Title

Computer program for elastic-plastic analysis of axisymmetrically loaded shells of revolution

Author
Khojasteh-Bakht, Mahmoud

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COMPUTER PROGRAM FOR ELASTIC-PLASTIC ANALYSIS OF AXISYMMETRICALLY LOADED SHELLS OF REVOLUTION

By

Mahmoud Khojasteh-Bakht

Faculty Investigator: E. P. Popov

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Structural Engineering Laboratory
College of Engineering
University of California
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Programmed by: M. Khojasteh-Bakht, University of California, June 1967

I. INTRODUCTION

The computer program presented here is developed for the analysis of elastic-plastic shells of revolution under axisymmetric loading and support conditions. The basic theory is fully discussed in Report No. SESM 67-8, titled "Analysis of Elastic-Plastic Shells of Revolution Under Axisymmetric Loading by the Finite Element Method," by M. Khojasteh-Bakht (April 1967). However, as an aid to the potential user, a few remarks follow which precede the Input Data Instructions, the Description of Output, and the actual listing of the Program in the FORTRAN IV language.

The Kirchhoff hypothesis together with Love's first approximation and small deflection theory are adopted.

The finite element method using the displacement model is selected for analysis. For an accurate idealization of the shell geometry, a curved frustum is taken as the primary element. This element can take specified slopes and curvatures at its nodal circles.

The displacement pattern of the curved element is expressed in local (rectilinear) coordinates, and an incremental technique using the tangent stiffness method is used to achieve elastic-plastic solution.

Flow theory of plasticity is employed, which enables one to trace the loading history. The program is specialized for elastic-perfectly plastic and elastic-isotropic hardening material. The vonMises yield condition and its associated flow rule is utilized.

For the purpose of analysis, the shell is subdivided into a number of elements. For a closed shell, numbering of nodal circles should be started from the point on the axis of symmetry.

The shell is assumed to be initially stress free. The first increment of loading is applied, and the magnitude of load is scaled such that the plastic deformation just sets in at some region within the shell. This constitutes an elastic analysis of the system. In the remainder of the elastic-plastic problem, the loading is continued in small increments.

II. INPUT DATA INSTRUCTIONS

1. Number of Input Control Card (I5)

Col. 1 to 5 - number of structural systems to be analyzed at the same time in one run

Note: Only one card is necessary for any number of input structural systems

2. Title Card (12A6)

Col. 1 to 72 - alphameric information to be printed in the output

3. Control Card (4I5)

Col. 1 to 5 - NN, number of nodal circles (max. 100)
Col. 6 to 10 - NL, number of layers in shell thickness h (max. 20)
Col. 11 to 15 - NLI, number of load increments
Col. 16 to 20 - NUMBC, number of boundary conditions (max. 5)

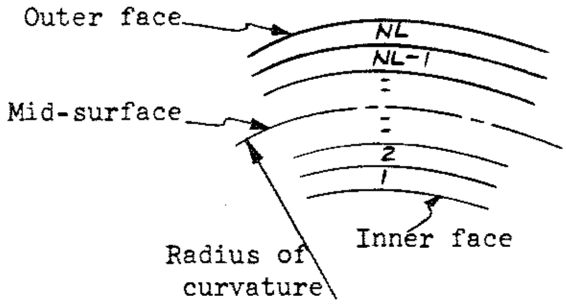


Fig. 1 - Numbering of Layers Across Thickness, NL

4. Nodal Coordinate Cards (4F10.0)

One card for each nodal point (total of NN)

Col. 1 to 10 - r_i, radical coordinate of the node
Col. 11 to 20 - z_i, vertical coordinate of the node
Col. 21 to 30 - PHI_i, latitude angle ${}_i$ of node
Col. 31 to 40 - H_i, shell thickness at node i

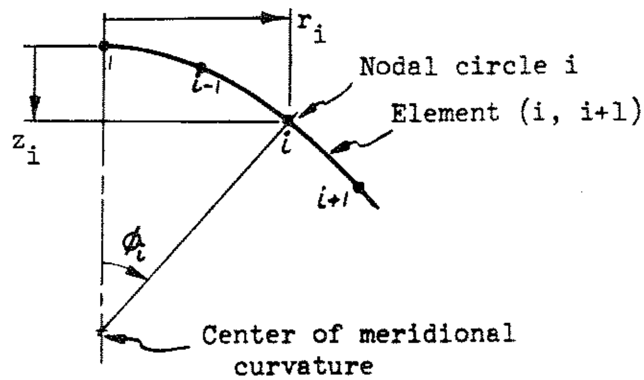


Fig. 2 - Nodal Coordinate Sign Convention

5. Element Curvature Cards (2F15.0)

One for each element (total of NN-1)

Col. 1 to 15 - CRV(m,i), Meridional Curvature at i of element (1,i+1)
Col. 16 to 30 - CRV(m,i+1), Meridional Curvature at i+1 of element (1,i+1)

6. Material Index Card (I5)

Col. 1 to 5 - NP, number of points which describe the $\sigma - \epsilon$ relation ($NP \geqslant 2$)

7. Material Property Card (3E15.0)

(Total of NP cards) describing ϵ_i, σ_i, E_i at each station starting from $\epsilon_1 = 0$, σ_1, E_1^t, (elastic limit)

Col. 1 to 15 - ϵ_i, strain at i

Col. 16 to 30 - σ_i, stress at i

Col. 31 to 45 - E_i^t, tangent modulus at i

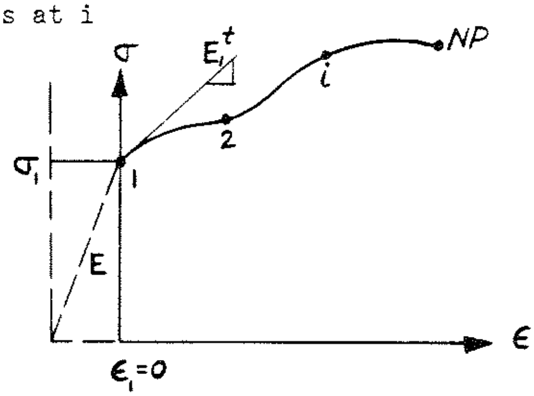


Fig. 3 - Stress-strain Diagram

8. Elastic Constants Card (E10.3, F5.0)

Col. 1 to 10 - E, Elastic Young's Modulus
Col. 11 to 15 - ν, Poisson ratio

9. Boundary Conditions Cards (I4, 1X, 3I1)

(Total of NUMBC cards). For closed top shells, the boundary condition at node 1 is not required.

9. (Cont'd)

Col. 1 to 4 - $NBC_{(i)}$, Boundary node number

Col. 6 - NTAG(1), displacement u_i at boundary node i

Col. 7 - NTAG (2), displacement w_i at boundary node i

Col. 8 - NTAG (3), rotation χ_i at boundary node i

NTAG (i) { = 1 constrained displacement or rotation; = 0 free displacement or rotation

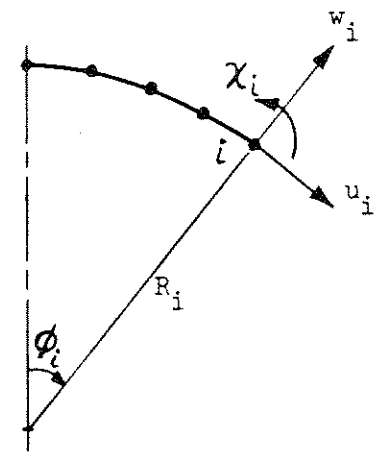


Fig. 4 - Sign Convention for Displacement and Rotation

10. Load Index Card (I5)

Col. 1 to 5 - INDEX, two cases may occur:

A. INDEX = 0, (or blank) when non uniform and/or concentrated load is acting on shell. In this case, one must specify the magnitude of loads on all the nodes of shell - see 11.

B. INDEX = number of uniformly loaded nodal points. This can occur when:

1) the entire shell is subjected to a uniformly distributed loading; or

2) the top part of shell (say node 1 to n) are under a uniformly distributed load and no load is acting on the remainder of the shell. (Here INDEX = n).

When Option B is used only one load card is the input and program will generate the same loading for all the INDEX nodes.

Note: When a concentrated load is acting anywhere, Option B cannot be used.

11. Nodal Load Card(s) (6E12.0)

If INDEX = 0 (or blank), one node-load card per node. If INDEX ≠ 0, only one load card is required.

Col. 1 to 12 - (Meridional Concentrated force, P_t) x r_i; where r_i is the radial coordinate of nodal circle (see Fig. 2)
Col. 13 to 24 - (Radial concentrated force. P_r) x r_i
Col. 25 to 36 - (Concentrated moment, M) x r_i
Col. 37 to 48 - Meridional distributed force, p_t (force/area)
Col. 49 to 60 - Radial distributed force, p_r (force/area)
Col. 61 to 72 - Distributed moment, m (force-length/area)

Note:
a. in step 11, the intensity of load at the nodal points are the input, the program will compute the equivalent nodal loads.

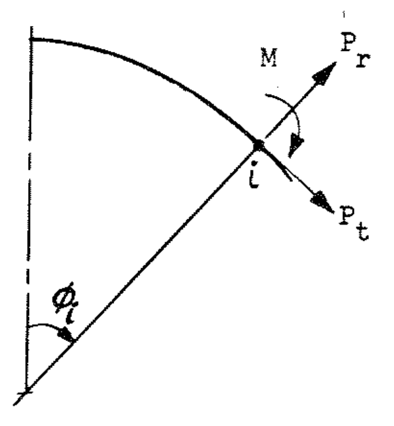
b. steps 10 and 11 must be repeated NLI times (see 3)

c. a concentrated force cannot be applied at the apex

d. the concentrated loads must be multiplied by their respective radial distances from shell axis.

If more input is wanted; i.e., different structural systems are to be analyzed, card in step 1 is set equal to the number of input cases and steps 2 - 11 are repeated that many times.

Fig. 5 - Nodal Load Sign Convention



III. OUTPUT DESCRIPTION

The following information is printed out on the basis of the above program:

1. Complete echo check of the input data

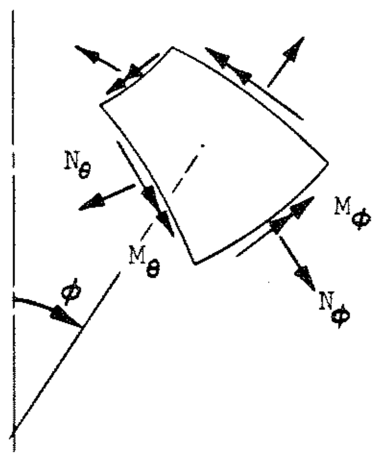
2. Computed nodal forces on system

3. Incremental and total magnitudes of:

   a. Nodal displacements in u-w-X coordinates (see Fig. 4 for sign convention)

   b. Nodal forces, N_θ, N_ϕ, M_θ, M_ϕ

Fig. 6 - Sign Convention for Output Forces



4. For each nodal point and at each layer across the thickness, the following quantities are output:

   a. Increments of ϵ_θ and ϵ_ϕ

   b. Total σ_θ, σ_ϕ, σ_e (equivalent stress) and the modification factor.

$$M_F \begin{cases} = 1 \text{ if state of stress is inside the yield surface} \\ \neq 1 \text{ if state of stress is on the yield surface} \end{cases}$$

$$\sigma_e = (\sigma_\theta^2 + \sigma_\phi^2 - \sigma_\theta\sigma_\phi)^{\frac{1}{2}}$$

σ_θ - hoop stress

σ_ϕ - meridional stress

ϵ_θ, ϵ_ϕ - hoop and meridional strains

Strain and stress are positive when tension.

IV. LISTING OF COMPUTER PROGRAM

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      ELASTIC-PLASTIC ANALYSIS OF AXISYMMETRICALLY LOADED SHELLS
      OF REVOLUTION.

      PROGRAM MAIN (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4,TAPE5=INPUT,
     1 TAPE6 = OUTPUT ,TAPE 8, TAPE9 )
C
      COMMON/ DIV  / NE , NL , NLI
C
      READ (5,22)NIPT
      DO 100 I=1, NIPT
    1 CALL INPUTD
C
      CALL GEOMTY
C
      DO 100 NLL = 1,NLI
C
      WRITE (6,1000)  NLL
C
      CALL NODLOD
C
      CALL STIFNS (NLL)
C
      CALL DISPL
C
      CALL STRESS(NLL)
C
      CALL MATPP
C
  100 CONTINUE
C
      STOP
C
   22 FORMAT (I5)
 1000 FORMAT(31H1NUMBER OF LOADING INCREMENT = ,I5)
C
      END
```