 5.2.3 on page 236).

You must submit *electronically* the following items to *ecampus*: (1) input for the problems analyzed using the program and (2) plots/tables of the numerical results obtained for the problems.

ADDITIONAL NOTES ON BEAMS

- One may define another parameter, MODEL, to make the code valid for three different cases: MODEL = 1, bar like problems; MODEL = 2, Euler–bernoulli beams, and MODEL > 2, Timoshenko beams. Accordingly, the parameter NDF (number of degrees of freedom per node) is defined:

```
IF(MODEL.EQ.0)THEN
    NDF = 1
ELSE
    NDF = 3
ENDIF
```

  Parameter NET = NPE*NDF is also needed to operate with full element matrix (which is 6×6) in the element subroutine.

- You must read parameters like AXX ($= EA$), DXX ($= EI$), and SXZ ($= GAK_s$) for the beam problems.

- You may also represent the distributed axial and transverse loads ($f(x)$ and $q(x)$) as FX=FX0 + FX1*X + FX2*X*X and QX=QX0 + QX1*X + QX2*X*X by reading the following values:

```
READ(IN,*)FX0,FX1,FX2
READ(IN,*)QX0,QX1,QX2
```

- The element solution vector ELU (6×1) can be extracted from the global solution vector GLU as follows (N is the element counter, N = 1, NEM):

```
          LL = 0
          DO 140 I = 1,NPE
          NI = NOD(N,I)
          ELX(I) = GLX(NI)
          IF(MODEL.EQ.0)THEN
               ELU(I) = GLU(NI)
          ELSE
               ND = (NI - 1)*NDF
               DO 130 J = 1,NDF
               ND = ND + 1
               LL = LL + 1
130        ELU(LL) = GLU(ND)
             ENDIF
140   CONTINUE
```

- The subroutine will have two separate Do-loops for Gauss quadrature: one on full integration and the other on reduced integration. Only after the coefficients $K_{ij}^{\alpha\beta}$, f_i, and q_i are evaluated completely, other operations like moving rows and columns to have the element solution vector (ELU = $\{\mathbf{\Delta}\} = \{\mathbf{u_1}, \mathbf{w_1}, \theta_1, \mathbf{u_2}, \mathbf{w_2}, \theta_2\}$) and calculating residual vector, are carried out.

- All stiffness coefficients that contains GAK_s (transverse shear stiffness coefficients) and nonlinear terms should be evaluated using reduced integration. All other terms, including f_i and q_i should be evaluated using full integration.

- Calculation of nonlinear terms needed (in the reduced integration loop) require the element solution vector ELU, which is transferred from the main program to the element subroutine. We can calculate U, DU, W, and DW as follows:

```
IF(NONLIN.GT.0)THEN
    U=0.0
    DU=0.0
    DW=0.0
    DO 120 I=1,NPE
    L=I*NDF-1
    K=2*I-1
    U = U+SFL(I)*ELU(L-1)
    DU=DU+GDSFL(I)*ELU(L-1)
    IF(MODEL.EQ.2)THEN
        DW=DW+GDSFH(K)*ELU(L)+GDSFH(K+1)*ELU(L+1)
    ELSE
        DW=DW+GDSFL(I)*ELU(L)
```

```
                   ENDIF
  120            CONTINUE
                   AXW =AXX*DW
                   AXWH=0.5*AXW
                   AN0 =AXWH*DW
                   AN1 =AXX*(DU+DW*DW)
               ENDIF
```

Announcement: Test No. 1 is scheduled for **Feb. 16, 2023**. Part 1 is to be done in the class and Part 2 must be returned by **5pm on Feb. 17, 2023**. Part 1 covers theoretical developments from Chapters 4, 5, and 6 while Part 2 covers problems that can be solved by Programs 1 and 2 (i.e., 1-D problems) and its modifications.
