ABSEA FINITE ELEMENT SYSTEM

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ABSTRACT

ABSEA is a continually evolving modular suite of finite element programs that can, under the user control, be linked together by a simple command statement to produce a package tailored to the needs of the user.

The system provides comprehensive solution facilities and a wide range of element types. It covers the static and dynamic analysis of structures with elastic, elastoplastic and viscoplastic materials. The system has a powerful interactive mesh generator. Modular, user-friendly data are employed and the results can be tabular or graphical.

The ABSEA system which was designed and tested at Cranfield, has proved to be more efficient than some of the available well-known commercial packages.

I. INTRODUCTION

The finite element method is a computer-oriented technique which can deal with initial and boundary value problems of continuum mechanics. It usually requires the formulation and solution of a very large number of equations. The ideal finite element programming system should satisfy the requirements of:

(a) Versatility
(b) Modularity
(c) Controllability
(d) User-Friendly Data
(e) Interactive Graphics
(f) Error Diagnosis
(g) Reliability
(h) Economy

There are many large finite element systems on the market (1), which do satisfy such requirements.

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The ABSEA system (from Applied Mechanics Grouo Bespoke Suite for Engineering Analysis) is unique, for not only does it qualify as an efficient system, but also it has been specifically designed for the relatively small jobs of the majority of finite-element users, for whom the large systems are extremely expensive. The ABSEA system contains many of the latest developments of the finite element method, most of which have been developed in the School of Mechanical Engineering at Cranfield.

II. THEORY AND CHARACTERISTICS OF THE ABSEA SYSTEMS

1. Finite Element Library

Although serendipity elements are economical and efficient, their derivation is complex and limited to some quadrilateral and hexahedral elements (2-4). A general theory for boundary-described hypercubic (quadrilateral-hexahedral), simplex (triangular-tetrahedral), and pentahedral elements has been developed using Lagrangian and Hermitian interpolation (5). With the aid of this theory, the ABSEA system can generate shape functions for almost any engineering finite element.

2. Mesh Generation

Mesh generation can be interpolative (6), intuitive (7), or recursive (8). The recursive technique has been employed for the ABSEA mesh generator. The following development has been applied to the original approach of Reference 8,

(i) The use of arbitrarily-curved elements for the description of blocks.
(ii) The use of tetrahedral blocks which has been avoided by many other finite-element systems.
(iii) The recursive technique has been extended to transition and zooming blocks.
(iv) The use of transition finite elements.

Other characteristics of the ABSEA mesh generator can be summarised as follows:

(a) An editing facility which enables the user to modify any generated mesh.
(b) The generated mesh is a geometrical entity which can be employed for different applications.
(c) An interactive mesh generation facility.
(d) The generated elements can be renumbered so as to obtain the minimum front width.

3. New Elements

The Timoshenko-beam element and its generalised Mindlin-plate-bending element (9) are not accurate for thin beams and plates. A new derivation for these elements, which enables them to perform well irrespective of their thickness, has been achieved (5) and implemented in the ABSEA system.

4. Structure Types

The ABSEA system can deal with the following types of structures:

(i) Plane and space-framed structures.
(ii) Plane-stress and plane-strain continua.
(iii) Three-dimensional structures.
(iv) Axisymmetric structures.
(v) Plates and shells.

5. Nonlinear Analysis

The latest work in the literature (10-14), together with some developments described in (5), have been implemented in the ABSEA system. Von Mises or Tresca yield criteria can be employed with an isotropic, kinematic or mixed hardening rule, for an elasto-plastic, creep or visco-plastic analysis. An incremental, interpolative or iterative frontal solver can be used.

6. Dynamic Analysis

Efficient eigenvalue solvers using simple and subspace iterations (15) are employed for the ABSEA system with or without dynamic condensation (16). Steady-state response with hysteretic and/or viscous damping is also available. The ABSEA system employs the finite-element system for rotor dynamics and whirl orbits and Argand diagrams can be plotted. Some efficient time-marching techniques have been developed (5) and employed for transient analysis.

7. Other Applications

(i) Nonlinear elasticity using secant and tangential approaches.
(ii) All types of loading systems can be used for the static analysis.
(iii) Steady-state and transient heat conduction.
(iv) An accurate method to obtain the torsional rigidity for any cross-section.
(v) Tabular and graphical display of the results.

8. Software

ABSEA system has been coded in about 12,000 FORTRAN-77 statements. Many checking case studies have been tested with the aid of VAX 11/780 computer of the Cranfield Institute of Technology. A command generator is available which generates the necessary VAX commands to run and control the part of the system relevant to the user data.

III. APPLICATIONS

1. Mesh Generation Case Study

It was required to find the natural frequencies and mode shapes of a rotating free-free ring. The ring was modelled into 250, 8-node, hexahedral elements with 500 nodes and 1500 degrees of freedom. The generated mesh, projected on two different planes, is shown in Figures 1(a) and 1(b).

2. Two-Dimensional Elasticity Case Study

This case was employed to test the transition elements, which are only available in the ABSEA system. A two-dimensional plate was subjected to a rigid punch. A fine mesh was used, where the original and deformed mesh are shown in Figure 2(a) and the maximum stress contours are shown in Figure 2(b). Then the case was calculated by an economical mesh, as shown in Figure 3(a). The resulting stress contours, illustrated in Figure 3(b), are very similar to those of Figure 2(b) underlining the accuracy of the ABSEA transition elements.

3. Elasto-Plastic Case Study

It was deemed necessary to investigate the accuracy of the ABSEA system for the different elastoplastic approaches, by comparing its results with data from a reliable source. A thick cylinder, subjected to an increasing internal pressure was selected because it had a known theoretical solution. The radial and hoop stress distributions are shown in Figures 4(a) and 4(b) for the different yielding criteria and hardening rules. It is clear that the results obtained by the ABSEA system agree with the theoretical solution.

4. Natural Frequencies and Mode Shapes of a Circular Disc

A simply-supported uniform disc was tested, and the resulting calculated natural frequencies shown to agree with the known theoretical solution. The mode shapes are shown in Figure 5, where some of the well-known circular and diametral modes can be observed.

5. Rotor Dynamics Case

A typical rotor, under a given unbalance force, was analysed. The ABSEA system has proved to be more efficient than the transfer-matrix programs. The whirl orbits, at certain speed, are shown in Figure 6 and the Argand polar plots, at one of the bearings, are illustrated in Figure 7.

REFERENCES

1. Brebbia,C.A.,(ed.), "Finite Element Systems. A Handbook", Springer-Verlag, (1982).
2. Ergatoudis, I., Irons, B.M. and Zienkiewicz, O.C., "Curved Isoparametric Quadrilateral Elements for Finite Element Analysis", Int.J.Solids & Structures, 4, 31-42, (1968).
3. Zlámal, M., "A Remark on the Serendipity Family", Int.J.Num.Eng., 7, 98-100 (1973).
4. Ball, A.A., "The Interpolation Function of a General Serendipity Rectangular Element". Int.J.Num.Meth.Eng., 15, 773-778, (1980).
5. El-Zafrany, A.M., "An Advanced Finite Element System for Engineering Analysis", Ph.D., Thesis, Cranfield Institute of Technology, U.K., (1983).
6. Gordon, W.J., and Hall, C.A., "Construction of Curvilinear Co-Ordinate Systems and Applications to Mesh Generation". Int.J.Num. Meth.Eng., 7, 461-477, (1973).
7. Imafuku, I., Kodera, Y., and Sayawaki, M., "A Generalised Automatic Mesh Generation Scheme for Finite Element Method". Int.J. Num.Meth.Eng., 15, 713-731, (1980).

8. Zienkiewicz, O.C., and Phillips, D.V., "An Automatic Mesh Generation Scheme for Plane and Curved Surfaces by Isoparametric Coordinates". Int.J.Num.Meth.Eng., 3, 519-528, (1971).
9. Hinton, E., Razzaque, A., Zienkiewicz, O.C., and Davies, J.D., "A Simple Finite Element Solution for Plates of Homogeneous, Sandwich and Cellular Construction". Proc.Inst.Civ.Engs., 59, 43-65, (1975).
10. Nayak, G.C., and Zienkiewicz, O.C., "Elasto-Plastic Stress Analysis. A Generalisation for Various Constitutive Relations including Strain Softening". Int.J.Num.Meth.Eng., 5, 113-135, (1972).
11. Weisgerber, F.E., and Anand, S.C., "Interpolative Versus Iterative Solution Schemes for Tresca Yield Condition in Elasto-Plastic Finite Element Analysis". Int.J.Num.Meth.Eng., 12, 765-777, (1978).
12. Axelsson, K. and Samuelson, A., "The Finite Element Analysis of Elastic-Plastic Materials Displaying Mixed Hardening". Int.J. Num.Meth.Eng., 14, 211-225, (1979).
13. Evans, W.J. and Harrison, G.F., "The Development of a Universal Equation for Secondary Creep Rates in Pure Metals and Engineering Alloys". NGTE Report R 340, (1976).
14. Zienkiewicz, O.C. and Cormeau, I.C., "Viscoplasticity-Plasticity and Creep in Elastic Solids - A Unified Numerical Solution Approach". Int.J.Num.Meth.Eng., 8, 821-845, (1974).
15. Bathe, K.J. and Wilson, E.L., "Solution Methods for eigenvalue Problems in Structural Dynamics". Int.J.Num.Meth.Eng., 6, 213-226, (1973).
16. Shah, V. and Raymund, M., "Analytical Selection of Masters for the Reduced Eigenvalue Problem". Int.J.Num.Meth.Eng., 18, 89-98, (1982).

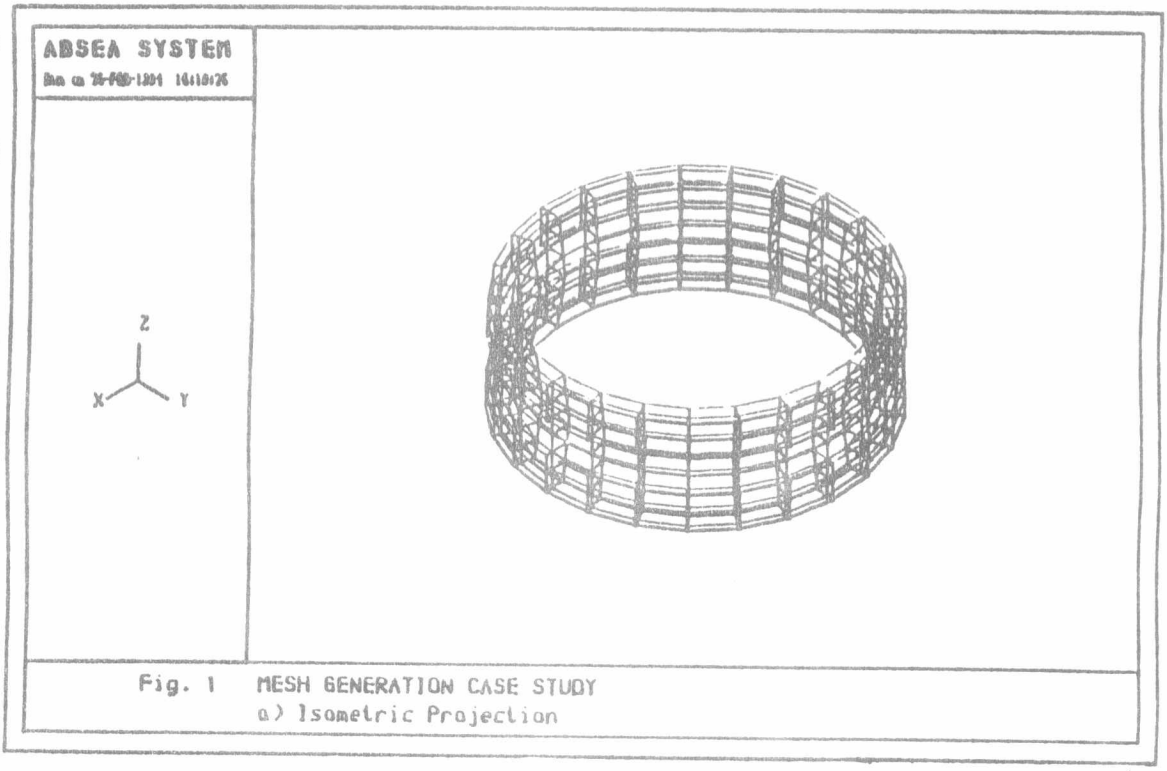

Fig. 1 MESH GENERATION CASE STUDY
a) Isometric Projection

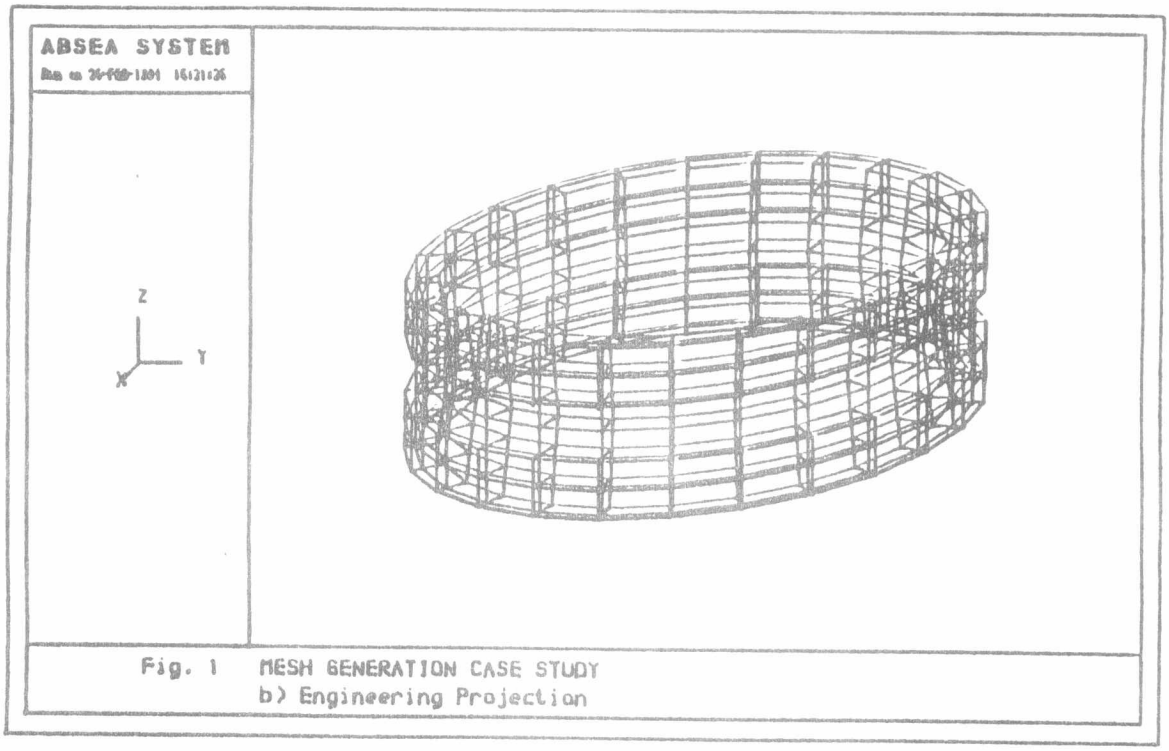

Fig. 1 MESH GENERATION CASE STUDY
b) Engineering Projection

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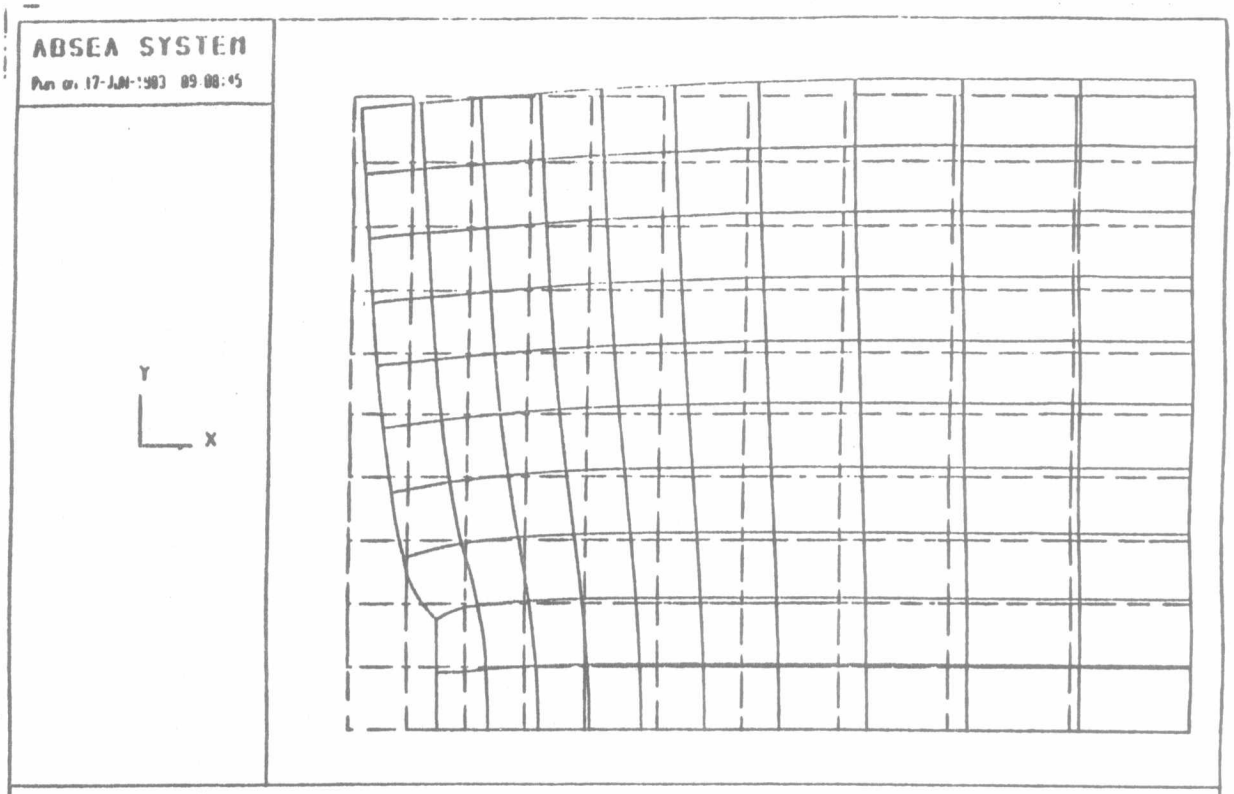

Fig. 2a TWO-DIMENSIONAL PLATE UNDER CENTRAL PUNCH
Uniform Mesh and Elastic Run

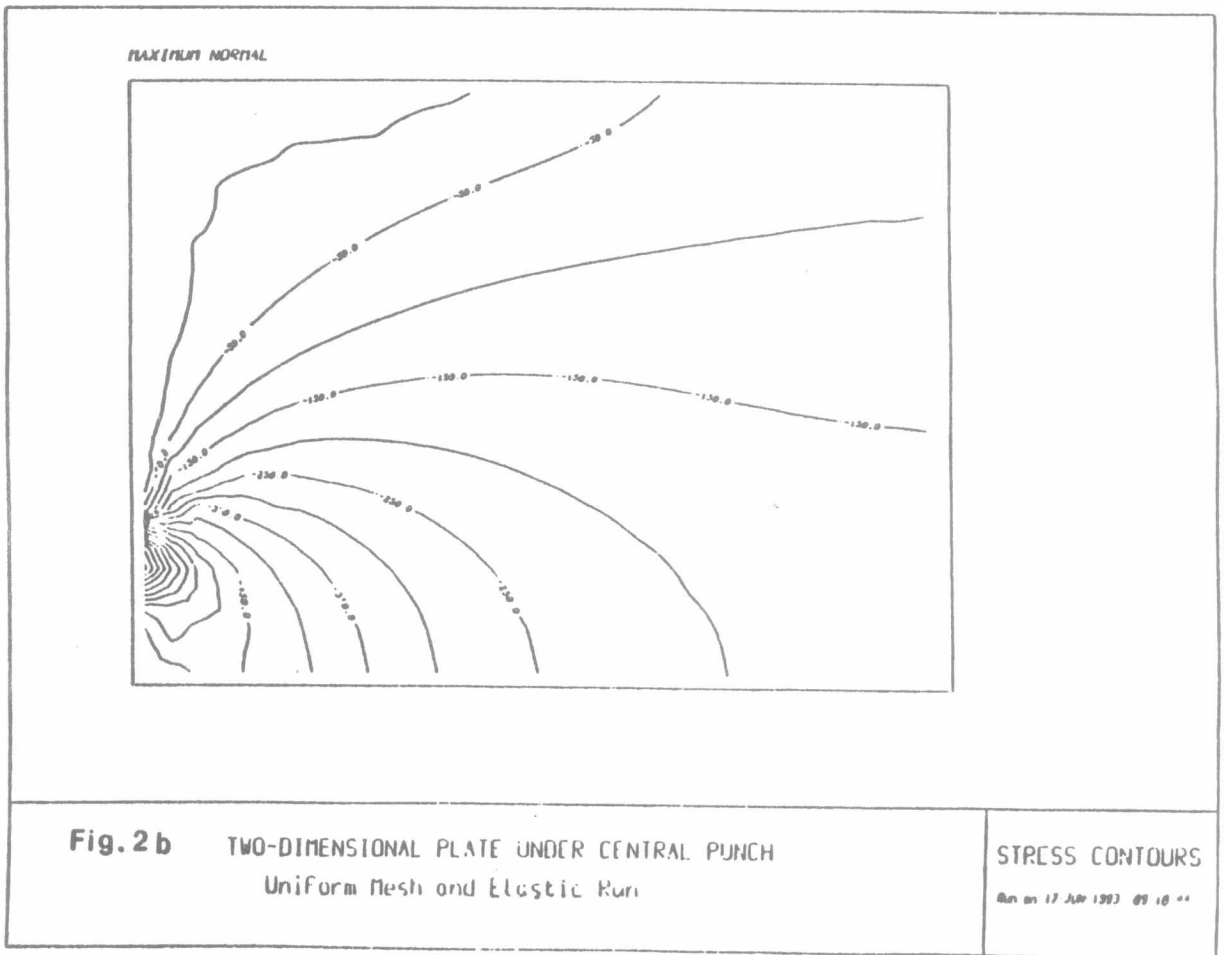

Fig. 2b TWO-DIMENSIONAL PLATE UNDER CENTRAL PUNCH
Uniform Mesh and Elastic Run

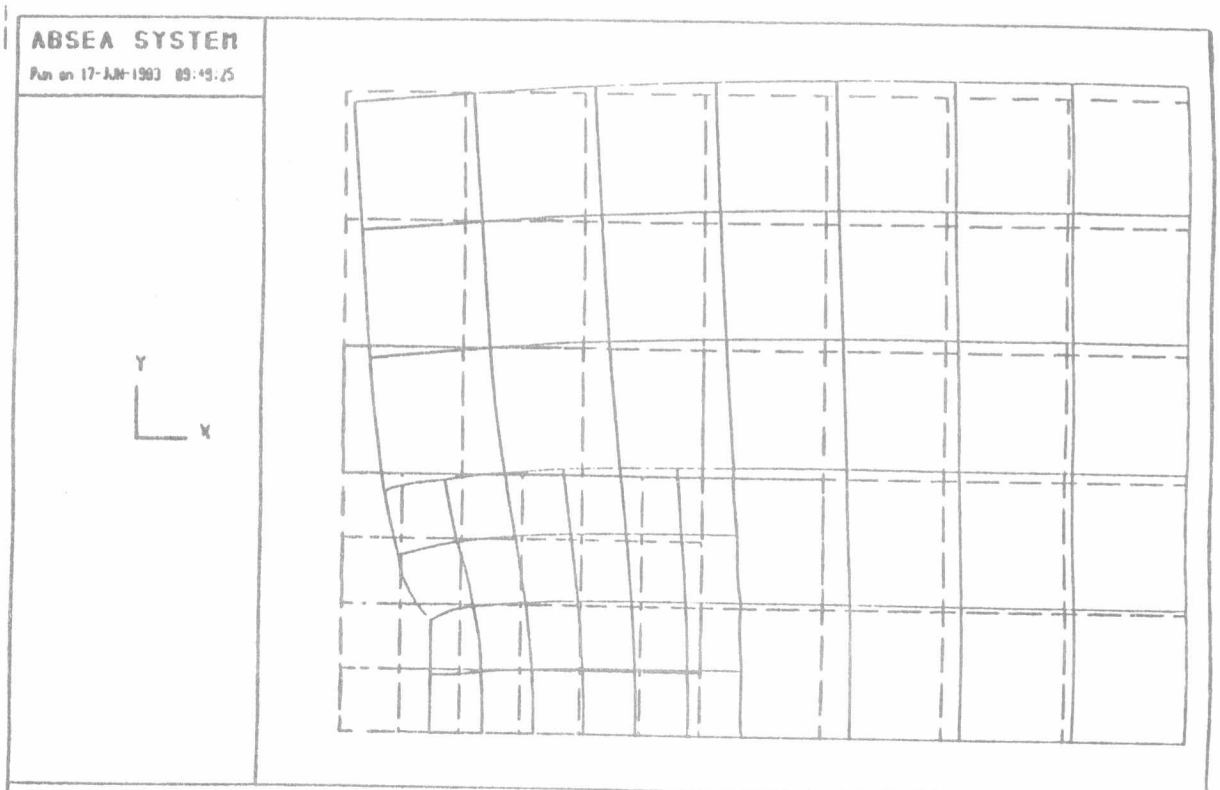

Fig.3a TWO-DIMENSIONAL PLATE UNDER CENTRAL PUNCH
Transitional Element and Elastic Run

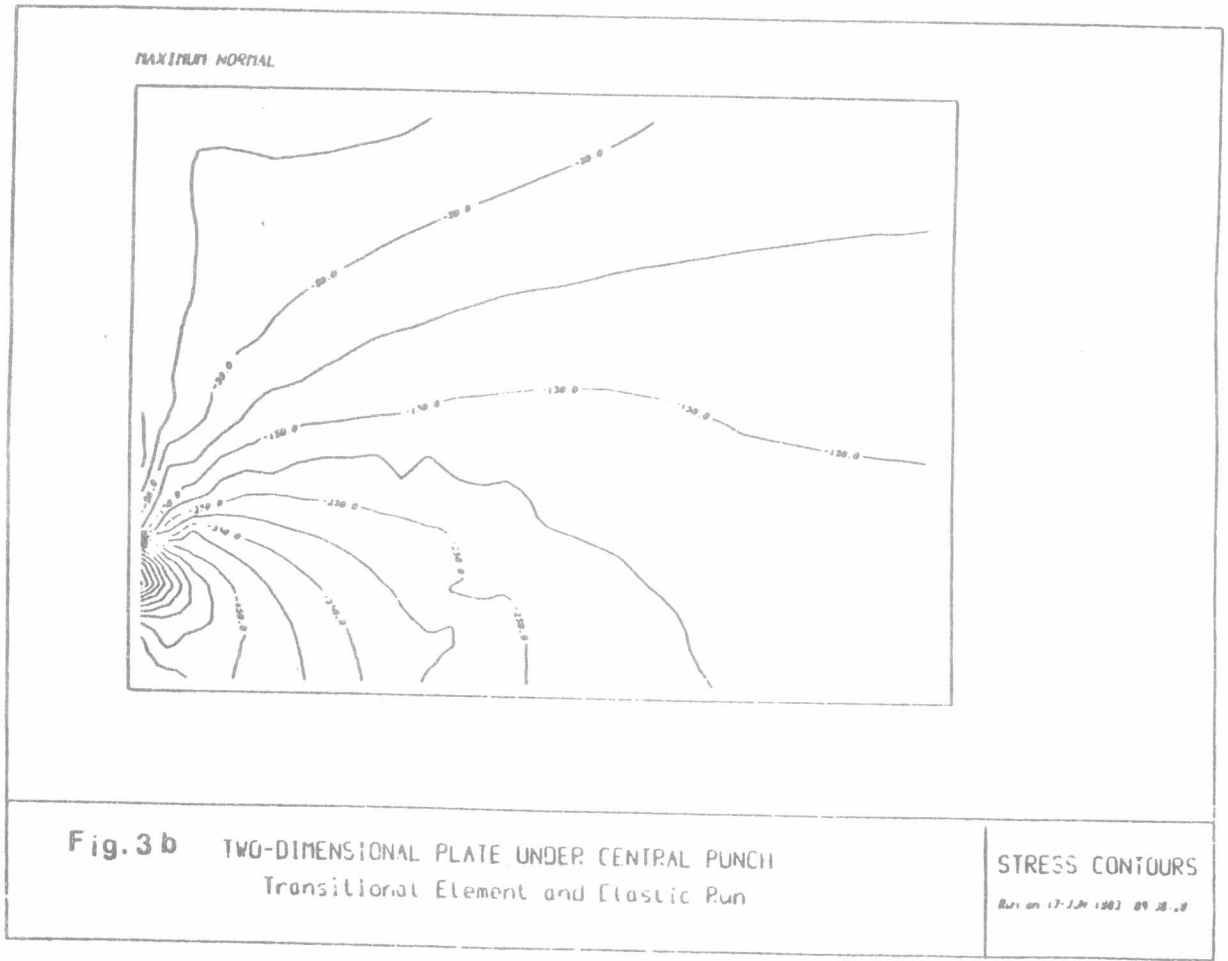

Fig.3b TWO-DIMENSIONAL PLATE UNDER CENTRAL PUNCH
Transitional Element and Elastic Run

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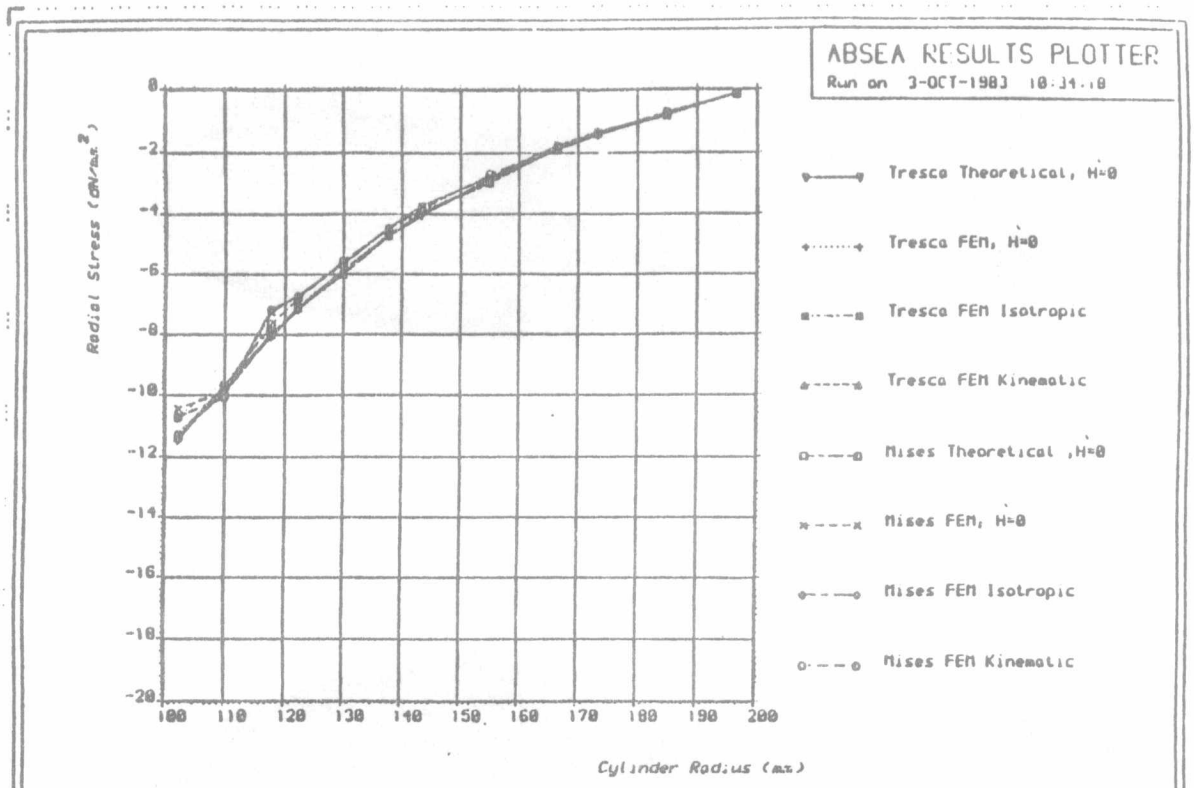


Fig.4a Elasto-plastic Analysis of a Thick Cylinder
Radial Stress Distribution at Pressure=12 (dN/mm^2)

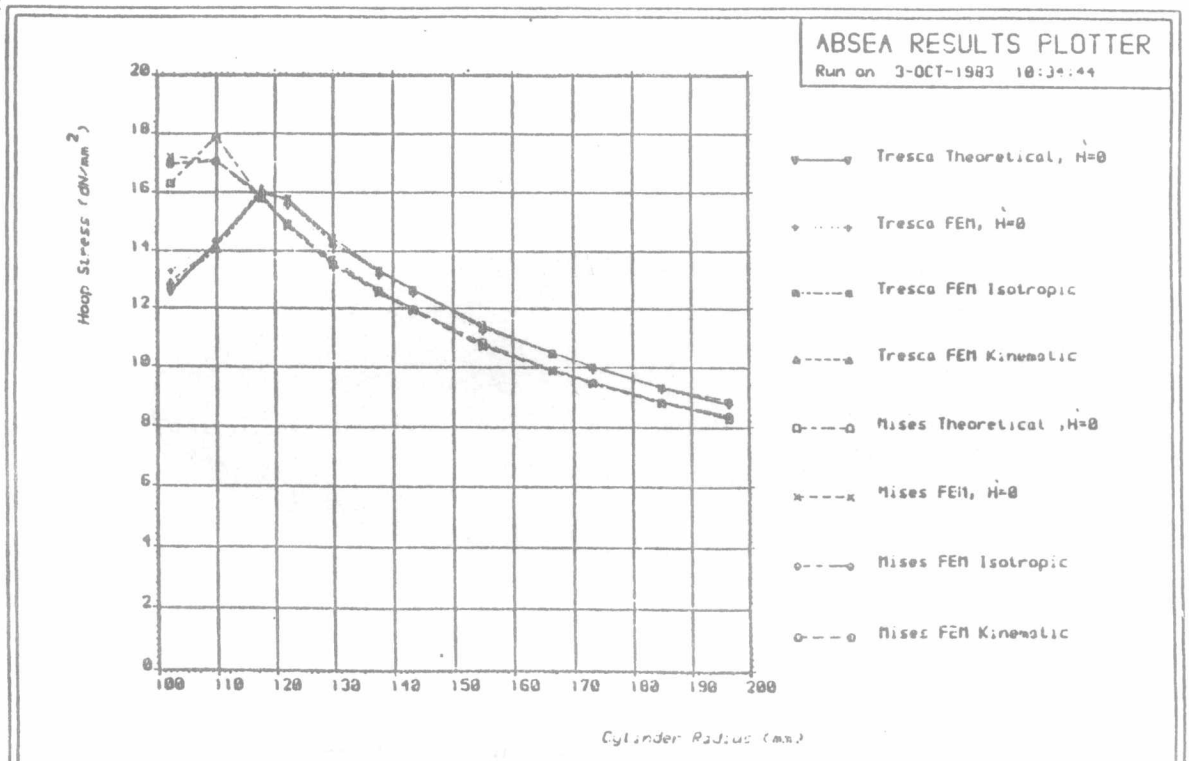
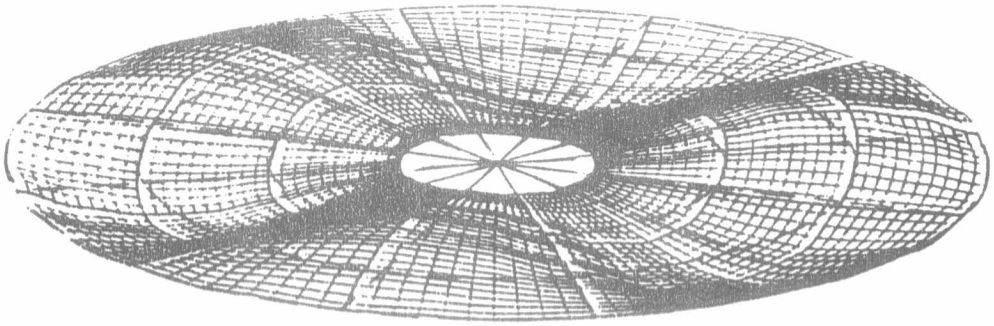
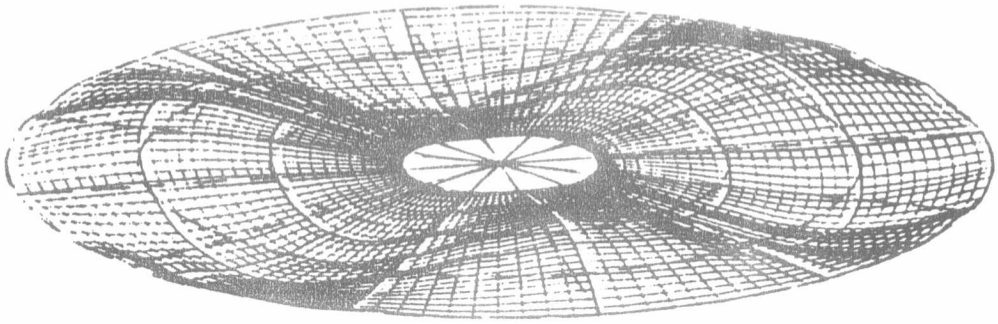


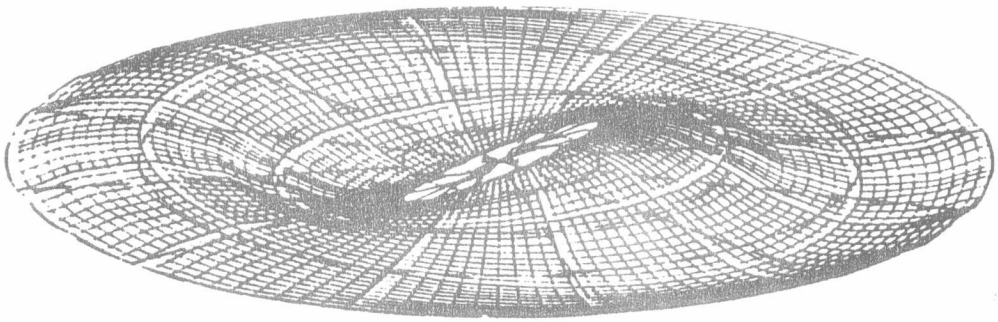
Fig.4b Elasto-plastic Analysis of a Thick Cylinder
Hoop Stress Distribution at Pressure=12 (dN/mm^2)



Mode 7



Mode 8



Mode 9

Fig.5 Mode Shapes of a Simply-Supported Disc Using Mindlin Plate-Bending Element

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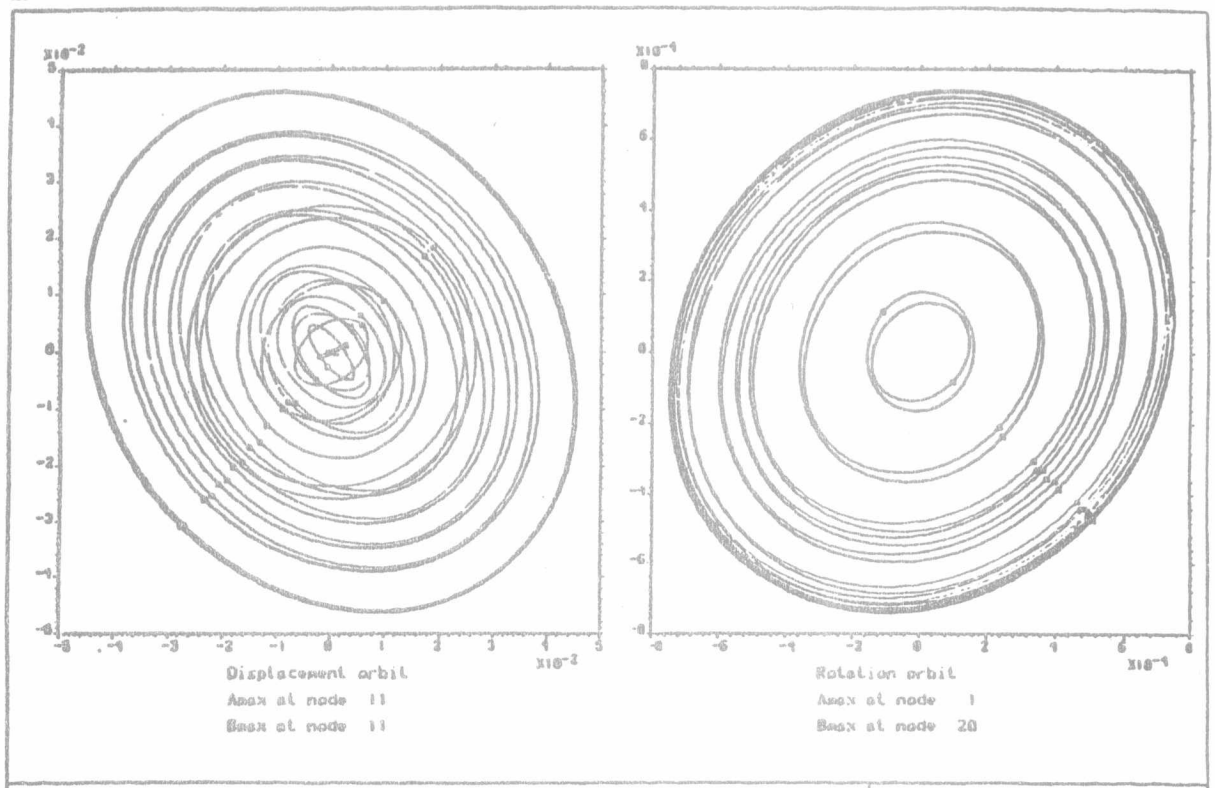

Fig.6 ROTOR DYNAMIC ANALYSIS CASE STUDY

WHIRL ORBIT PLOT
At speed .7000E 2
and all nodes
Run on 22-AUG-1983 15:32:19

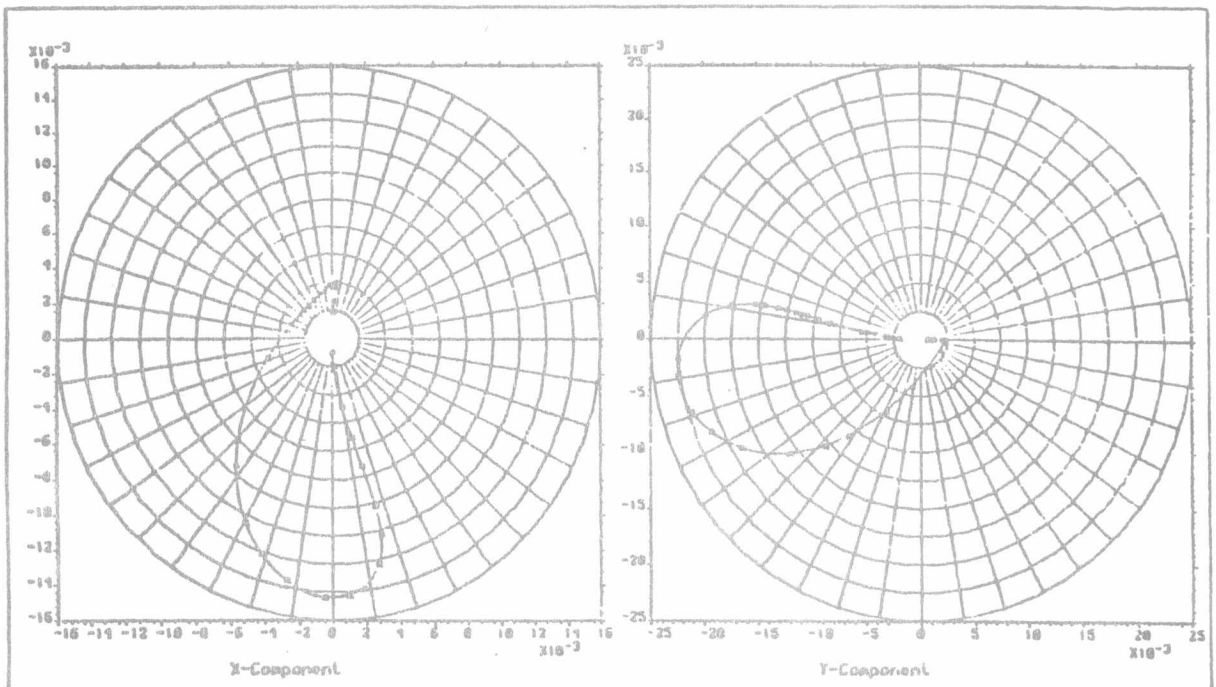

Fig.7 ROTOR DYNAMIC ANALYSIS CASE STUDY

ARGAND POLAR PLOT
Rotation response
At node 3
Run on 22-AUG-1983 15:13:22