E-ISSN: 2278–179X

JECET; September-November, 2012; Vol.1.No.3, 280-285.

Journal of Environmental Science, Computer Science and Engineering & Technology

Available online at www.jecet.org

Engineering & Technology

Research Notes

Computational Technique to solve structure problems

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Received: 1September 2012**; Revised:** 24September 2012**; Accepted:** 26 September 2012

Abstract: The stability problem of structures subjected to various types of loadings is studied using finite element method computer programming. In many circumstances the structures are found to be exposed to in-plane loading. Aircraft wing skin panels, which are made of thin sheets, are usually subjected to non-uniform in-plane stresses. Large number of references in the published literature deals with the buckling, vibration behaviour of structures and its computer programming but no where the actual logic and flow chart available. The purpose of the present work is to deal with the computer logic for solving any structures problems.

Keyword: matrix, Preprocessors, Processor, Postprocessor, orthonormalisation

1. COMPUTER PROGRAM

The plate skin and the stiffeners are modelled as separate elements but the compatibility between them is maintained[1-3]. A study of the stiffness and mass matrices of the stiffener element reveals that the contribution of the beam element is reflected in all 9 nodes of the plate element, which contains the stiffener. A computer program[4] is developed to perform all the necessary computations. The geometric stiffness matrix is essentially a function of the in-plane stress distribution in the element due to applied edge loading. Since the stress field is non-uniform, for a given edge loading and boundary conditions, the static equation, i.e. $\left[K\right]$ $\left\{\delta\right\} = \left\{F\right\}$ is solved to get these stresses. The geometric stiffness matrix[5-7] is now constructed with the known in-plane stresses. The computer program developed accepts two sets of boundary conditions, the first for the static analysis and second for the buckling analysis[8, 11]. For non-uniform in-plane edge loading case, a three-point integration scheme is adopted for the evaluation of all the matrices except the portion of the stiffness matrix related to shear strain components. The overall elastic stiffness matrix, geometric stiffness matrix and mass matrix are generated from the assembly of those element matrices and stored in a single array where the variable bandwidth profile storage scheme is used[12-14].

2.1. Solution procedure for linear static analysis:

The stiffness matrix is stored as one-dimensional array through skyline storage scheme. This scheme eliminates zeroes within the band after the last non-zero value and reduces the storage requirement. The static equations of equilibrium in the form of $[A]\{X\}=\{B\}$ is solved by Cholesky decomposition procedure according to the algorithm presented as. The algorithm contains three subroutines, REDUCE, FORSUB, BACKSUB. Subroutine REDUCE decomposes a symmetric matrix in the variable bandwidth store L (NK) with address sequence LD (N). On exit the Cholesky lower triangular matrix appears in L (NK) except in the case of a reduction failure. Subroutine FORSUB solves by forward substitution LV = U, where L is a lower triangular matrix in the variable bandwidth store L (NK). Subroutine BACKSUB solves by backward substitution L^T V = U.

2.2. Solution procedure for linear free vibration and buckling analysis

The equation of motion is first transformed into a standard form. The characteristic equations for a discretised elastic structural system undergoing small displacements having the material properties within the elastic range for the free vibration analysis can be expressed as:

$$\omega^2[M]\{q\}=[K]\{q\} \tag{1}$$

For the buckling analysis, the expression is given by**:**

$$\lambda[K_G]\{q\}=[K]\{q\} \tag{2}$$

Where [K], [M] and {q} are the overall elastic stiffness (plate and stiffener), mass matrix (Plate and stiffener), and the displacement vector respectively. In this method [K] is positive definite and can be decomposed into Cholesky factor as:

$$[K]=[L][L]^T \tag{3}$$

where $[L]$ is a lower triangular matrix. Using Eq.(3), Eq. (1) can be written as

$$\{[L]^{-1}[M][L]^{-T}\}\{[L]^T\{q\}\}=\frac{1}{\omega^2}[L]^T\{q\} \tag{4}$$

$$\{[L]^{-1}[K_G][L]^{-T}\}\{[L]^T\{q\}\}=\frac{1}{\lambda}[L]^T\{q\} \tag{5}$$

Equation (4) and (5) show that they have an eigen values of $\frac{1}{\omega^2}$ and $\frac{1}{\lambda_i}$ respectively. Thus the eigen-values corresponding to lowest natural frequencies and buckling loads are obtained performing simultaneous iteration on them.

$$[A]\{x\}=\lambda\{x\} \tag{6}$$

$$[A]=[L]^{-1}[M][L]^{-T},\{X\}=[L]^T \ and \ \lambda=\frac{1}{\omega^2} \tag{7}$$

This represents a standard Eigen values problem and simultaneous iteration technique has been used to extract the eigenvalues and eigenvectors.

The methodology is explained as follows:

1. Set a trial vector $[U]$ and orthonormalize
2. Backward substitute $[L][X] = [U]$
3. Multiply $[Y] = [M][X]$
4. Forward substitute $[L]^T [V] = [Y]$
5. Form $[B] = [U]^T [V]$
6. Construct $[T]$ so that $t_{ij} = 1$ and $t_{ij} = \frac{-2b_{ij}}{\left[b_{ij} - b_{ij} + s\left(b_{ii} - b_{ij}\right)^2\right]}$

   Where s is the sign of $(b_{ii} - b_{ij})$
7. Multiply $[W] = [V][T]$
8. Perform Schmidt orthonormalisation to derive $[\overline{U}]$
9. Check tolerance $[U]$ -- $[\overline{U}]$
10. If not satisfactory, go to step 2

2.3. Description of the problem:

The computer code developed using the method of finite element involves three basic steps in terms of computational procedure.

- Preprocessor
- Processors
- Postprocessors

The different functions of these steps have been elaborated in figure 6.1.

2.3.1. Preprocessors:

The preprocessor is instrumental in reading the necessary details of the given structure such as geometry, boundary conditions, material properties, loading configurations and their magnitudes, stiffener location, stiffener parameters in detail etc. The desired data for the plate and the stiffeners are read in the INPUT.

The following variables are used in the INPUT to generate the data required for the analysis of stiffened plate for buckling, vibration, dynamic stability analysis.

A flowchart of the preprocessor unit has been shown in the figure 2

2.3.2. Processor:

Based on the finite element formulation, the processor unit of the computer code performs the following tasks:

- Generation of elastic stiffness, mass and geometric stiffness matrices of the plate and the stiffener element.
- Assembly of the element matrices using the skyline storage scheme.

- Imposition of boundary conditions
- Solution of algebraic equations for static analysis to obtain nodal displacements and stress resultant for the plate and stiffener at all nodes.
- Extraction of the eigen values for the free vibration, buckling analysis using the simultaneous iteration technique.
- Computation of buckling load, buckling parameter, frequency for required values etc.

The various operations used in this processor unit of the computer code are presented briefly.

2.3.3. Postprocessor

In this final stage of programming, all the input data are echoed to check their accuracy. The output sets the desired data in the form of displacements, stresses, strains, eigen values etc. depending on the type of analysis carried out.

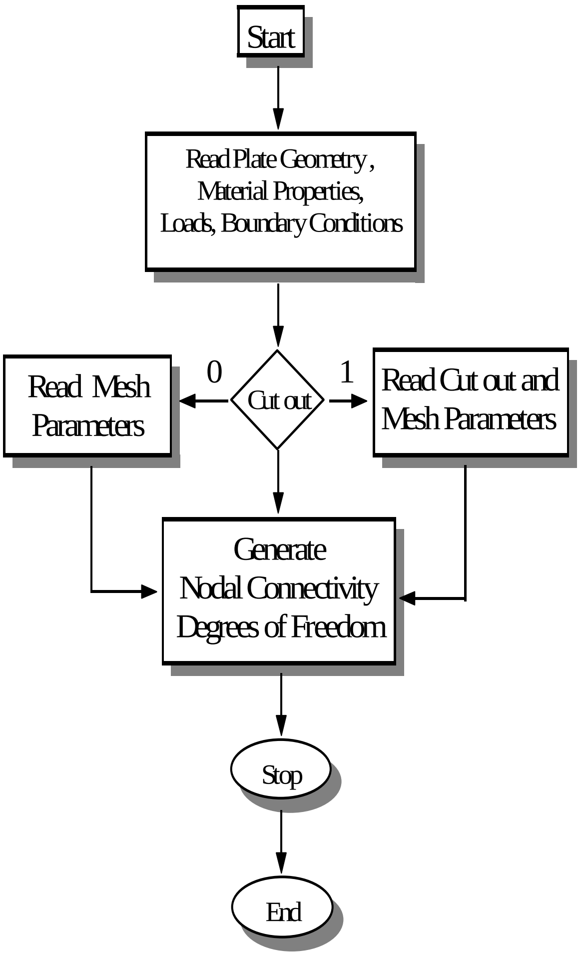

Fig.1-Preprocessor Unit of Finite Element Code

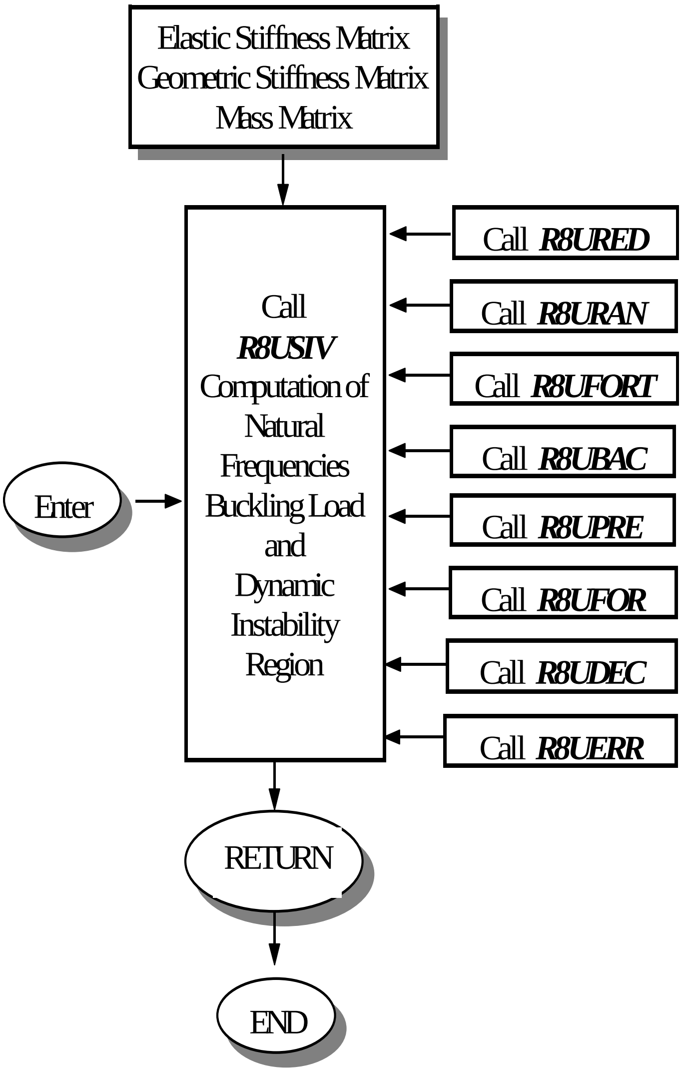

Fig.2- Flow Chart of Different Analysis

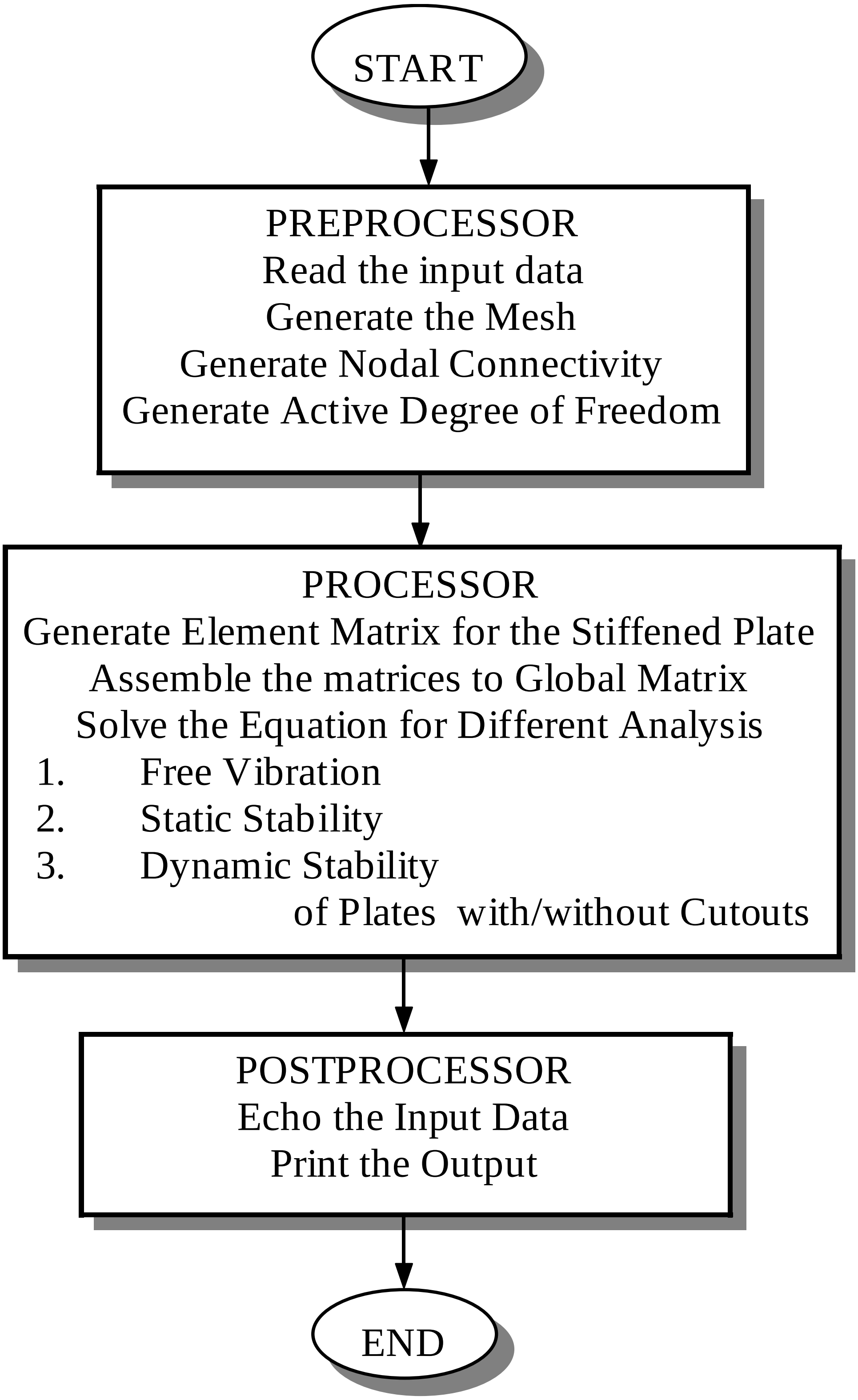

Figure. 3- Basic Elements of Finite Element Code

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