APPLICATION OF FINITE ELEMENT METHOD IN ANALYSING GENERATOR BARREL FOUNDATION

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
WATER RESOURCES DEVELOPMENT

By

UMA SHANKAR VIDYARTHI

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

FEBRUARY, 2001

CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in this dissertation entitled **"APPLICATION OF FINITE ELEMENT METHOD IN ANALYSING GENERATOR BARREL FOUNDATION"** in the partial fulfillment of the requirement for the award of Degree of **Master of Engineering** in **Water Resources Development** and submitted in the department of Water Resources Development Training Center of the University, is an authentic record of my own work carried out during a period of July 2000 to Feb. 2001 under the supervision of **Dr. B.N. Asthana,** Emeritus Fellow, WRDTC, **Prof. Gopal Chauhan**, Professor, WRDTC **and Dr. B.K.Mishra,** Assistant Professor, Mechanical and Industrial Engineering, University of Roorkee, Roorkee.

The matter presented in this dissertation has not been submitted by me for award of any other degree.

Dated: February,27 2001

Place: Roorkee

(U.S.Vidyarthi)

This is to certify that the statement made by the candidate is correct to the best of our knowledge.

(Dr. B.N. Asthana)
Emeritus Fellow, WRDTC
University of Roorkee
Roorkee

(Prof. Gopal Chauhan)
Professor, WRDTC
University of Roorkee
Roorkee

(Dr. B.K. Mishra)
Assistant Professor, MIED
University of Roorkee
Roorkee

ACKNOWLEDGEMENT

I express my deep sense of gratitude and indebtness to my guides **Dr. B.N. Asthana**, Emeritus Fellow, WRDTC, **Prof. Gopal Chauhan**, Professor, WRDTC and **Dr. B.K. Mishra**, Associate Professor, MIED, University of Roorkee, Roorkee for their valuable guidance and constant encouragement at every stage of preparation of this dissertation. The valuable hours of discussions and suggestions that I had with them, have really helped in supplementing my thoughts in the right direction for attaining the desired objective of completing the work in its present form.

I respectfully offer my sincere gratitude to Prof. Devadutta Das, Director, WRDTC for providing all possible facilities at the Centre during my study at WRDTC.

Further, I also acknowledge, with thanks the advice and inspiration that I received from other faculty members besides the staff of the WRDTC Computer Lab., Library and office for their co-operation extended throughout the course and dissertation.

I am extremely grateful to my parent department, Central Soil And Materials Research Station, Ministry of Water Resources, Government of India, especially Dr. K. Venkatachalam, Director for giving me this opportunity for undergoing training and higher study in the area of Water Resources Development.

I would like to express my greatest appreciation to my family members especially my son Aditya and wife Kiran and friends for their forbearness during this work.

Finally my special thanks to all co-trainee officers in WRDTC for their suggestions and helps during this work.

(UMA SHANKAR VIDYARTHI)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYNOPSIS

The generator supporting structure has the important function of carrying and transmitting large generator loads to the substructure and then to foundation. As the size of units is increasing, so the size of supporting structure is almost in direct proportion. Therefore it was considered necessary to design the generator supporting structure rationally and economically for which accurate and reliable analysis is required.

As the recent trend is to have two basic type of generator foundations termed as 'barrel' and Arbor' type foundation, the scope of this dissertation is limited to analysis of barrel foundation only. The barrel type foundation is an indeterminate structure due to number of blockouts, recess and discontinuity due to access to turbine pit, the conventional method of analysis is not very rational. It was therefore considered necessary to analyse the barrel foundation by Finite Element Method. The pattern of stress distribution in the barrel foundation is of great concern for safety and economy of a power house, which can be effectively achieved by analysing it by finite element method.

In this dissertation, the stresses have been studied by using three dimensional finite element method. The study is divided into two parts :

Part : I - Analysis of 3-D model without openings.

Part : II- Analysis of 3-D model with openings.

Both model have been analysed for three types of load i.e. tangential load, radial load and vertical load acting individually and all combined. Results of this study which deal with distribution of stresses have been analysed and discussed in this dissertation.

These have been compared with the results of conventional method in case of Chilla Power house.

The study shows that distribution of stress due to tangential load does not follow conventional pattern though they are comparable in magnitude. In conventional analysis maximum and minimum shear stresses occur at outer and inner surfaces of the barrel respectively. But analysis by FEM shows that maximum shear stress occurs in a central annular ring in which stator pedestals are located.

In radial loading, there is considerable value of longitudinal stress (tensile or compressive), though it is concentrated at the base plate edge indicating edge effect only. The stresses due to vertical load have not been distributed uniformly at the base. It is therefore concluded that in case of very small L/D ratio, barrel does not behave like a cylinder and it should be designed as pedestals with adequate edge effect.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Hydropower generation is the conversion of the potential energy of the usable water resources and about one quarter of the world's power requirement is at present produced in this way. A hydropower scheme may form part to any water resources program as it is non-consumptive use of water and therefore is economical. It is eco-friendly, non polluting and has inherent advantage of meeting peak demands.

A hydropower plant mainly consists of a prime mover working on potential energy of water, to which a generator is coupled to generate electricity. Water power stations generally use three phase A.C. generators, delivering their output to an electric power transmission system. Due to remarkable progress over the last 40 years in the generator cooling system, availability of higher tensile steel for rotor rim punching and improvement in mechanical design, it has been possible to considerably increase the individual generator capacity.

As the size of units is increasing, the size of supporting structure increases almost in direct proportion. In India units of 165 MW are in operation and 250 MW generators are being installed at Nathpa Jhakari and Tehri Power Plants. In other developed countries units as big as 800 MW are in operation.

The generator foundation has to perform important function of carrying and transmitting large generator loads (vertical, tangential and radial forces) to the foundation through the sub-structure. Therefore, it is necessary to design the generator supporting structure rationally and economically for which accurate and reliable analysis is required. The recent trend is to have either of the two basic type generator foundations termed as 'Barrel' and 'Arbor' type foundation.

1.2 NECESSITY OF FINITE ELEMENT METHOD

The Barrel type foundation is an indeterminate structure due to number of block outs, recess and discontinuity due to access to turbine pit, the conventional method of analysis is not very rational. It has therefore been considered appropriate to analyse the barrel foundation by finite element method which has become a powerful tool for numerical solution of a wide range of indeterminate structural problems. Although finite element method has been in practice for a long time, but its use was limited due to complexity involved in solving complex equations. Now with advances in computer technology, complex problems can be modeled and analysed with relative ease. In this method of analysis, complex region defining a continuum is discretized into simple geometric shapes called finite elements. The material properties and the governing relationships are considered over these elements and expressed in terms of unknown values at element corners called nodes. An assembly process, duly considering the loading and constraints, results in a set of equations. Solution of these equations gives us approximate but realistic behavior of the continuum. It is possible to analyse the barrel foundation by using finite element method which is very versatile and some of the advantages of this method are:

- Good accuracy and reliability of the stress and displacement results when used idealized mathemetical model properly.

- The ability to modify loading and / or boundary conditions and material properties and quickly determining the effect of the changed conditions.
- The ability to analyse quickly the effects of change in shape.

For the above reasons, FEM analysis has been adopted in this study to find the stress distribution in generator barrel foundation

1.3 OBJECTIVE AND SCOPE OF STUDY

Since barrel foundation is the most common type of generator supporting structure, it is aimed in this dissertation to analyse a generator barrel foundation by finite element method and to compare the results with the conventional method.

The generator barrel has been analysed for the following three major loads only:

(a) Torsional load due to short circuit in stator winding

(b) Vertical loads

(c) Radial Loads due to one sided magnetic attraction.

Change in stress pattern due to opening is also aimed to be analysed in this dissertation.

1.4 ORGANIZATION OF DISSERTATION

The study is presented in this dissertation in 6 Chapters. The contents of each chapter are briefly indicated below:

In chapter -2 generator and generator barrel has been described.

In chapter –3 loads and load combinations have been discussed.

In chapter – 4 methodology of FINITE ELEMENT has been described.

In chapter – 5 conventional analysis in case of Chilla power house has been done and parameters for 3-D FEM analysis are also given..

In Chapter – 6 Results of FEM analysis have been presented and discussed. Conclusions of the study along with suggestions for further study have also been given.

CHAPTER – 2

GENERATOR AND GENERATOR FOUNDATION

2.1 GENERATOR

The mechanical power output of the turbine is transformed into electric power by the generator. The two main parts of the generator are the field windings and the armature. If one of them is displaced relatively to the other by means of introducing mechanical power, an electromotive force (e.m.f.) will be induced in the armature windings as a consequence of the intersection of conductors and magnetic flux lines. The mechanical energy, to be expended for the rotation of the armature or of the exciting field windings, is transformed into electric energy to be utilized in consumer circuits connected to the generator. Generators employed in hydro electric power stations have a rotating exciting field, the exciting field windings performing a rotating movement, with the armature remaining stationary. The former, carrying field windings, is also called the rotor while the latter is the stator.

2.2 GENERATOR ARRANGEMENT

A hydro generator consists mainly an armature known as stator and a field coil known as the rotor. While the stator rests directly on the foundation, the weight of rotor is transmitted through the thrust bearing. In order to keep the common shaft of turbine and rotor vertical, which is the most common arrangement for hydro generators, guide bearings are introduced.

2.2.1 Stator Housing

The stator housing is manufactured generally of welded construction. The vertical type stator frames of large size units have an exceedingly large outside diameter. Limitation on the dimension and weight imposed by transport considerations make it necessary to sometime build the stator housing in sectors. The sectors are usually 2 to 8 in numbers. With vertical machines the housing is generally mounted on feet which must transfer the weight to the foundations and which are grouted into the foundations. Some times, a foundation ring is also used to support the stator

The stator housing must have a margin of expansion in the radial direction as its diameter will expand with increase of temperature during operation.

2.2.2 Stator Mantle

To protect the windings as well as the rotating parts, the stator is provided with a sheet steel mantle, which is stiffened by ribs, in order to damp the vibrations and to reduce noise. The mantle is made in sections and can be dismantled easily. Covered ports are provided for inspection facilities.

2.2.3 Rotor

The design of the rotor is determined by the power of the generator, the normal and runway speed, and the flywheel effect. The rotor consists of a shaft, spider rim and the poles as well as the ventilators and slip rings. With high speed machines the spider is sometimes omitted by mounting the rotor rim directly on the shaft. The two basic methods of rotor construction are punched segmental rim type or solid disc type. The stator and rotor and its components are shown in Fig.2.1. In this case the thrust bearing is placed below rotor.

2.2.4 Shafts

Shafts are made of forged steel of good quality. They are built in one body and a forged flange to couple the rotor with the water wheel. They are designed to have a diameter not only big enough to transmit the driven torque but also to be in proper size to permit rotor to have a higher critical speed than the run away speed of water wheel. Hollow shafts and welded shafts are now a days being used for large size machines to eliminate forging of shafts. In case of long shafts, shaft is divided into the parts and coupled by a flange. The shaft lengths are provided as bare necessity for accommodating the thrust and guide bearings and a working space.

2.3 BEARING ARRANGEMENT FOR VERTICAL UNITS

Vertical units are normally used with medium and high head plants. They have two or three guide bearings and a thrust bearing which is combined, where possible, with a guide bearing. The main types of bearing arrangements are shown in fig.2.2

The arrangement in Fig.2.2a shows the conventional design with three guide bearings and a thrust bearing in the upper bracket. At one time it was exclusively employed arrangement because the thrust bearing was considered to be the most vulnerable part of the unit and, therefore, had to be placed such that it could be easily dismantled. It is still suitable for high-speed sets where space between the generator and turbine is so restricted that it is impossible to place the thrust bearing under the generator.

The arrangement in Fig. 2.2b is a variation of the arrangement shown in Fig. 2.2a. In this arrangement there are two guide bearings. The guide bearing is placed below the

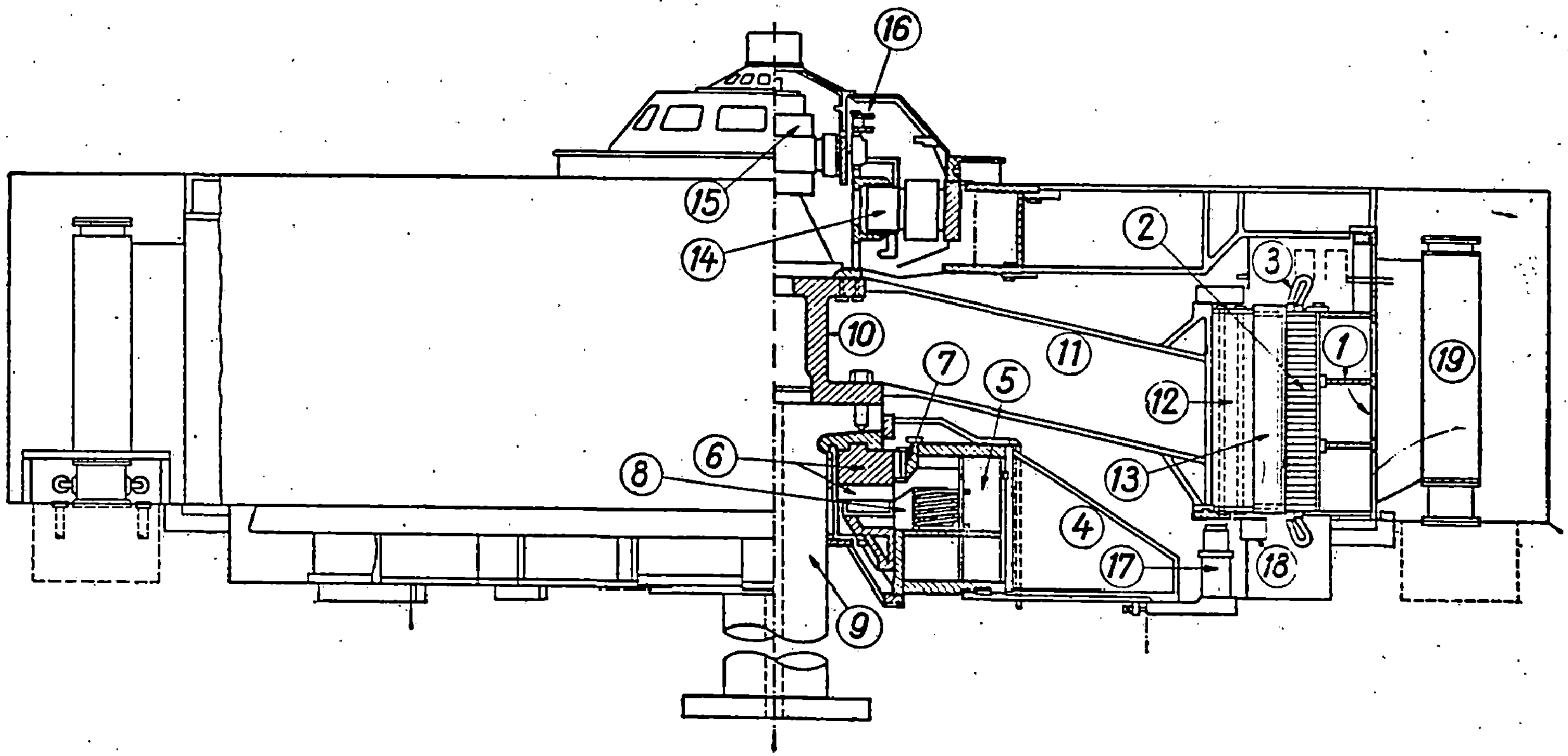


Fig. 2·1 A vertical-type generator (*Westinghouse Electric Corp.*) : *1* — stator case, *2* — stator core, *3* — stator windings, *4* — spider, *5* — oil tank, *6* — thrust bearing, *7* — guide bearing, *8* — oil cooler (coil type), *9* — shaft, *10* — rotor hub, *11* — rotor arm, *12* — rotor rim, *13* — pole, *14* — exciter, *15* — pilot exciter, *16* — slip ring, *17* — brake, *18* — cooling blower, *19* — air cooler. (After *R. A. Hopkins*, in *Hydroelectric Handbook* by *W. P. Creager* and *J. D. Justin*)

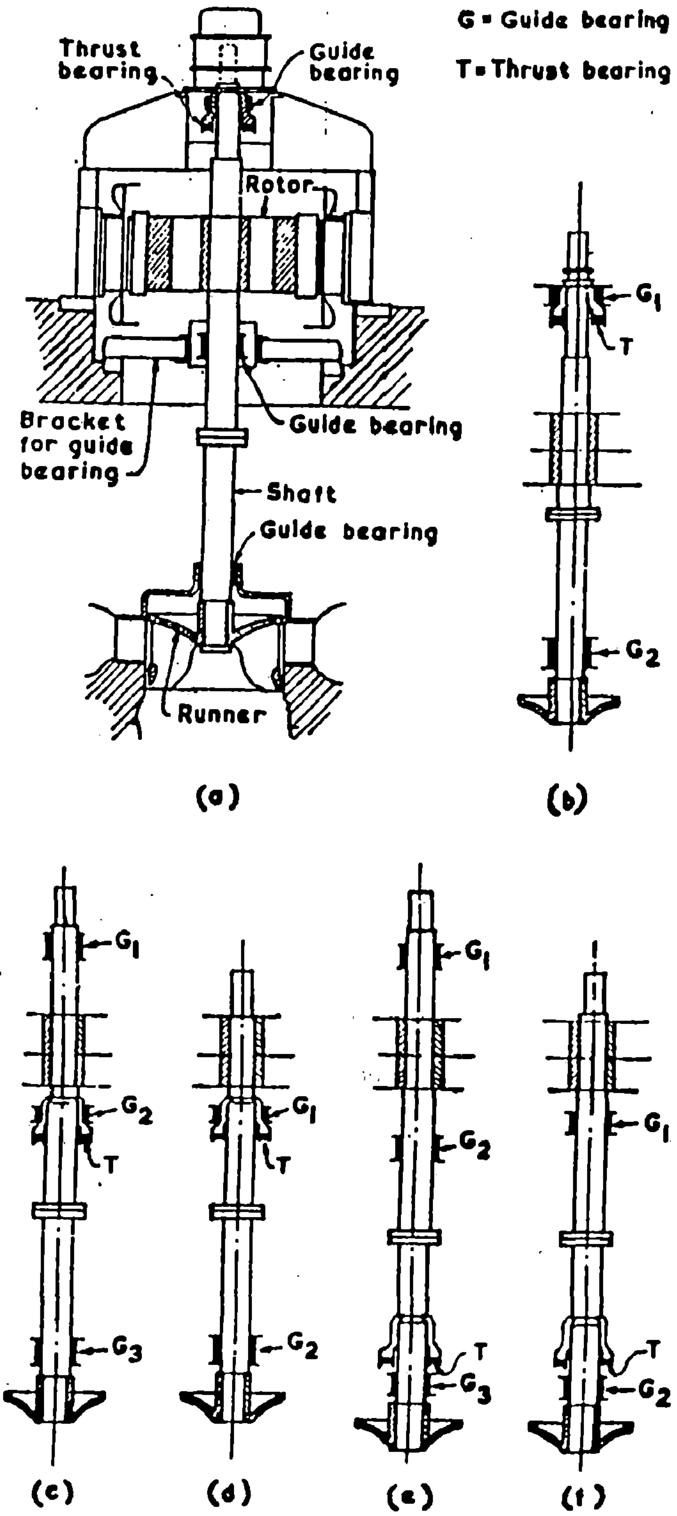


Fig.2.2 Bearing arrangements for vertical hydrogenerator units

rotor and in consequence the lower bearing bracket is dispensed with. The arrangement is employed for restricted station heights, but has the disadvantage that the generator cannot be run with the turbine uncoupled as, for example, for test purposes.

Since thrust bearings of present design are just as any other component of hydro-electric set, they can now also be placed under the generator.

Fig.2.2c shows an arrangement with three guide bearings in which the thrust bearing is in the lower bearing bracket. This arrangement is frequently preferred for comparatively slow-speed sets with large diameters, i.e. in cases where space conditions permit easy access to the thrust bearing. The upper bearing bracket, in which only the upper guide bearing is fitted, can be made much lighter while only the lower bracket, which is in any case designed to carry the weight of the rotating parts of the generator and turbine when dismantling, has to be slightly reinforced to withstand the thrust of the turbine. As a rule, the span of the lower bearing bracket is smaller than that of the upper bracket, which is also an advantage. Since, moreover, the stator frame can be made somewhat lighter the entire weight of the generator is reduced, if only slightly.

The umbrella type of construction shown in Fig. 2.2d, has two guide bearings with the thrust bearing in the lower bearing bracket. The name "umbrella type" results from the fact that, in order to lower the centre of gravity, the rotor arms are inclined downwards thereby giving the rotor the appearance of an umbrella. With the latest Kaplan turbines the oil supply head is no longer used; the control oil is led to the servo-motor located in the rotor hub over the generator guide bearing. In such cases it is desirable not to mount the exciter directly on the shaft since commutation may suffer and running may possible become noisy. Separate exciter units are preferred which make an umbrella type generator without any superstructure. Since the upper bearing bracket is entirely dispensed with and since moreover, the generator only needs a light weight housing, the weight reduction here is considerable.

The arrangement in Fig.2.2e shows three guide bearings with the thrust bearing mounted on the turbine cover. This arrangement is being increasingly used for slow-speed units since it offers advantages from the point of view of the entire unit. The turbine cover is, in any case, very strong and need only be slightly reinforced to take the load of the thrust bearing. In the case of the generator, the two bearing brackets and the stator frame can be of lighter construction so that the weight of the unit is considerably reduced. A substantial saving can be achieved where the foundations of the unit are concerned since a major part of the load is supported where it is produced, i.e. in the turbine.

For the arrangement in Fig.2.2f, which again represents the umbrella type of construction with the thrust bearing on the turbine cover, the same remarks apply as for the arrangement in Fig.2.2d. The advantages with respect to the weight of the set and the foundations are naturally the same as for the arrangement in Fig.2.2c.

When the thrust bearing is fitted in the upper or lower brackets it is combined with the corresponding guide bearing to form one single unit. The advantages of self-lubricating bearings, now also employed for the largest units at the highest speeds, are particularly pronounced here. With this construction, it is of course, absolutely necessary that the thrust bearing be supplied with the generator since only in this way can the most favourable design be achieved.

2.4 EFFECT OF THE GENERATOR CONSTRUCTION ON THE SUPPORTING STRUCTURE

The generator supporting structure has the function of transmitting the large vertical downward loads and tangential and radial forces along with seismic forces to the foundation concrete without exceeding the strength of concrete.

In the vertical shaft generating units, with the thrust bearings in the upper bracket, the weight of the stationary part and the weight of the rotating parts are carried by stator frame and its supports. But in case of units with thrust bearing in the lower bracket, the weight of rotating parts including the turbine runner is carried by a separate bearing support and only a small load viz, the weight of stationary parts of generator are carried by the stator support. The peripheral short circuit torque on the stator is transmitted, in either case from stator frame to its supports . In case the thrust bearing is located on the turbine cover the upper bracket will carry only the weight of the stationary parts of the generator. The weight of rotor, runner and hydraulic thrust will be taken by the turbine cover.

The height of the generator support will be considerably reduced in the case of the umbrella type as the shaft length is smaller.

The generator diameter and height also affects the overall dimensions of the generator supporting structure.

2.5 TYPES OF GENERATOR SUPPORTING STRUCTURES

Generally two basic types of generator foundations are currently used. They are termed as "barrel" and "arbor" foundations. Both types of foundations have advantages and disadvantages.

2.5.1 The Barrel Foundation

The barrel foundation is the more common type in use and has the arrangement shown in Fig.2.3. It has the advantages of permitting a lower generator setting and more space outside the turbine pit. It is structurally indeterminate because of equipment openings and recesses required as well as because of discontinuity caused by passage ways in the turbine pit.

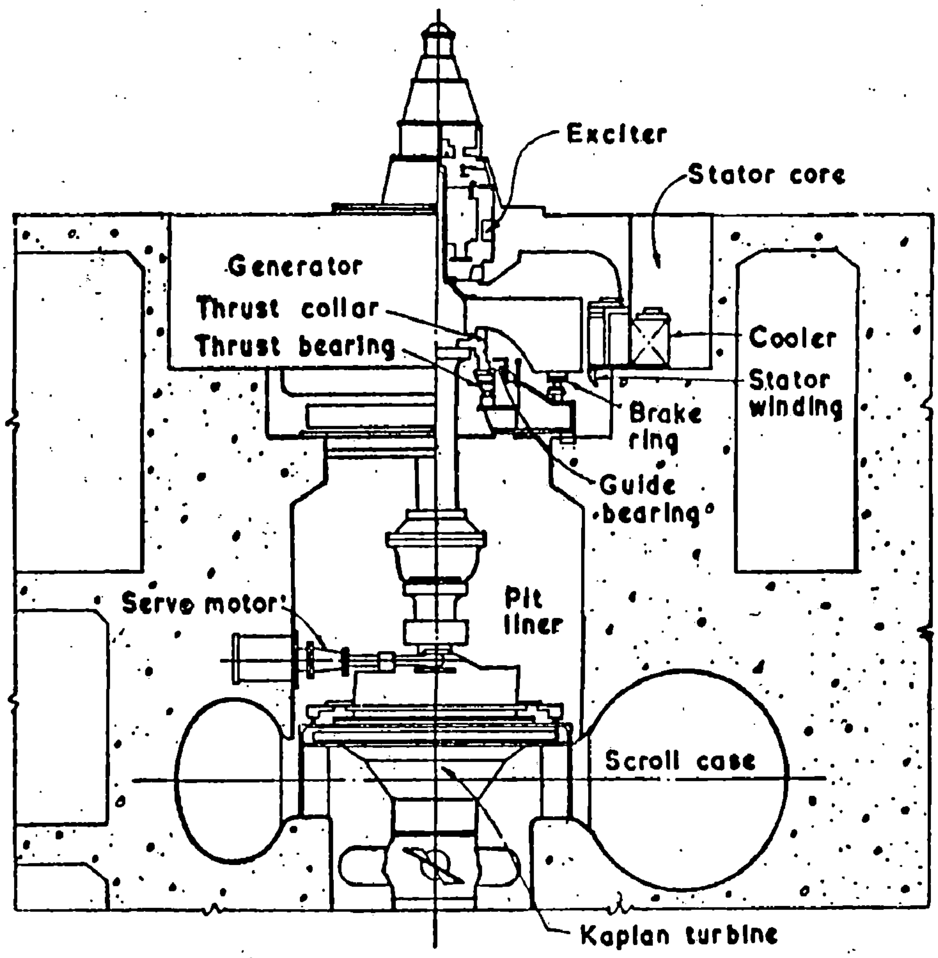


Fig. 2.3 Concrete barrel type foundation

The maximum barrel thickness is usually determined by the difference between the radii of the generator housing and turbine pit. The minimum thickness is the difference between the radii of stator sole plate and the turbine pit.

2.5.2 The Arbor Foundation

The arbor foundation is a more comprehensive structure of structural elements. Since the two longitudinal wall girders can span across the spiral case and thereby permit a determinate analysis. The horizontal girders spanning between the wall girders complete the foundation. As some generator foundation plates must be located on these horizontal girders, the generator setting is necessarily higher than that with a barrel foundation. However, when the plant is subjected to a higher water surface above the generator floor or if it is desired to provide for the removal of the turbine runner in a longitudinal gallery above the spiral casing, the arbor foundation affords a means of structural planning which is superior to barrel foundation with no increase in cost. The typical arbor type arrangement is shown in Fig 2.4.

The wall thickness for the arbor foundation is found in a manner similar to the barrel foundation. The horizontal girder must be designed to minimize any deflection at the generator sole plates.

2.5.3 Floor System

The generator support system may be divided into the single floor system, the double floor system and the multi-floor system; of these the two former systems are ones which are more commonly used.

The double floor system, in which the generator floor is separated from the turbine floor may be sub-divided in the beam and arch types. In the beam type, two pairs of columns are constructed, horizontal beams are fixed to the columns to support the generator as shown in Fig.2.4. In arch type, two pairs of large columns are erected in the direction of the power house at right angles to the penstock, on which two arches are built to support the generator.

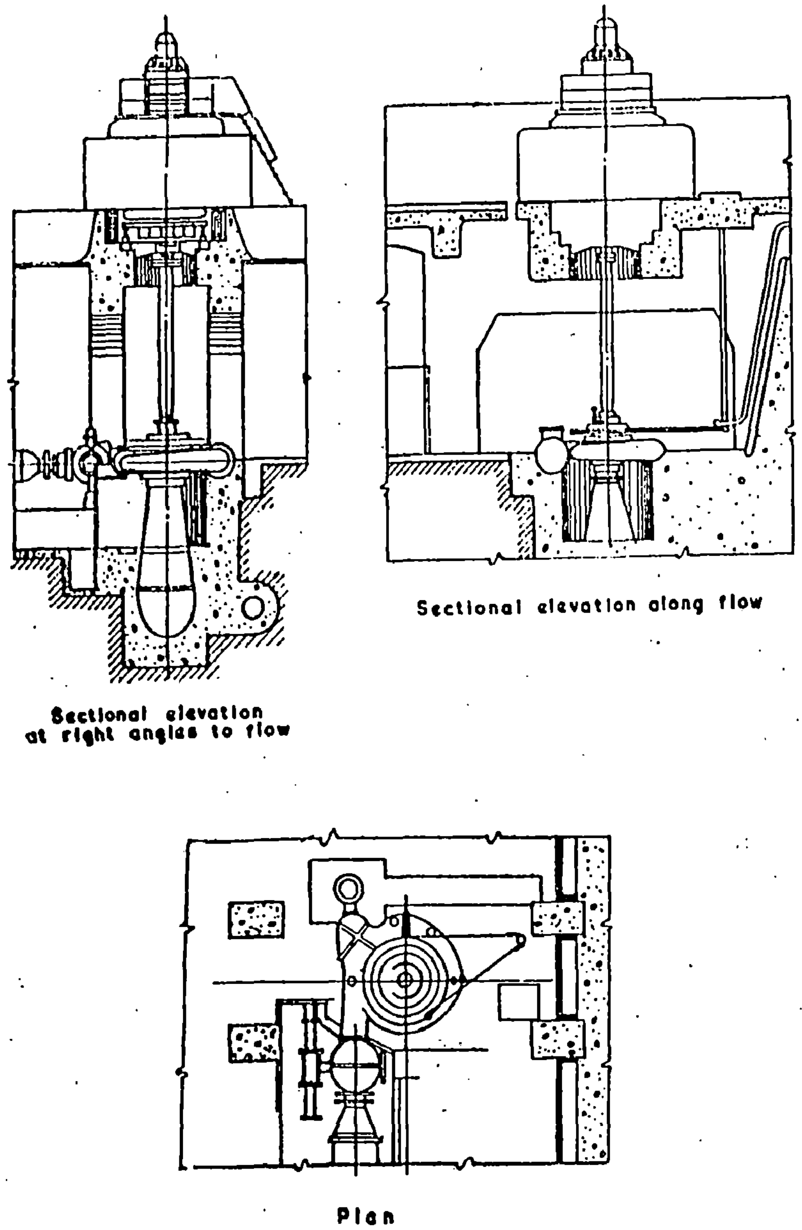


Fig. 2.4 A generator support of rigid frame type

As the turbine capacity increases it becomes progressively difficult for the generator floor to support the weight of stationary parts of the generator as well as the downward thrust on the thrust bearing caused by the weight of the turbine, the generator rotating parts and the hydraulic thrust on the runner. It then becomes more suitable to use the single floor system and to support the load directly on the power house substructure through the side of the turbine casing and the stay vanes of the speed ring.

The single floor system is of the barrel type and may be of concrete or steel. A steel barrel is fixed on the speed ring as shown in fig. 2.5 and supports the weights of stator and the guide bearings, while the weight of the thrust bearing is transmitted to the turbine cover. Sometimes, the steel barrel is supplemented by reinforced concrete encasing it. Here the thrust bearing rests on the turbine cover, the diameter of which is less than that of upper generator bracket and of the stator frame. It, thus, reduces both the cost and weight of the generator as well as the height of the power house by reducing the length of main shaft.

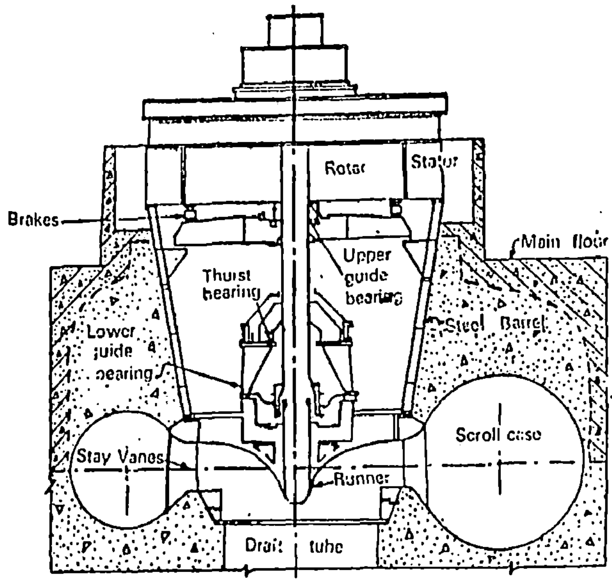


Fig. 2.5 Steel barrel supporting a generator

In another arrangement steel barrel is reinforced with concrete to make it rigid against torsion. The concrete is supported by vertical ribs distributed round the periphery of scroll case. The vertical ribs not only support the main floor but also help in connecting the barrel to the mass concrete. By this arrangement a considerably large quantity of concrete can be saved.

In case of concrete barrel type of floor the weight of the guide and thrust bearings and of stator is taken by the concrete barrel directly which is acted upon by torques from the short circuit and braking also.

In the single floor type of support it was at one time considered difficult to assemble and dismantle the turbine separately from the generator. However, recent advances have made it possible to dismantle the runner from the turbine without dismantling the generator.

In single floor system, concrete barrel type foundation is most common and most frequently used for supporting the vertical shaft generators, while in double floor system frame structure made of columns or walls and horizontal beams is more commonly used.

CHAPTER –3

GENERATOR LOADS AND FORCES

3.0 GENERAL

The loads and forces which are considered for designing a generator foundation are discussed in this chapter. All these loads may not be applicable in the design of every generator foundation. Any other load due to any particular foundation arrangement and recommended by the generator manufactures shall also be considered. The design is generally finalized through close coordination with the manufactures and electrical and mechanical engineers.

3.1 VERTICAL LOAD

Vertical loads may comprise the following

a) Dead load from civil works

b) Live loads on floors transmitted to the generator foundations

c) Vertical load on stator sole plate (shown as P1 in fig.3.1 and 3.2) which may comprise the following.

   i) weight of permanent magnet generator

   ii) weight of pilot and main excitor

   iii) weight of thrust bearing, rotor, shaft, turbine, rotating parts and hydraulic thrust(if thrust bearing is above stator).

   iv) Weight of top guide bearings

   v) Weight of top bracket, stator flooring and stator

vi) Any other load due to equipment on the generator foundation recesses in the pit, linear housing gate operating servo-motor etc.

d) Vertical loads on lower bracket (shown as P4 in fig. 3.1 and 3.2) which may comprise the following:

i) weight of lower bracket, brakes and jets.

ii) Load while lifting the rotor on jacks

iii) Weight of thrust bearing, rotor, shaft, turbine rotating parts and hydraulic thrust (if thrust bearing is below rotor).

Weight of high powered vertical shaft hydro-generator may be calculated by the the following empirical approximate formula:

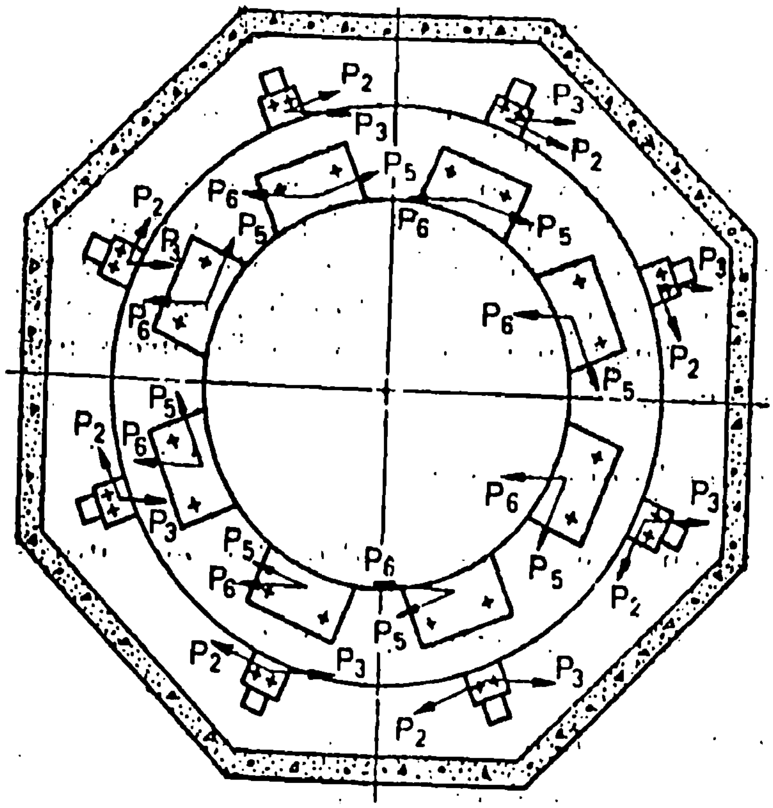
$$W = G\sqrt{\frac{k}{n}} - 85 \text{ (tonnes)}$$

where n = speed in rpm

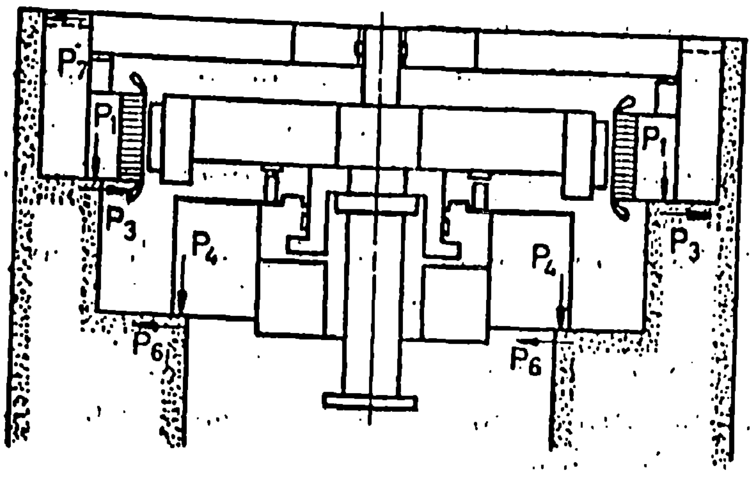
k = apparent generator power in KVA.

G = coefficient having a value between 25 and 32 according to design and construction of the generator. For high capacity low speed machines the coefficient G may be smaller, not more than about 20.

The weight of the revolving part in a vertical-shaft generator (including appropriate section of main shaft) will amount to 50-55 percent of total generator weight 'W'.



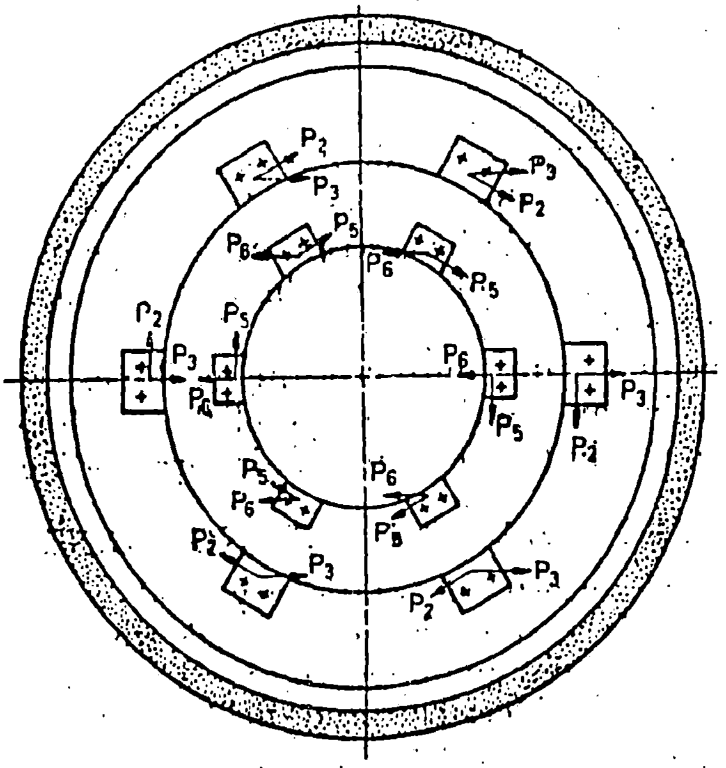
PLAN



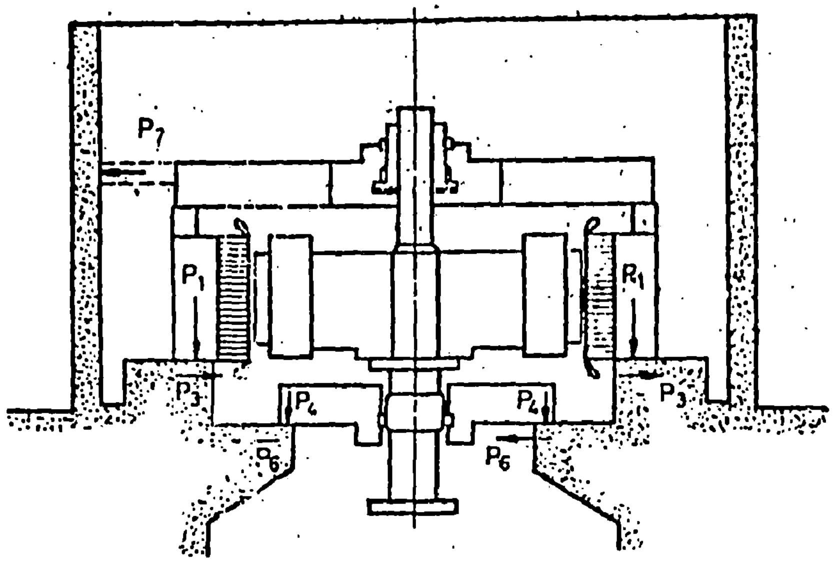
SECTIONAL ELEVATION

P_1 = vertical force on stator sole plate
P_2 = tangential force on stator sole plate
P_3 = radial force on stator sole plate (direction assumed; may act in any direction in horizontal plane)
P_4 = vertical force on lower bracket sole plate
P_5 = tangential force on lower bracket sole plate
P_6 = radial force on lower bracket sole plate
P_7 = radial force on R. C. C. generator housing (present only if bracing provided between housing and top bracket)

Fig.3.1 R.C.C. Octagonal generator foundation with combined thrust and guide bearing located below the stator



PLAN



SECTIONAL ELEVATION

P_1 = vertical force on stator sole plate

P_2 = tangential force on stator sole plate

P_3 = radial force on stator sole plate (direction assumed; may act in any direction in horizontal plane)

P_4 = vertical force on lower bracket sole plate

P_5 = tangential force on lower bracket sole plate

P_6 = radial force on lower bracket sole plate

P_7 = radial force on R. C. C. generator housing (present only if bracing provided between housing and top bracket)

Fig.3.2 R.C.C circular generator foundation with thrust bearing on top of

3.2 TORSIONAL LOAD

It may comprise the following: -

a) Maximum tangential force at the sole plate due to short circuit in the stator winding (shown as P2 in fig.3.1 and 3.2), and

b) Tangential force at lower bracket sole plate due to braking (shown as P5 in fig.3.1 and 3.2).

The torque developed under normal operating conditions may be expressed with sufficient accuracy by

$Tn = K/n$

where

Tn = the torque under normal operating conditions in tonne.metres (t.m).

K = the output of machine in kilowatts

n = the speed of the machine in rpm.

The short circuit torque of low speed hydro generators may be expressed under average conditions by

$Ts = 5Tn = 5K/n$

where,

Ts = the short circuit torque in t.m.

The braking torque Tb in t.m can be expressed by

$Tb = [GD^2/ 374] \times n/t$

where,

G = the weight of the rotating masses reduced to the rotor circumference in tonnes

D = the diameter of the fly wheel or rotor in metres

t = total deceleration time in seconds.

It can be stated, in general Ts is much greater than Tb. This means that design twisting moment is equal to short circuit torque Ts. This value therefore should be asked from manufactures accurately for final design.

3.3 RADIAL FORCE

It may comprise the following

a) Radial force on stator sole plate/ R.C.C generator housing due to one sided magnetic attraction (shown as P3 in fig.3.1 and 3.2) and

b) Radial force on lower guide bearing due to one sided magnetic attraction (shown as P6 in fig.3.1 and 3.2).

The value of this force shall also be obtained from manufacturers.

3.4 FORCE DUE TO ECCENTRICITY IN ROTATING PARTS

Although each generator should be well balanced, yet certain unbalanced forces caused by the fact that the centre of gravity of rotating parts may not exactly coincide with the axis of rotation may induce vibrations, should be accounted for in the design of foundation in consultation with the manufactures.

3.5 SEISMIC FORCES

The generator foundation should be designed for a suitable seismic coefficient (IS 1893-1984) depending on the zone in which the power plant is located. This seismic coefficient should be applied in any of the horizontal direction taken one at a time and in combination with loads established under 3.1 to 3.4

A vertical seismic coefficient of half the values of the horizontal seismic coefficient may be used simultaneously with the horizontal one.

In case of underground power house, reduction in the seismic coefficient by 50% is allowed till definite information about reduction is established.

In case generator foundation is in seismic zones, the sole plate for stator and bottom bracket shall be anchored not only vertically and transversally but also radially.

3.6 FORCES DUE TO TEMPERATURE AND SHRINKAGE

Forces due to temperature variation and shrinkage in generator foundation shall be taken as the difference of temperature developed during the machine in action from that of average surrounding temperature. Since clear reference points of temperature grades cannot be given, a temperature rise of 20^0C is to be assumed for reinforced concrete from which the stresses due to shrinkage can be deducted.

The stresses due to shrinkage is determined on the assumption that it undergoes a temperature fall of 10^0C.

CHAPTER – 4

FINITE ELEMENT METHOD

4.1 BASIC CONCEPT

The basic idea in the finite element method is to find the solution of a complicated problem by replacing it by a simpler one. Since the actual problem is replaced by a simple one, we generally find by FEM only an approximate solution rather than the exact solution. The existing analytical methods of analysis are generally not adequate to give exact solution (and sometimes, not even an approximate solution) to most of the practical problems. Thus, in the absence of any other convenient method to find even the approximate solution of a given problem, we have to go for the finite element method. Moreover, in the finite element method, it is often possible to improve or refine the approximate solution by putting in more computational effort.

In finite element method, the solution region is considered as built up of many small interconnected sub-regions called finite elements. In each element, a convenient approximate solution is assumed and the conditions of overall equilibrium of the structure are derived. The satisfaction of these conditions yields an approximate solution for the displacements and stresses.

4.2 GENERAL APPLICABILITY

Although the method has been extensively used in the field of structural mechanics, it has been successfully applied to solve several other types of engineering problem like heat conduction, fluid dynamics, seepage flow, electric and magnetic fields.

The general applicability of the method prompted mathematicians to use this technique for the solution of complicated boundary value and other problems also.

4.3 GENERAL DESCRIPTION OF THE FINITE ELEMENT METHOD

In the finite element method, the actual continuum or body of matter is represented as an assemblage of sub-divisions called finite elements. These elements are considered to be interconnected at specified joints which are called nodes or nodal points. The nodes usually lie on the element boundaries where adjacent elements are considered to be connected. Since the actual variation of the field variable like displacement, stress, temperature, inside the continuum is not known, we assume that the variation of the field variable inside a finite element can be approximated by a simple function. These interpolation functions are defined in terms of the values of the field variables at the nodes. When field equation for the whole continuum is written, the new unknowns will be the nodal values of the field variable. By solving the field equations, which are generally in the form of matrix equations, the nodal values of the field variable are known. Once these are known, the interpolation functions define the field variable throughout the assemblage of elements.

The solution of a general continuum problem by the finite element method always follows an orderly step-by-step process. With reference to static structural problems, the step-by-step procedure can be stated as follows :

Step – I : Discretization of the Structure :

The first step in the finite element method is to divide the structure or solution region into sub-divisions or elements. Hence the structure that is being analysed has to be modelled with suitable finite elements. The number, type, size and arrangements of elements have to be decided.

Step – 2: Selection of a proper interpolation or displacement model :

Since the displacement solution of a complex structure under any specified load conditions cannot be obtained exactly, we assume some suitable solution within an element to approximate the unknown solution. The assumed solution must be of a simple form from computational point of view but it should satisfy certain completeness and compatibility requirements. In general, the solution or the interpolation model is taken in the form of a polynomial.

Step 3 : Derivatoin of Element stiffness matrices and load vectors.

From the assumed displacement model, the stiffness matrix [K] and the load vector $p^{(e)}$ of element "e" are derived by using either an equilibrium condition or a suitable variational principle.

Step 4 : Assemblage of element equations to obtain the overall equilibrium equation.

Since the structure is composed of several finite elements, the individual element, stiffness matrices and load vectors are to be assembled in a suitable manner and the overall equilibrium equations have to be formulated as:

$$[\underset{\sim}{K}]\ \underset{\sim}{\vec{\phi}} = \underset{\sim}{\vec{P}}$$

where $[\underset{\sim}{K}]$ is called the assembled stiffness matrix, $\underset{\sim}{\vec{\phi}}$ is the vector of nodal displacements and $\vec{P}$ is the vector of nodal forces for the complete structure.

Step 5 : Solution for unknown nodal displacements

The overall equilibrium equations have to be modified to account for the boundary conditions of the problem. After the incorporation of the boundary conditions, the equilibrium equations can be expressed as [K] $\vec{\phi} = \vec{P}$

For linear problem, the vector $\vec{\phi}$ can be solved very easily. But for non-linear problems, the solution has to be obtained in a sequence of steps, each step involving the modification of the stiffness matrix [K] and or the load vector $\vec{P}$.

Step 6 : Computation of element strains and stresses.

From the known nodal displacements $\vec{\phi}$, if required, the element strains and stresses can be computed by using the necessary equation of solid or structural mechanics.

ANALYSIS OF GENERATOR BARREL

5.1 GENERAL

Rational and economic design of a structure requires an accurate and reliable analysis. In conventional analysis of complex structure, like generator barrel, which is an indeterminate structure due to number of blockouts, recesses and discontinuities, a number of assumptions are made to carry out the stress analysis in a simple way . Due to simplifying assumptions, conventional analysis is generally too approximate . An attempt is made to analyse the generator barrel by Finite Element method so that an insight to the behavior of the structure under various loads may be obtained.

Here, analysis of generator barrel has been done by both conventional as well as Finite Element Method for comparison purpose. For this study, data of Chilla power house has been considered.

5.2 INPUT DATA FROM CHILLA POWER HOUSE

5.2.1 General

Chilla Power House consists of Umbrella type generators with all the rotating parts including runner and rotor supported on the top of the stator frame as shown in Fig.5.1. The stator frame in turn is supported over six pedestals 1200 x 1050 mm projecting above the mass concrete around spiral case. The lower bracket assembly, which supports the rotor while jacking it up for lubrication etc. before starting the machine also house the lower guide bearing which is also supported on six pedestals

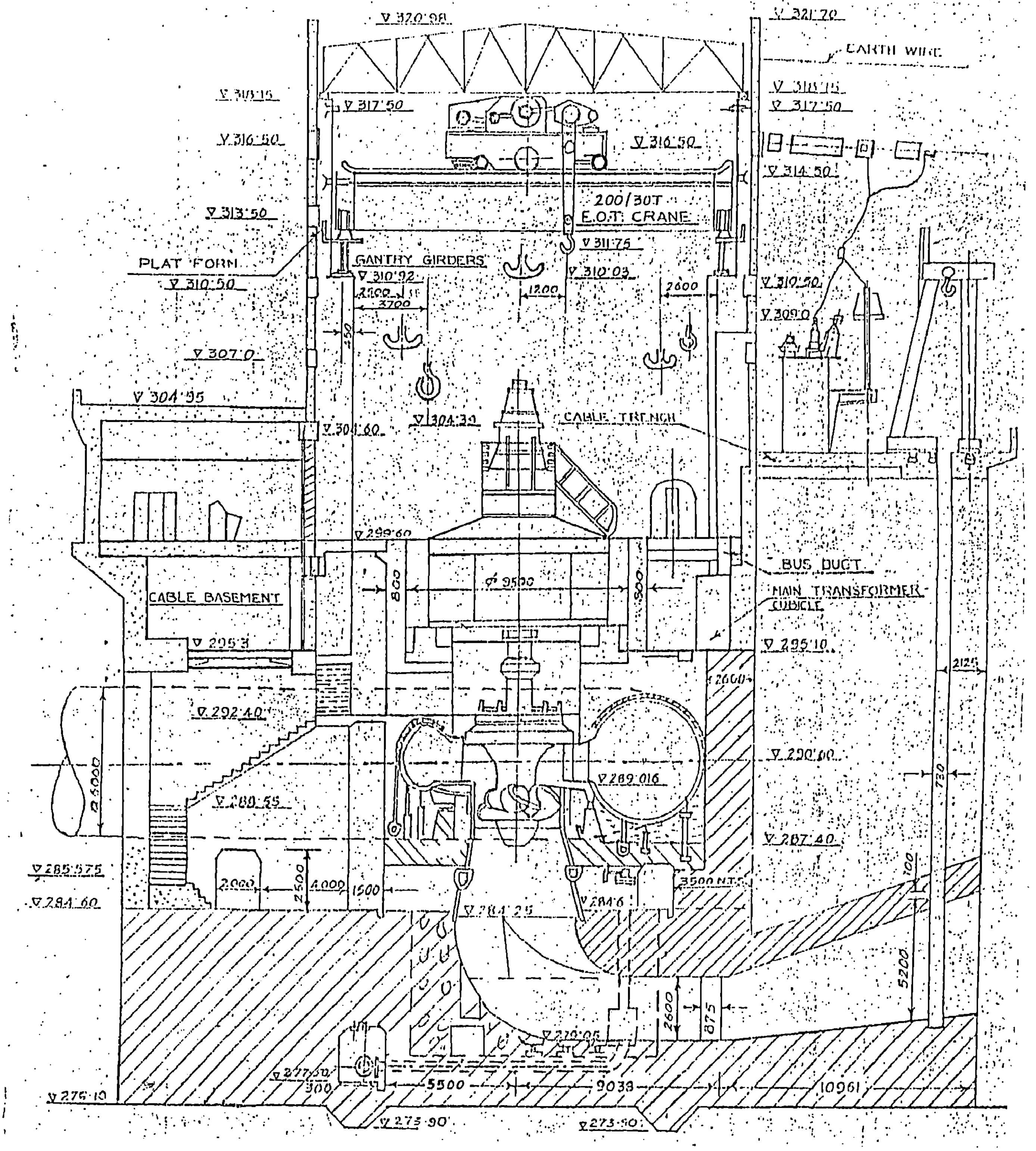


Fig.5.1 Transverse section of Chilla power House through center line of Unit

1200 x 600 mm in size. The top bracket assembly is provided with six radial jacks between the generator housing barrel and the top spiders to take the horizontal loads through the top guide bearings. In addition, there are six more pedestals in between the stator pedestal to accommodate the air coolers.

The generator housing barrel of Chilla Power House comprises 800 mm thick R.C.C. cylindrical shell with its external diameter as 11,100 mm. The barrel is rigidly fixed at the base to the spiral case encasing concrete at EL 295.05 m. To support the generator floor, 600 X 600 mm wide bracket around the barrel below EL 298.75 mm has been provided. There are three major openings in the barrel, two 1600 x 600 mm high for generator terminals and one 1250x2000 mm high for access to generator housing. Other openings in the barrel are comparatively minor comprising pipe embedments etc.

5.2.2 Design Loads

The following design loads have been adopted :-

(i) The self weight of the barrel and live load on generator floor equal to 1.0 t/m^2

(ii) Machine loads provided by manufacturer, are enumerated below :

(a) Load/force on each stator foundation plate :

1. Load of generator, turbine rotating parts, water reaction and generator stationery parts except the lower bracket, equal to 135 tonnes acting at 3820 mm from C.L. of the machine.

2. Circumferential shear force due to maximum moment at two phase short circuit of stator windings equal to 92 tonnes acting at EL 296.050 m (i.e. top of the pedestal).

3. Radial force due to unilateral magnetic attraction at double short circuit of rotor windings, equal to 60.6 tonnes acting at EL 296.050 m.

(b) Load/force on each lower bracket foundation plate :

1. Load of rotating parts of turbine and generator lower bracket and water leakage while lifting the rotor, equal to 48 tonnes acting at 2750 mm from C.L. of machine

2. Load of lower bracket as assembly during normal operation of machine equal to 6.67 tonnes at 2750 mm from C.L. of machine

3. Pretension in the foundation bolts equal to 30 tonnes.

4. Circumferential shearing force during braking equal to 1 tonne at EL 295.555 m i.e. top of pedestal.

5. Radial force due to unilateral magnetic attraction at double short circuit of rotor windings equal to 80 tonnes at EL 295.555 m.

6. Additional vertical load due to eccentricity of unilateral magnetic attraction equal to 5 Tonnes at 2750 mm from C.L. of the machine.

5.2.3 Material properties

For generator barrel generally M-20 or higher strength concrete is used. For analysis purpose M-20 concrete has been considered.

Properties considered are

(i) Elastic Modulus of concrete (E_c) as per BIS code (IS: 456-1978)

$E_c = 5700 \sqrt{fck}$

Where, fck is the characteristic strength of concrete in N/mm^2

$\therefore E_c = 5700 \sqrt{20} = 25491.175 \text{ N/mm}^2$

$= 2.55 \times 10^{10} \text{ N/m}^2$

(ii) Density, $\nu = 2500 \text{ kg/m}^3$

(iii) Poisson's ratio, $\nu = 0.20$

5.3 ANALYSIS BY CONVENTIONAL METHOD (8)

In case of a continuous, cylindrical supporting well with a few small openings, forces due to the torque are resisted by an annular cross-section without developing excessive stresses. Various torques are the main forces which will determine the requirement of reinforcement. The torque will cause the shear stress. It is proposed to consider the barrel as open section subjected to uniform torsion as there will be no warping effect because the height of the barrel is very small when compared to the diameter.

For an open section the maximum shear stress 's' can be calculated in terms of θ the angle of twist., G modulus of rigidity and L the length by Roark (11) formula due to uniform torque T, as

$$S = G\frac{\theta}{L}.C$$

$$or\ S = \frac{T}{K}C$$

where,

$$C = \frac{D}{1+\frac{\pi^2 D^4}{16A^2}}[1+0.15(\frac{\pi^2 D^4}{16A^2}-\frac{D}{2r})]$$

D = It is the maximum thickness of barrel

r = radius of curvature of boundary at point

A = area of section

$$\text{and } K = \frac{\left(\frac{1}{3}\right)F}{\left(1+\frac{4}{3}.\frac{F}{AU^2}\right)}$$

$$\text{where } F = \int_o^u t^3 du$$

du = elementary length along median line

t = thickness normal to median line

Total twisting moment due to tangential load i.e. short circuit torque,

T = 3.82 x 6 x92 = 2108.64 t.m

D = total thickness = 5.55-2.45 = 3.1 m

r_0 = 5.55 m

r_i = 2.45 m

A = π (5.55^2 - 2.45^2) x 20/21* = 74.20m^2

U = 2π{(5.55 + 2.45)/2 }x (20/21)* = 23.9 m

* coefficient to adjust for the area of opening.

C at outer surface,

$$C_o = \frac{3.1}{1+\dfrac{\pi^2 x3.1^2}{16x74.2^2}}\left[1+0.15\left(\frac{\pi^2 x3.1^2}{16x74.2^2}-\frac{3.1}{2x5.55}\right)\right] = 2.782$$

$$= 2.944$$

C at inner surface,

$$C_i = \frac{3.1}{1+\dfrac{\pi^2 x3.1^2}{16x74.2^2}}\left[1+0.15\left(\frac{\pi^2 x3.1^2}{16x74.2^2}-\frac{3.1}{2x2.45}\right)\right] = 2.782$$

$$F = \int_0^U t^3 du = 3.1^3 \text{ x } 23.9 = 712.0$$

$$K = \frac{\frac{1}{3}xF}{1+\frac{4}{3}x\frac{F}{AU^2}} = \frac{\frac{1}{3}x712}{1+\frac{4}{3}x\frac{712}{74.2x23.9^2}} = 232.135$$

So shear stress at outer surface,

$$S_0 = (T/K)\, C_0 = \frac{2108.64}{232.135}x2.944 = 26.74 \text{ t/m}^2$$

$$= 2.62 \text{ x } 10^5 \text{ N/m}^2$$

and shear stress at inner surface,

$$S_i = (T/K)\, C_i = \frac{2108.64}{232.135}x2.782 = 25.27 \text{ t/m}^2$$

$$= 2.48\text{x}10^5 \text{ N/m}^2$$

The vertical loads are assumed to cause uniform compressive stress at the fixed base of the barrel. The stress due to radial loads are assumed nominal. These are considered for designs of pedestals and anchors.

5.4 ANALYSIS BY FINITE ELEMENT METHOD

5.4.1 Loads

Analysis by FEM has been done on two models, (i) 3-D Model without openings and (ii) 3-D Model with openings in order to see the change in stress patterns. Both models have been analysed for three loads, acting individually and all combined. These three loads are:

(i) Tangential loads

(ii) Radial loads

(iii) Vertical loads

The combination of the three loads is considered as an emerging loading condition. For FEM analysis ANSYS package has been used. ANSYS has powerful inbuilt tools for mesh generation, applying loads and boundary conditions, solution and presentation of results.

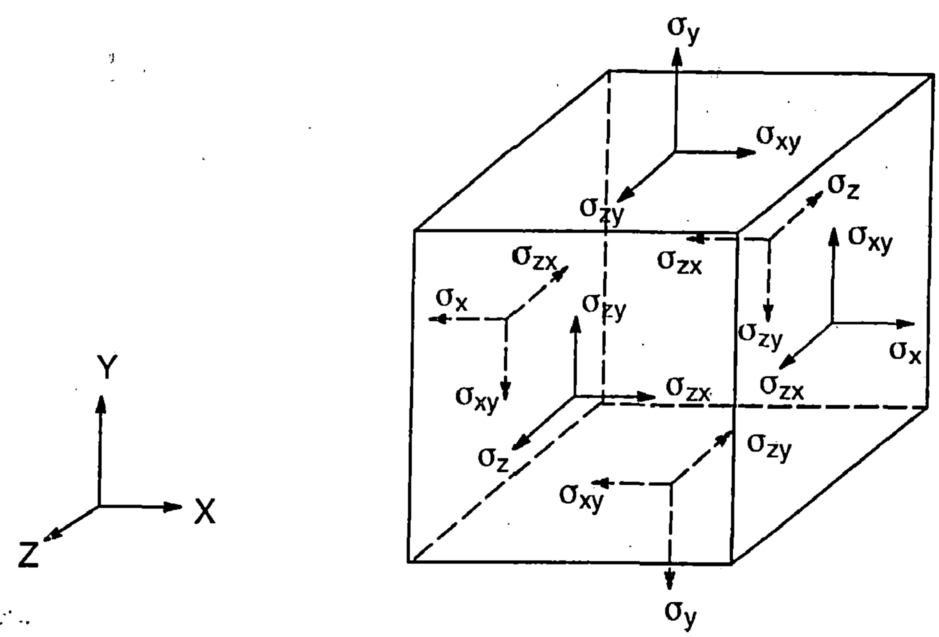


Figure 5·2 Stress Vector Definition

5.4.2 Sign Convention

The stress vectors are shown in Fig. 5.2. The sign convention for direct stress and strains used throughout the ANSYS program is that tension is positive and compression is negative, shears is positive when the two applicable positive axes rotate towards each other.

5.4.3 Preparation of 3-D Model

While modelling, EL 295.05 m which is the base of generator barrel has been assumed as y=0.

A direct 3–D model has not been prepared due to difficulty in making provision for openings. Therefore a 2–D model is initially made and it is rotated about the axis of barrel to convert it into 3-D model. The procedure is explained in following steps.

(i) A 2-D model was prepared in X-Y plane (Fig. 5.3) as combination of a number of elements so that different openings can be provided by deleting some elements while converting it in 3-D model.

(ii) 2-D model was meshed with 4-noded plane elements.

(iii) 2-D meshed model is swept about centre axis of generator barrel generating 8-noded brick elements for 3-D model. During sweeping total volume were divided in 21 parts and each part was divided in 4 elements along circumference. Logic of dividing solid model in 21 parts is that if any cutout is to be provided, only part segments representing the opening can be deleted. During meshing and sweeping care was taken to ensure that the aspect ratio of any 3-D element is not greater than 2.5.

(iv) After generating 3–D model initial 2-D model was deleted .

(v) Total number of nodes and elements are 15288 and 11928 respectively in the 3-D model without opening .

(vi) For making openings, corresponding parts were selected. Selected parts were deleted. Total number of nodes and elements are 15105 & 11772 respectively in this model. 3-D isometric model is shown in Fig. 5.4. Plan of 3-D model showing the location of pedestals is shown in Fig. 5.5

5.4.4 Application of Loads and Boundary Conditions

(a) Tangential force

Tangential force due to maximum moment at two phase short circuit of stator windings equal to 92 tonnes per pedestal has been considered. This force has been applied at 15 nodes per pedestal.

Therefore force per node $= \dfrac{92 x 9.8 x 10^3}{15} = 60106.7 N$

This force has been applied in circumferential direction on each node.

(b) Radial force :

Following redial forces have been considered :

(i) Radial force due to unilateral magnetic attraction at double short circuit of rotor windings equal to 60.6 tonnes acting at El 296.050 M

(ii) Radial force due to unilateral magnetic attraction at double short circuit of rotor windings equal to 80 tonnes at El 295.555 M.

Both forces have been considered to be distributed over 15 nodes per pedestal.

Therefore radial force at each node is as follows :

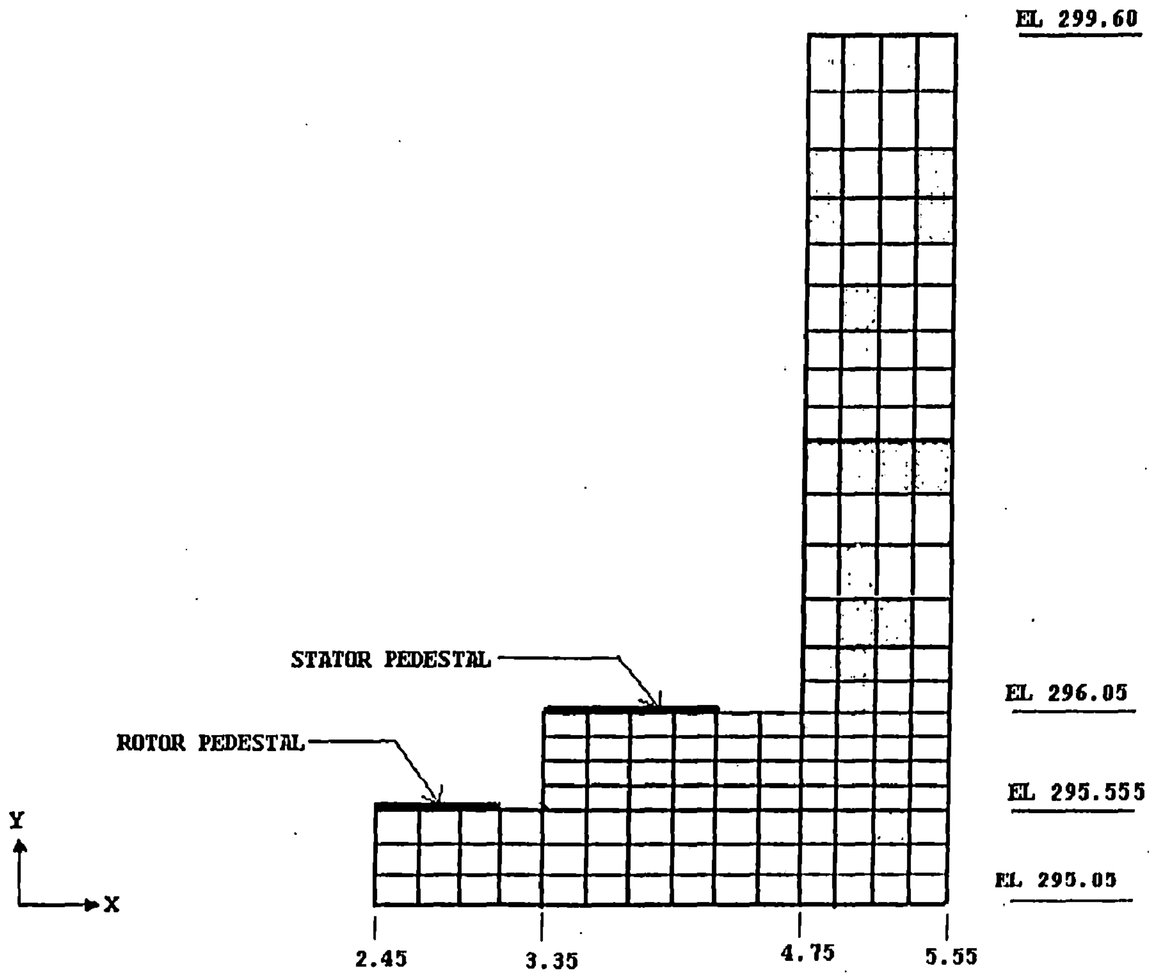


FIG. 5.3 TWO DIMENSIONAL MESHED MODEL OF GENERATOR BARREL

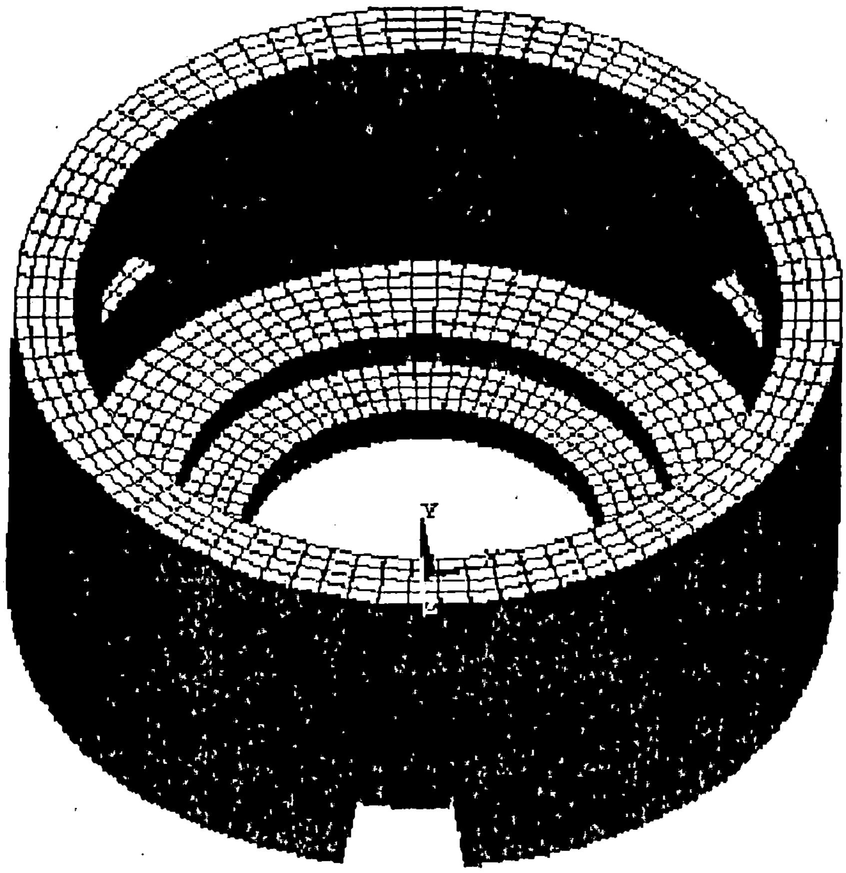


FIG. 5.4 ISOMETRIC VIEW OF THREE DIMENSIONAL MODEL
(SHOWING MESHING IN CIRCUMFERENTIAL DIRECTION)

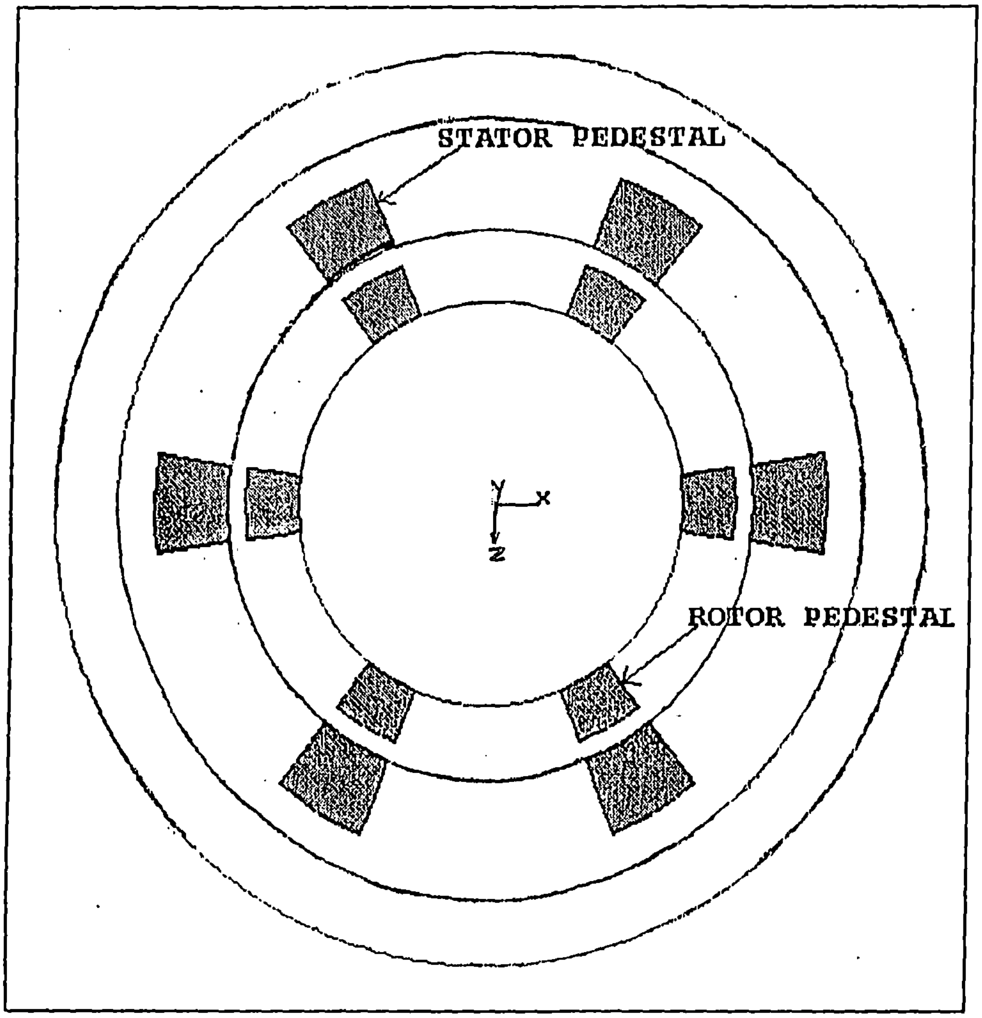


FIG. 5.5 PLAN OF THREE DIMENSIONAL MODEL (SHOWING PEDESTALS LOCATION)

For stator pedestal = $\frac{60.6x9.8x10^3}{15}$ =39592N

For rotor pedestal = $\frac{80x9.8x10^3}{15}$ =52266.7 N

Radial forces on stator and rotor pedestals have been considered to be applied in positive and negative direction respectively, the direction as shown in Fig.3.1 & 3.2 .

(c) Vertical loads

In vertical loads mainly three loads have been considered :

(i) Load of machine equal to 135 tonnes acting on pedestal at 3820 mm from C.L. of machine. This load has been considered to be distributed over 15 nodes per pedestal. So, load per node = $\frac{135x9.8x10^3}{15}$ =88200N.

(ii) Self weight of barrel : Self weight has been applied by considering acceleration due to gravity, g = 9.8 m/sec^2.

(iii) Live load on generator floor equal to 1 t/m^2.

Total live load on generator floor has been calculated and only half of that has been assumed to be supported on barrel . It is applied as uniformly distributed pressure over annular cross section area of generator housing.

(d) Boundary conditions :

As stated above barrel is rigidly fixed at the base to the spiral case encasing concrete at EL 295.05 m. So all nodes at this level (i.e. y = o) were restrained against displacement in x, y and z direction.

5.4.5 Analysis

Both 3-D model (with and without opening) were analysed for four loading cases

(i) only tangential load is acting

(ii) only radial load is acting

(iii) only vertical load is acting

(iv) all three loads, tangential, radial and vertical loads are acting.

All four loading cases for two 3-D models are listed in the following table .

Table 5.1 : Table of cases analysed

Sl.No.	Type of model	Load type	Model name
1.	3-D model without opening	Tangential only	Chila39E1
2.	-do-	Radial only	Chila39E2
3.	-do-	Vertical only	Chila39E3
4.	-do-	All three loads acting	Chila39E4
5.	3-D Model with opening	Tangential only	Chila39F1
6.	-do-	Radial only	Chila39F2
7.	-do-	Vertical only	Chila39F3
8.	-do-	All three loads acting	Chila39F4

CHAPTER 6

DISCUSSION OF RESULTS AND CONCLUSION

6.1 RESULTS OF ANALYSIS

In each case analysed by 3-D FEM for any load we get three normal stresses (SX, SY & SZ), three shear stress components (SXY, SYZ & SZX) , major and minor principal stresses (S1 & S3) and stress intensity SINT. The notations SX, SY, SZ, SXY, SYZ & SZX corresponds to σ_X, σ_Y, σ_Z, σ_{XY}, σ_{YZ} and σ_{ZX} respectively which are shown in Fig. 5.2.

SINT = (S1-S3) and in three dimensional case maximum shear stress

$$= \frac{S1 - S3}{2} = \frac{SINT}{2}$$

For the all 8 cases analysed values of SX, SZ & SXZ have been ignored as these are not found significant in comparison to other stresses. The vertical axis of the barrel is taken to be in Y-direction, X-Z is a cross-sectional plane of the barrel. The stress values for SY, SXY, SYZ, S1, S3 & SINT on some nodes at which they are either maximum or minimum have been tabulated in each case. Stresses have been considered at base only (Y=0) . Below the table the location of all these nodes are also indicated in plan. Value of all stresses are in SI units i.e. in N/m^2.

In addition to tabular presentation, stress contours and distribution on some discrete nodes has also been plotted for only significant stresses.

Results presentation of all 8 cases analysed are given below.

6.1.1 3-D Model Without Opening

3-D solid barrel model has been analysed for 4 cases (individual loads and combined loads and results of each case is discussed below :

(a) Only tangential load is acting : It is model Chila39E1 analysed for tangential load only. Maximum and minimum values of significant stresses at some points are given in Table 6.1 and stress distribution pattern for SY , SYZ and SINT are plotted in Fig. 6.1 to 6.3. The values of SY indicate vertical stresses both compression and tension under each stator plate on which tangential load is acting. It is of the order of 1.33×10^5 N/m^2. Maximum shear stress SYZ is 1.36×10^5 N/m^2 at the centre of section under the sole plate. At outer and inner surface the shear stress is less . The distribution of shear stress can be seen in the contour plan (Fig. 6.2). It is also tabulated across the radius of maximum stress in table 6.9

(b) Only Radial load is acting : It is model Chila39E2 analysed for radial load only. Maximum and minimum values of significant stresses at some points are given in Table 6.2 and stress distribution pattern for SXY & SY are plotted in Fig. 6.4 and 6.5 .The shear stresses SXY are found maximum (3.8×10^5 N/m^2) at the inner edge of the barrel at base plate locations. These are concentrated in the inner half of the barrel section . The value of SY, vertical stresses both compression and tension is found at the inner edge of the section under the base plate depending on direction of load. It is of the order of 15×10^5 N/m^2.

(c) Only vertical load is acting : It is model Chila39E3 analysed for vertical load only. Maximum and minimum values of significant stresses of this model are given in Table 6.3 and stress distribution pattern for only SY is plotted in Fig. 6.6. as all other stresses are insignificant. Maximum compressive stress of 6.5×10^5 has been found under each base plate

(d) All three loads are acting : It is model Chila39E4 analysed for all three loads acting simultaneously. Maximum and minimum values of significant stresses of this model are given in Table 6.4 and stress distribution pattern for SXY, SY & SINT are plotted in Figs. 6.7 to 6.9. The maximum shear stress SXY of 3.9×10^5 N/m^2 occurs at the inner surface at base plate locations and vertical stress is also at the inner edge, same as found for radial load .

6.1.2 3-D Model (with Openings)

Similar to solid barrel model, this model(barrel with openings) has also been analysed for 4 loading cases :

(e) Only tangential load is acting : It is model Chila39F1 analysed for only tangential load. Maximum and minimum values of significant stresses of this model are given in Table 6.5 and stress distribution pattern for SYZ , SY & SINT are plotted in Figs. 6.10 to 6.12.The values of SY indicating vertical compressive and tensile stress under each sole plate are found of the order of $1.2 \times 10^5 N/m^2$ .But at sharp corners of the opening there is concentration of tensile and compressive stresses. The maximum tensile stress is 4.2×10^5 N/m^2 and compressive stress is $2.28 \times 10^5 N/m^2$. The pattern of distribution and magnitude of shear stress is same as in solid barrel. The shear stress has slightly increased to 1.36×10^5 N/m^2 because of reduction in area. The shear stress distribution across a radius are tabulated in table 6.10 showing maximum stress at the center and reducing both on inner and outer surface.

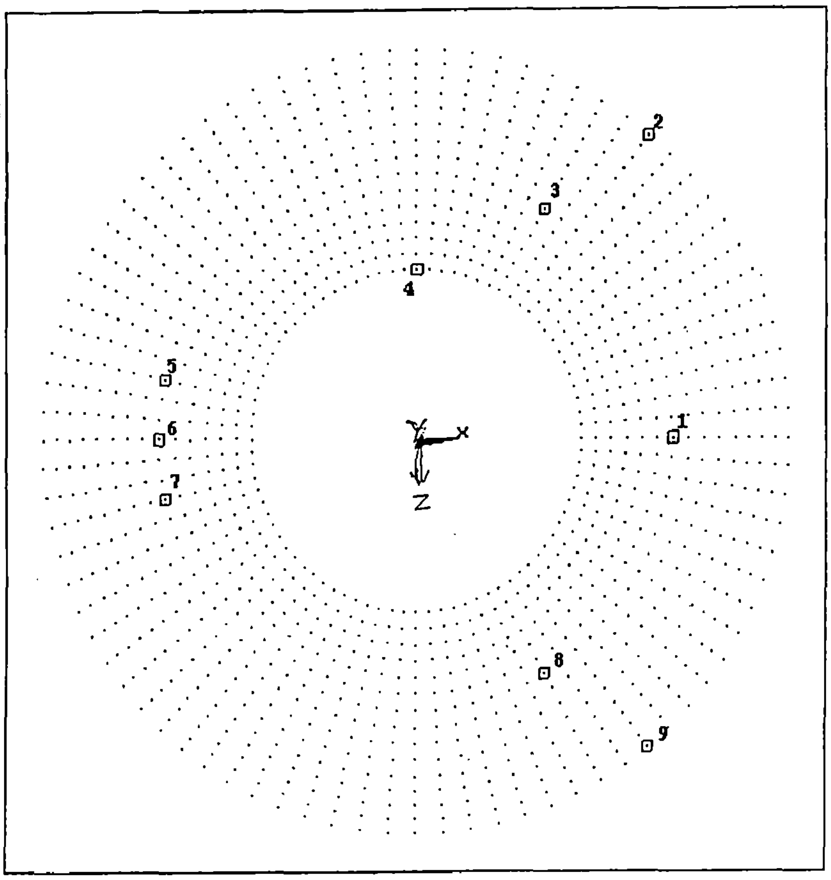
(f) Only Radial load is acting: It is model Chila39F2 analysed for radial load only. Maximum and minimum values of significant stresses on some points are given in Table 6.6 and stress distribution pattern for SXY & SY are plotted in Fig. 6.13 and 6.14. The pattern of distribution of stresses and the magnitudes are the same as for a solid barrel.

(g) Only vertical load is acting: It is model Chila39F3 analysed for vertical load only. Maximum and minimum values of significant stresses on some points are given in Table 6.7 and stress distribution pattern for SY is plotted in Fig. 6.15. The pattern of distribution of stresses and the magnitudes are the same as for a solid barrel.

(h) All three loads are acting: It is model Chila39F4 analysed for all three loads acting simultaneously. Maximum and minimum values of significant stresses on some points are given in Table 6.8 and stress distribution pattern for SXY , SY & SINT are plotted in Figs. 6.16 to 6.18. The pattern of stress distribution and the maximum value of stresses are particularly same as in case of solid barrel .

TABLE 6.1 NODAL STRESS COMPONENTS FOR MODEL CHILA39E1
(ONLY TANGENTIAL LOAD ACTING)

SL. NO.	NODE	CO-ORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	104	3.82, 0, 0	0	0	1.37E+05	1.37E+05	-1.37E+05	2.74E+05
2	2015	3.46, 0, -4.33	-58718	32486	2297.5	4537.7	-75513	80051
3	2456	1.91, 0, -3.31	-3.88E-02	1.18E+05	68380	1.37E+05	-1.37E+05	2.74E+05
4	3846	-1.51, 0, -2.45	0	10926	0	10926	-10926	21852
5	6825	-3.72, 0, -0.85	-1.33E+05	-574.46	-1.26E+05	54365	-2.18E+05	2.73E+05
6	7552	-3.82, 0, 0	0	0	-1.37E+05	1.37E+05	-1.37E+05	2.74E+05
7	8279	-3.72, 0, 0.85	1.33E+05	574.46	-1.26E+05	2.18E+05	-54365	2.73E+05
8	12648	1.91, 0, 3.31	3.88E-02	-1.18E+05	68380	1.37E+05	-1.37E+05	2.74E+05
9	12935	3.46, 0, 4.34	58718	-32486	2297.5	75513	-4537.7	80051
	MINIMUM VALUE							
	NODE		6825	12648	7552	2015	6825	3846
	VALUE		-1.33E+05	-1.18E+05	-1.37E+05	4537.7	-2.18E+05	21852
	MAXIMUM VALUE							
	NODE	8279	8279	2456	104	8279	12935	7552
	VALUE	31671	1.33E+05	1.18E+05	1.37E+05	2.18E+05	-4537.7	2.74E+05



NODE POSITION FOR TABLE 6·1

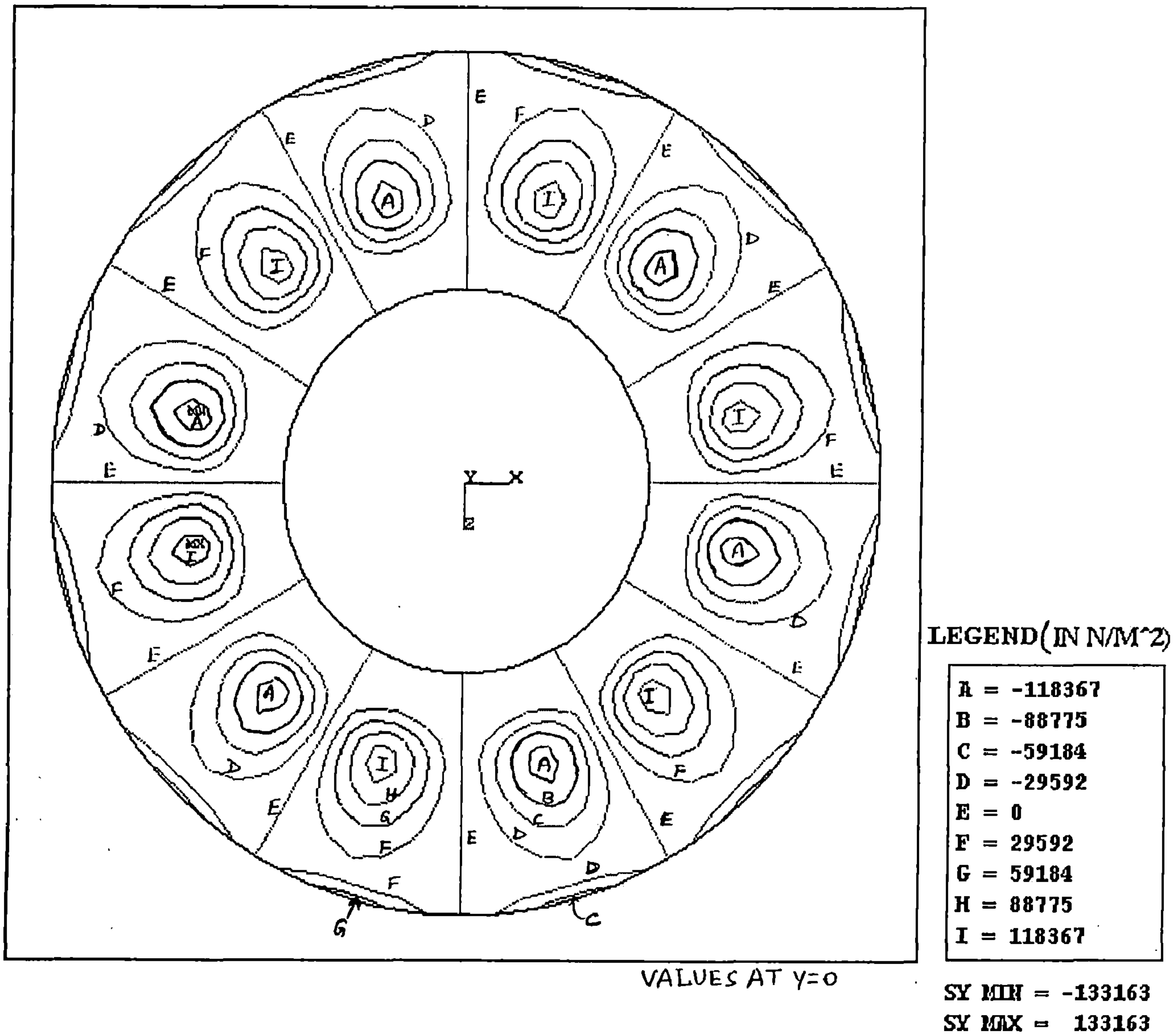
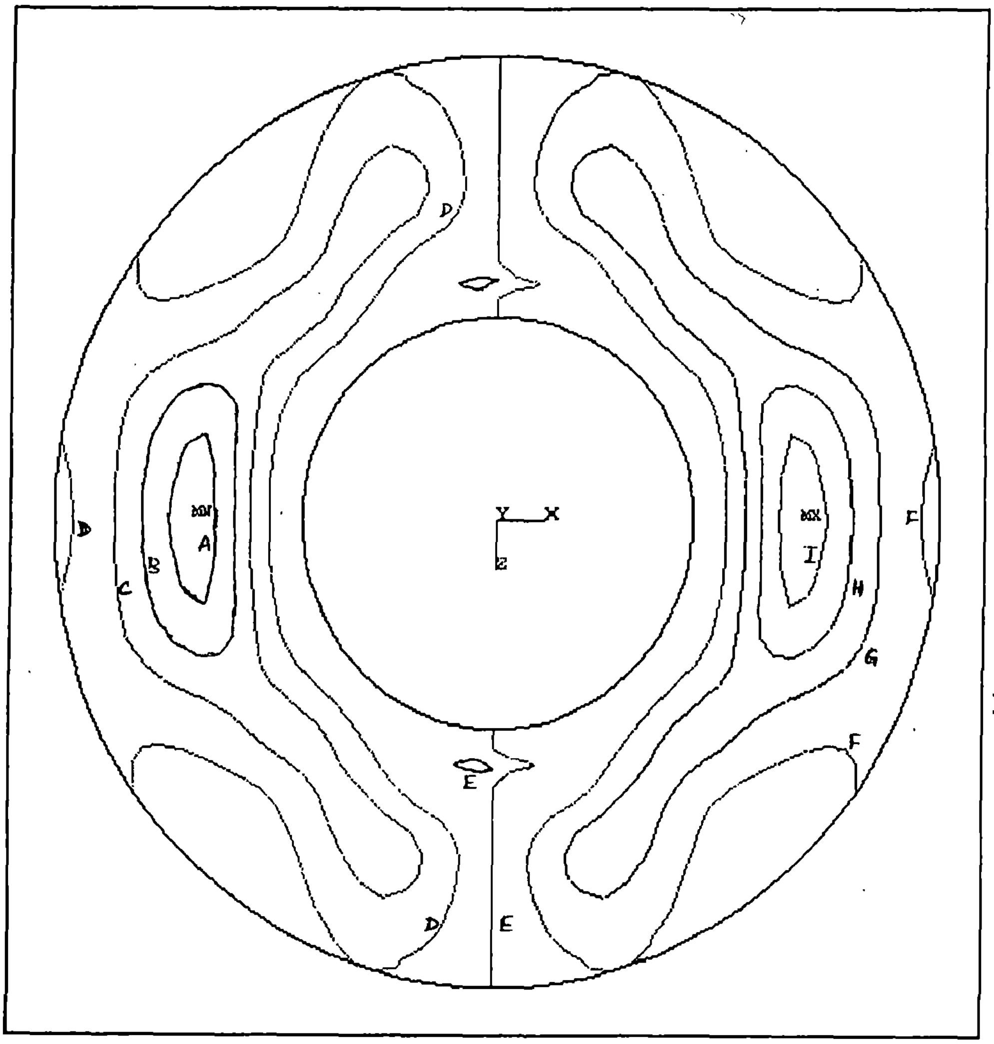


FIG. 6·1 CONTOUR OF SY FOR MODEL CHILA39E1
(ONLY TANGENTIAL LOAD ACTING)



LEGEND (IN N/M^2

A	= -121564
B	= -91173
C	= -60782
D	= -30391
E	= 0
F	= 30391
G	= 60782
H	= 91173
I	= 121564

VALUES AT Y = 0

SYZ MIN = -136759
SYZ MAX = 136759

FIG. 6·2 CONTOUR OF SYZ FOR MODEL CHILA39E1
(ONLY TANGENTIAL LOAD ACTING)

G10331.

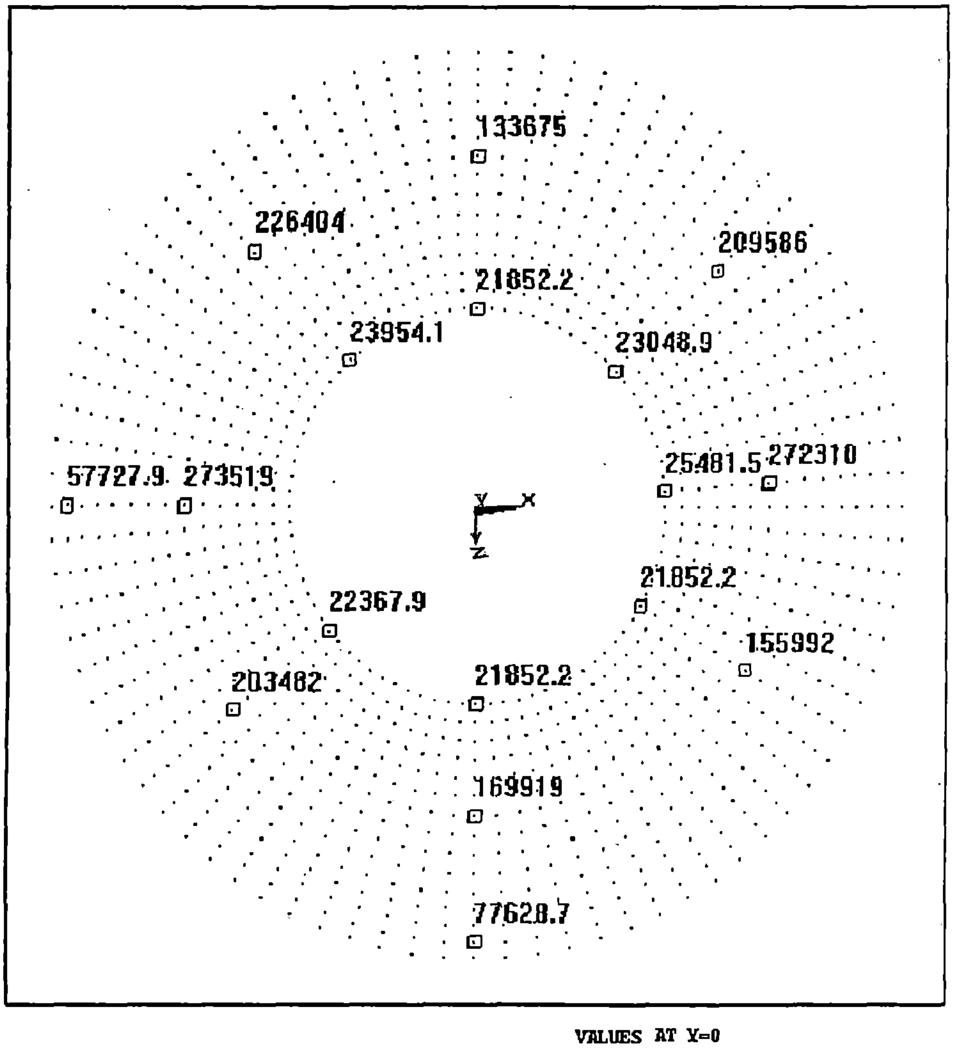
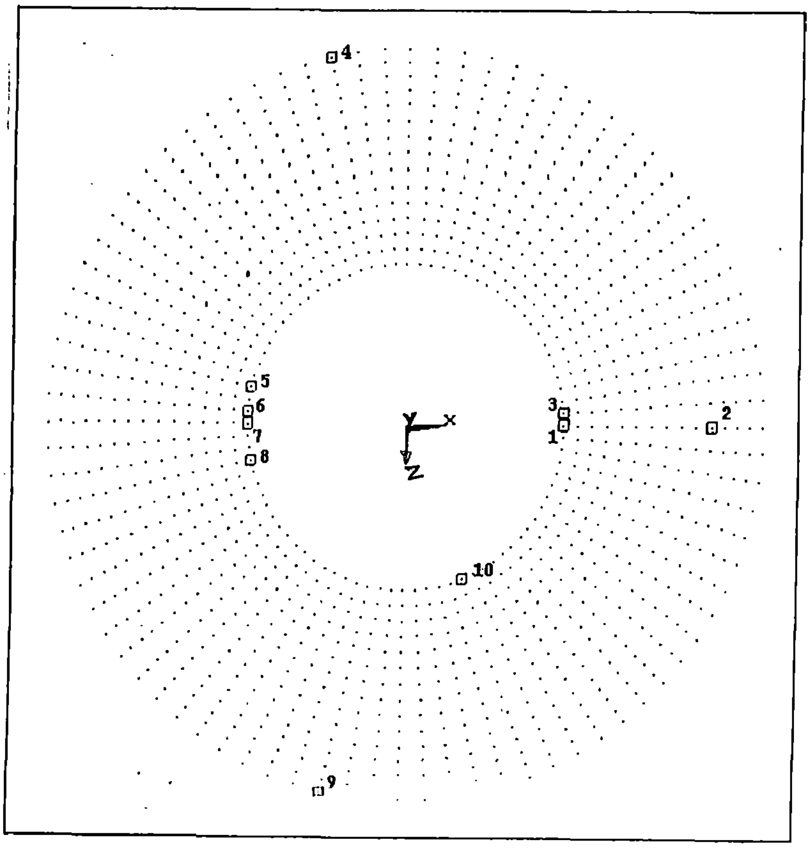


FIG. 6.3 DISTRIBUTION OF SINT FOR MODEL CHILA39E1
(ONLY TANGENTIAL LOAD ACTING)

TABLE 6.2 NODAL STRESS COMPONENTS FOR MODEL CHILA39E2
(ONLY RADIAL LOAD ACTING)

SL.	NODE	CO ORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	85	2.45, 0, 0	-1.50E+06	-2.48E+05	0	-1.73E+05	-1.55E+06	1.37E+06
2	124	4.75, 0, 0	-78856	82785	0	38651	-1.37E+05	1.76E+05
3	203	2.44, 0, -0.18	-1.47E+06	-2.44E+05	-1.01E+05	-1.74E+05	-1.53E+06	1.35E+06
4	4199	-1.23,0,-5.41	2540.4	8006.9	-3097.6	10344	-6907	17251
5	6760	-2.39,0,-0.55	8.80E+05	-1.81E+05	2.61E+05	1.00E+06	60168	9.44E+05
6	7486	-2.44,0,-0.18	1.47E+06	-2.44E+05	1.01E+05	1.53E+06	1.74E+05	1.35E+06
7	7487	-2.45,0, 0	1.50E+06	-2.48E+05	0	1.55E+06	1.73E+05	1.37E+06
8	8214	-2.39, 0, 0.55	8.80E+05	-1.81E+05	-2.61E+05	1.00E+06	60168	9.44E+05
9	10751	-1.23, 0, 5.41	2540.4	8006.9	3097.6	10344	-6907	17251
10	11832	0.9, 0, 2.28	-7.12E+05	-3.81E+05	83334	40478	-9.14E+05	9.55E+05
	MINIMUM VALUE							
	NODE		85	11832	8214	203	85	4199
	VALUE		-1.50E+06	-3.81E+05	-2.61E+05	-1.74E+05	-1.55E+06	17251
	MAXIMUM VALUE							
	NODE		7487	124	6760	7487	7486	85
	VALUE		1.50E+06	8.28E+04	2.61E+05	1.55E+06	1.74E+05	1.37E+06



NODES LOCATION FOR TABLE 6.2

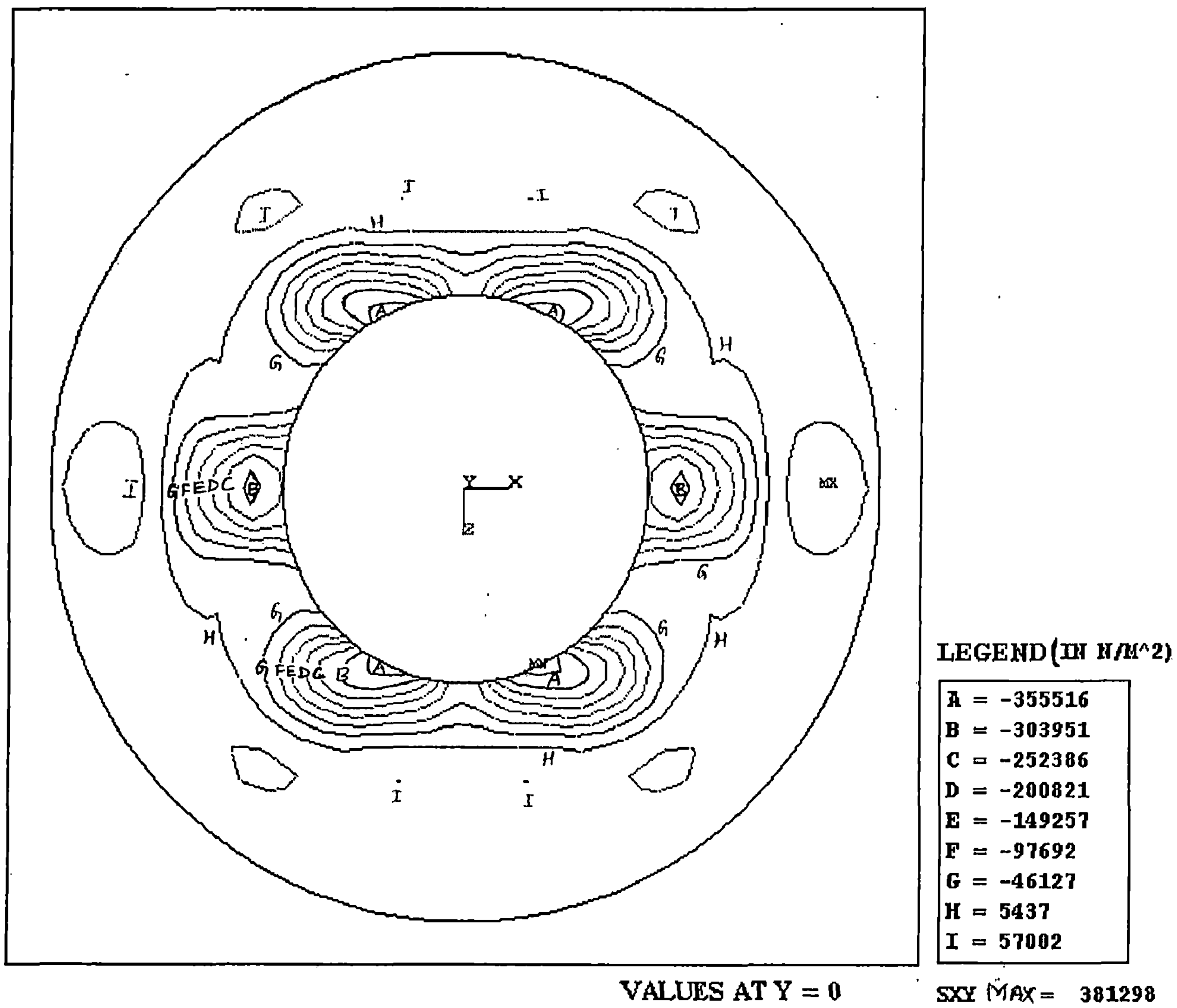


FIG. 6·4 CONTOUR OF SXY FOR MODEL CHILA39E2 (ONLY RADIAL LOAD ACTING)

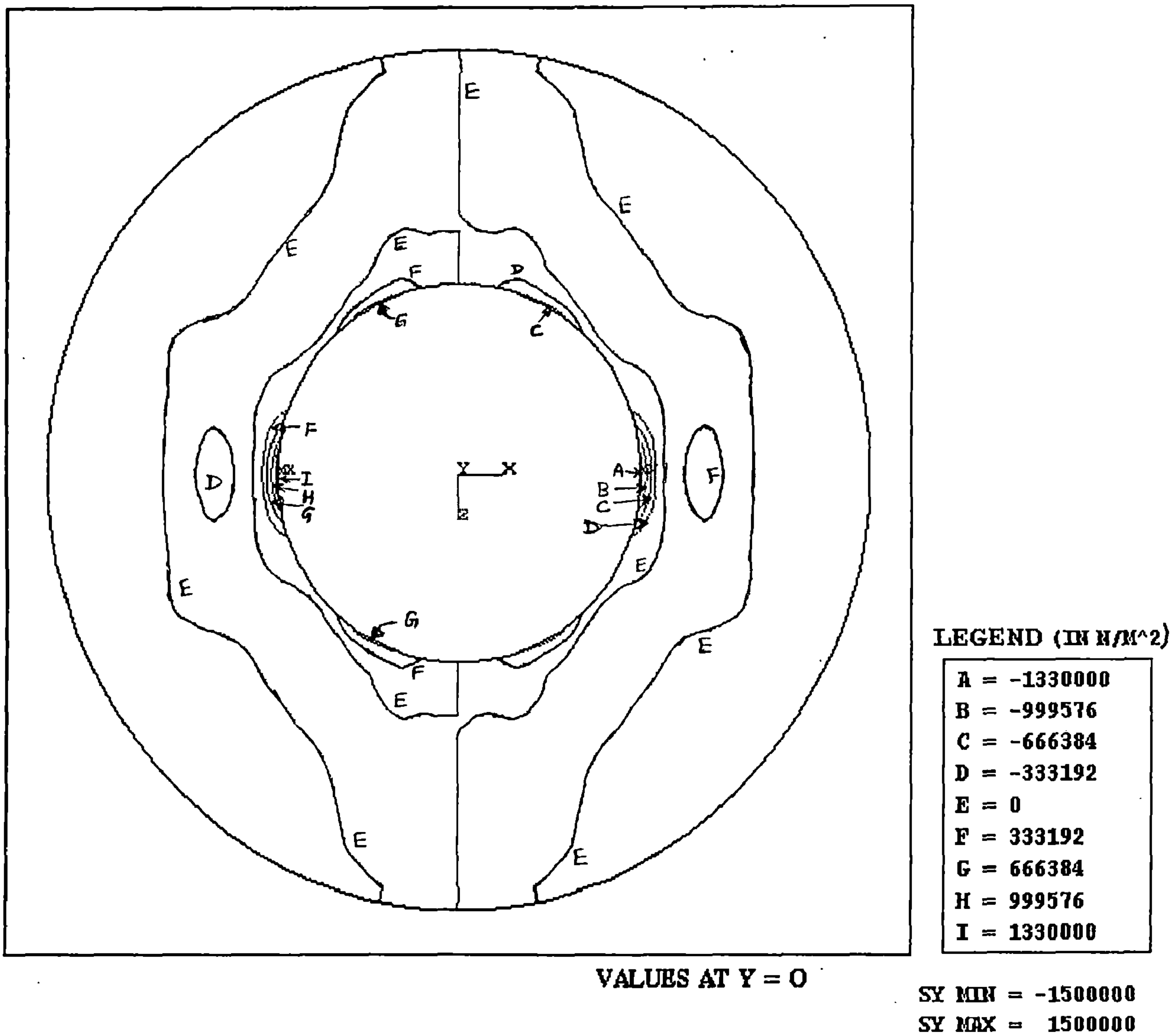
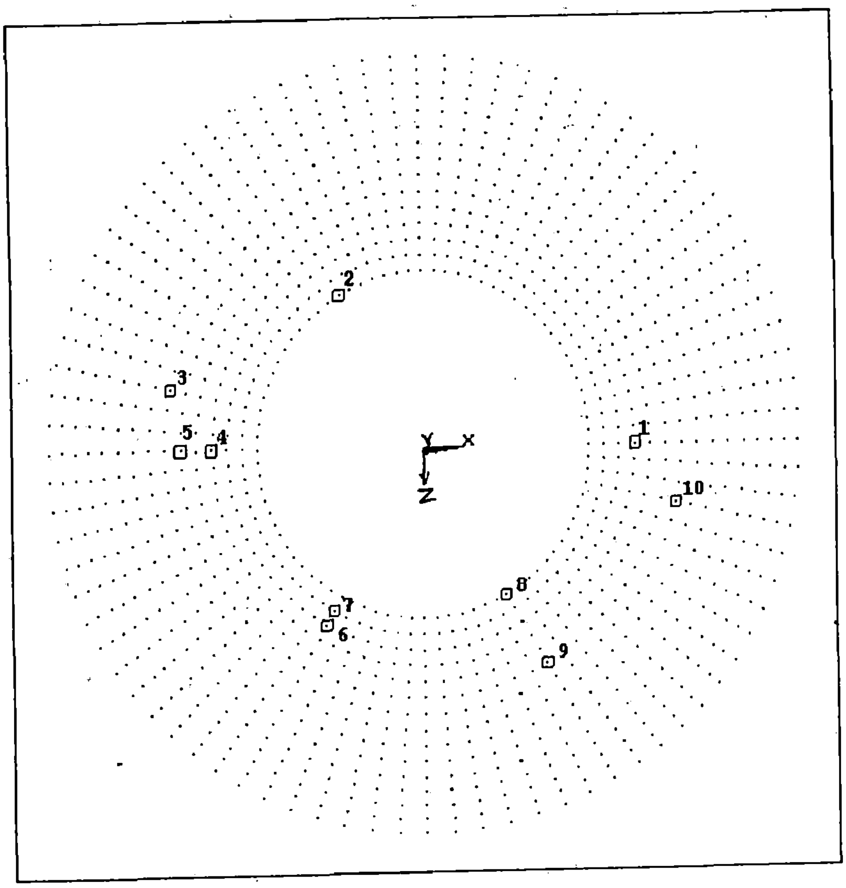


FIG. 6·5 CONTOUR OF SY FOR MODEL CHILA39E2
(ONLY RADIAL LOAD ACTING)

TABLE 6.3 NODAL STRESS COMPONENTS FOR MODEL CHILA39E3 (ONLY VERTICAL LOAD ACTING)								
SL. NO.	NODE	CO ORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	86	3.13,0,0	-2.31E+05	-96435	0	-19278	-2.75E+05	2.55E+05
2	4552	-1.23,0,-2.12	-5245.3	2585.7	4478.6	3076.9	-8458.8	11536
3	6825	-3.72,0,-0.85	-3.30E+05	-1750	-93072	-50998	-3.61E+05	3.10E+05
4	7496	-3.13,0,0	-2.31E+05	96435	0	-19278	-2.75E+05	2.55E+05
5	7558	-3.59,0,0	-6.50E+05	21541	0	-1.50E+05	-6.51E+05	5.01E+05
6	9650	-1.45,0,2.51	-46427	28609	-49552	25548	-91913	1.17E+05
7	9651	-1.34,0,2.32	-526.97	9016.7	-15617	16293	-19862	36154
8	12583	1.23,0,2.12	-5245.3	-2585.7	-4478.6	3076.9	-8458.8	11536
9	12654	1.79,0,3.1	-6.50E+05	-10771	-18655	-1.50E+05	-6.51E+05	5.01E+05
10	14803	3.72,0,0.85	-3.30E+05	1750	93072	-50998	-3.61E+05	3.10E+05
	MINIMUM VALUE							
	NODE		12654	86	6825	12654	7558	4552
	VALUE		-6.50E+05	-96435	-93072	-1.50E+05	-6.51E+05	11536
	MAXIMUM VALUE					VALUES		
	NODE		9651	7496	14803	9650	12583	7558
	VALUE		-526.97	96435	93072	25548	-8458.8	5.01E+05



NODES LOCATION FOR TABLE 6·3

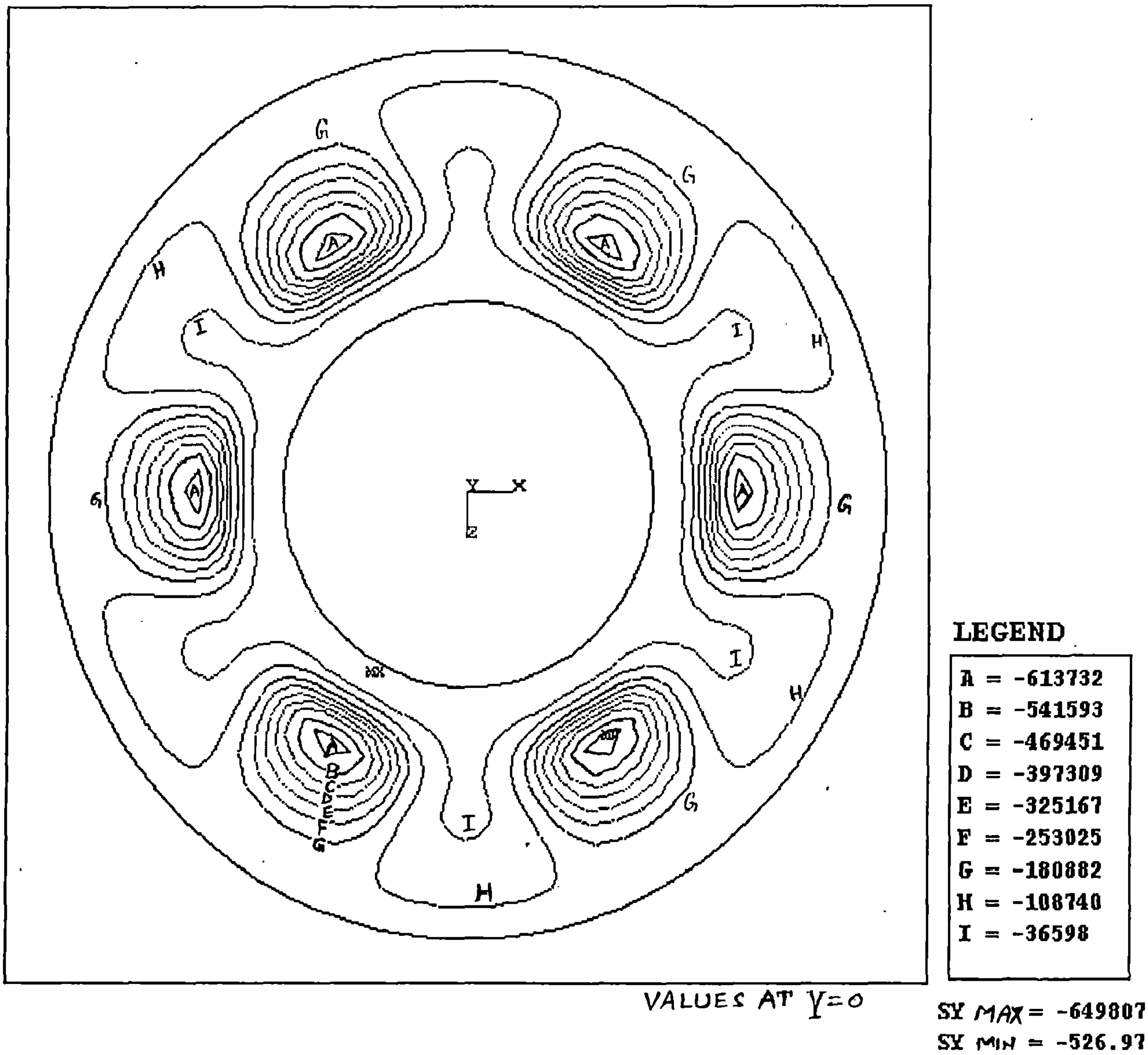
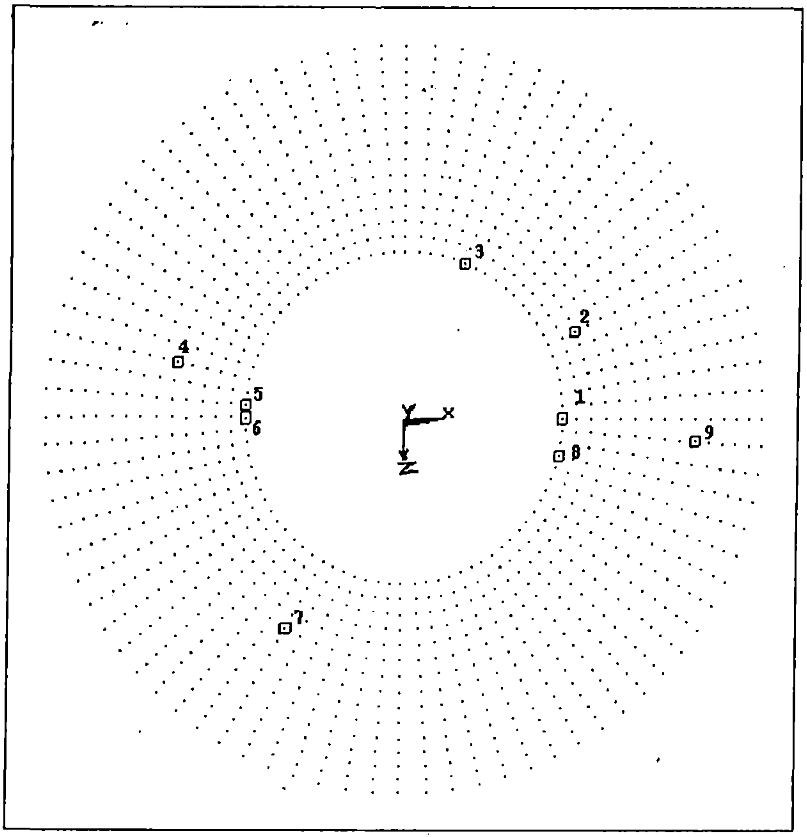


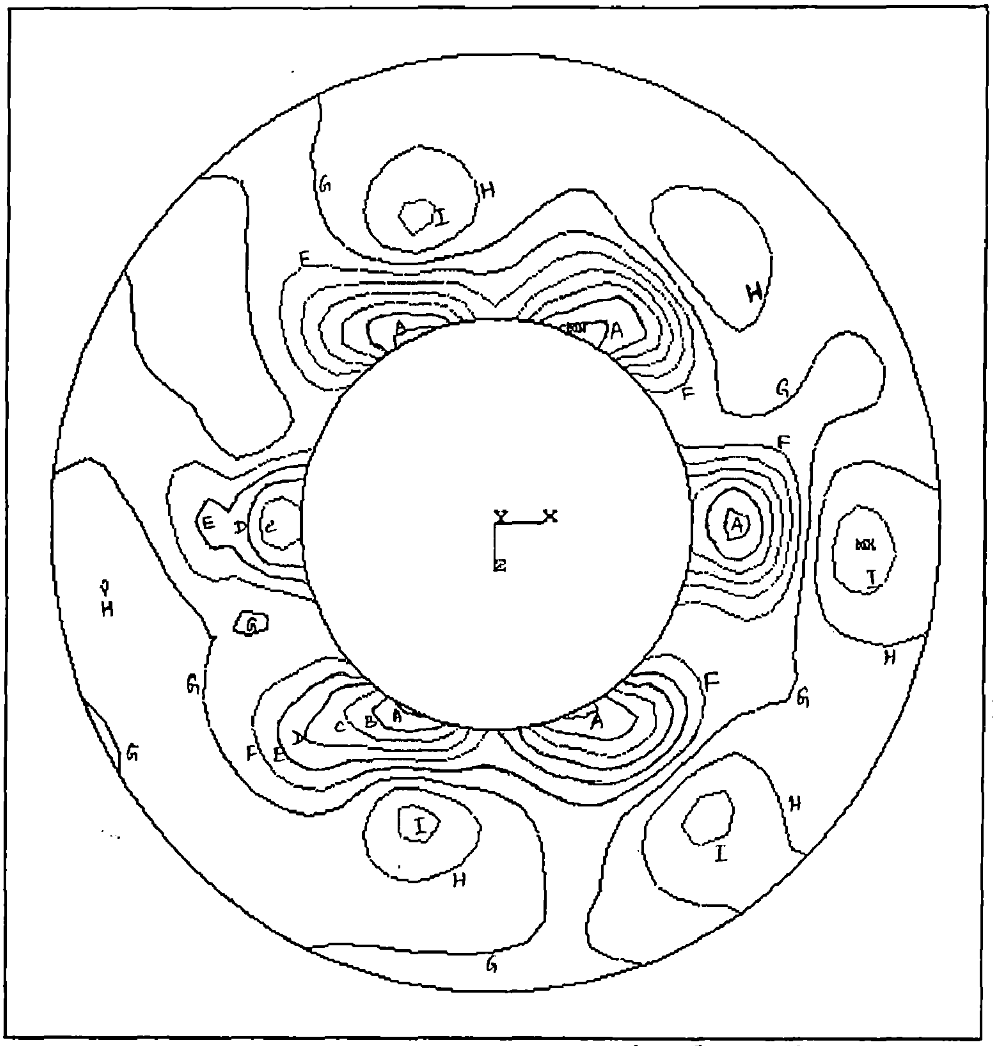
FIG. 6·6 CONTOUR OF SY FOR MODEL CHILA39E3
(ONLY VERTICAL LOAD ACTING)

TABLE 6.4 NODAL STRESS COMPONENTS FOR MODEL CHILA39E4
(ALL THREE LOADS ARE ACTING)

SL. NO.	NODE	CO-ORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	85	2.45,0,0	-1.50E+06	-2.54E+05	14750	-1.71E+05	-1.55E+06	1.38E+06
2	947	2.61,0,-1.26	-7424.6	-8895.8	1601.2	3861.4	-14796	18657
3	2368	0.9,0,-2.28	-7.43E+05	-3.92E+05	-67034	34056	-9.46E+05	9.80E+05
4	6831	-3.49,0,-0.8	-6.54E+05	-19948	-2.89E+05	-25440	-7.88E+05	7.62E+05
5	7486	-2.44,0,-0.18	1.47E+06	-2.38E+05	86855	1.52E+06	1.76E+05	1.34E+06
6	7487	-2.45,0,0	1.49E+06	-2.43E+05	-14750	1.54E+06	1.75E+05	1.36E+06
7	9728	-1.79,0,3.1	-9.07E+05	-33285	-2828.3	-2.09E+05	-9.08E+05	7.00E+05
8	14746	2.38,0,0.55	-8.89E+05	-1.88E+05	2.72E+05	-54301	-1.02E+06	9.67E+05
9	14871	4.50,0,0.34	-3.83E+05	1.54E+05	1.09E+05	-1917.2	-4.77E+05	4.75E+05
	MINIMUM VALUE							
	NODE		85	2368	6831	9728	85	947
	VALUE		-1.50E+06	-3.92E+05	-2.89E+05	-2.09E+05	-1.55E+06	18657
	MAXIMUM VALUE							
	NODE		7487	14871	14746	7487	7486	85
	VALUE		1.49E+06	1.54E+05	2.72E+05	1.54E+06	1.76E+05	1.38E+06



NODES LOCATION FOR TABLE 6·4



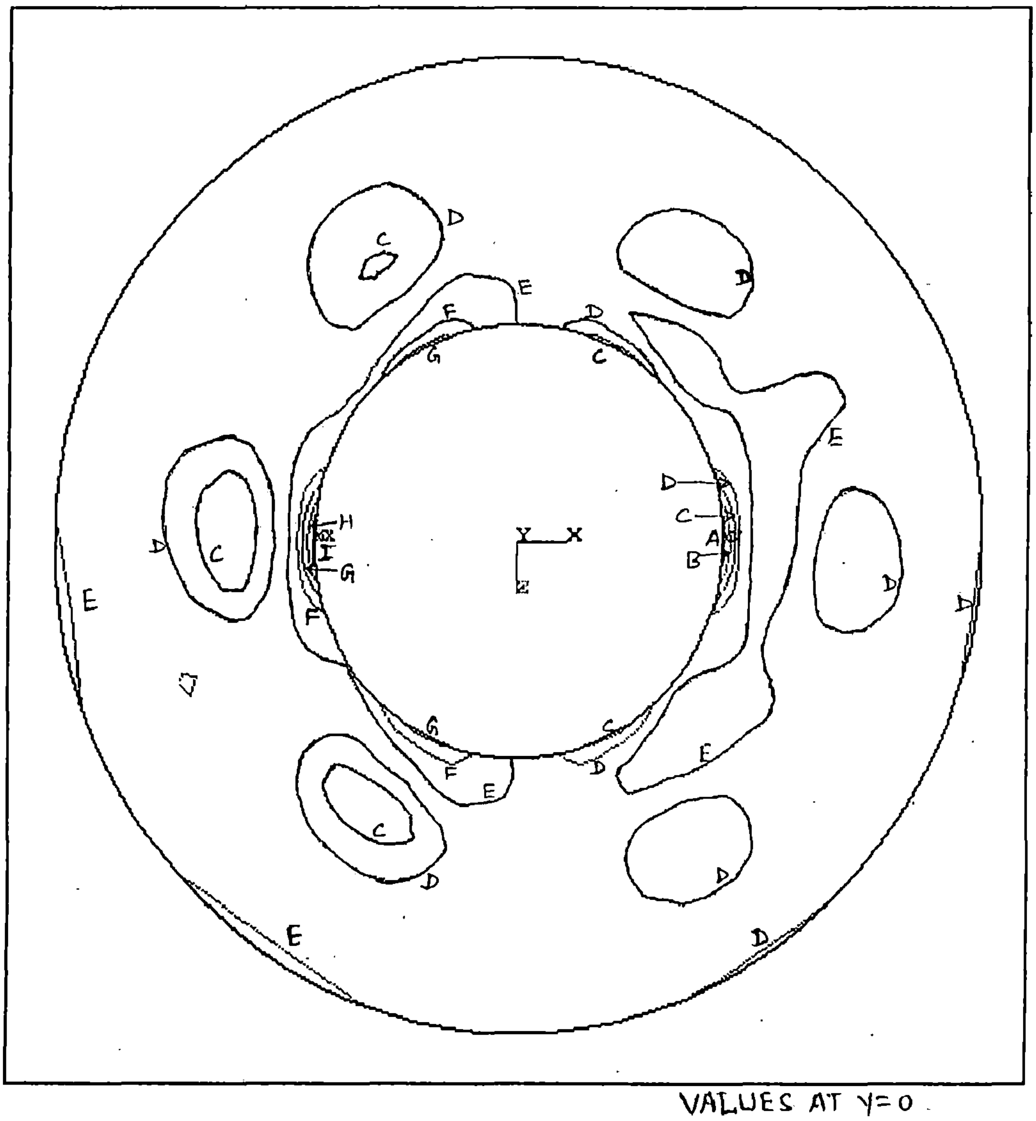
LEGEND (IN N/M^2)

A = -361255	
B = -300587	
C = -239920	
D = -179252	
E = -116565	
F = -57918	
G = 2749	
H = 63417	
I = 124084	

VALUES AT Y=0

SXY MAX = -391588

FIG. 6·7 CONTOUR OF SXY FOR MODEL CHILA39E4
(ALL THREE LOADS ACTING)



LEGEND (IN N/M^2)

A	= -1340000
B	= -1000000
C	= -671629
D	= -338437
E	= -5245
F	= 327947
G	= 661139
H	= 994331
I	= 1330000

SY MIN = -1500000
SY MAX = 1490000

FIG. 6.8 CONTOUR OF SY FOR MODEL CHILA39E4 (ALL THREE LOADS ACTING)

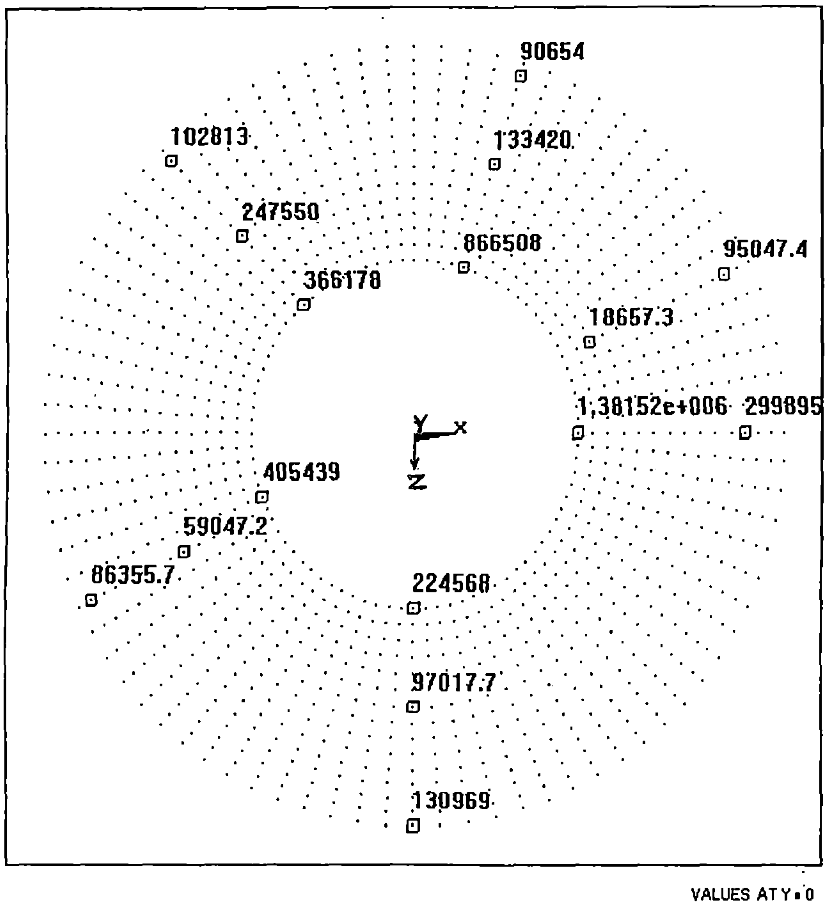
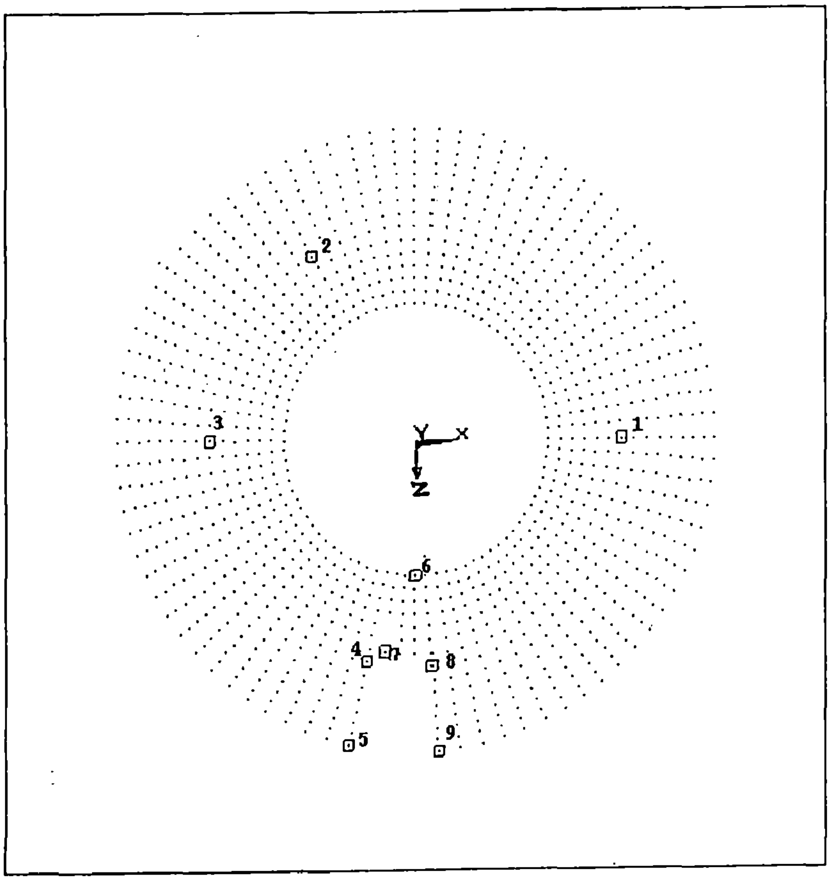


FIG. 6.9 DISTRIBUTION OF SINT FOR MODEL CHILA39E4
(ALL THREE LOADS ACTING)

TABLE 6.5 NODAL STRESS COMPONENTS FOR MODEL CHILA39F1
(ONLY TANGENTIAL LOAD IS ACTING)

SL.NO.	NODE	COORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	104	3.82,0,0	10.276	-9.0435	1.37E+05	1.37E+05	-1.37E+05	2.74E+05
2	4631	-1.91,0,-3.31	-9.23E-02	1.18E+05	-68380	1.37E+05	-1.37E+05	2.74E+05
3	7552	-3.82,0,0	-32.249	-32.998	-1.37E+05	1.37E+05	-1.37E+05	2.74E+05
4	10538	-0.9,0,3.95	4.21E+05	-1.11E+05	-86783	4.71E+05	28888	4.42E+05
5	10751	-1.23,0,5.41	2.58E+05	250.6	-68538	2.79E+05	30791	2.48E+05
6	11128	0,0,2.45	-1615.4	-10216	-687.59	9261.6	-11255	20516
7	11191	-0.57,0,3.78	1.85E+05	-1.56E+05	-39606	2.90E+05	-60991	3.51E+05
8	11266	0.3,0,4.04	-2.28E+05	-98232	30748	4327.3	-2.73E+05	2.78E+05
9	11479	0.41,0,5.53	-1.82E+05	-28556	36945	-21256	-1.96E+05	1.75E+05
	MINIMUM VALUE							
	NODE		11266	11191	7552	11479	11266	11128
	VALUE		-2.28E+05	-1.56E+05	-1.37E+05	-21256	-2.73E+05	20516
	MAXIMUM VALUE							
	NODE		10538	4631	104	10538	10751	10538
	VALUE		4.21E+05	1.18E+05	1.37E+05	4.71E+05	30791	4.42E+05



NODES LOCATION FOR TABLE 6.5

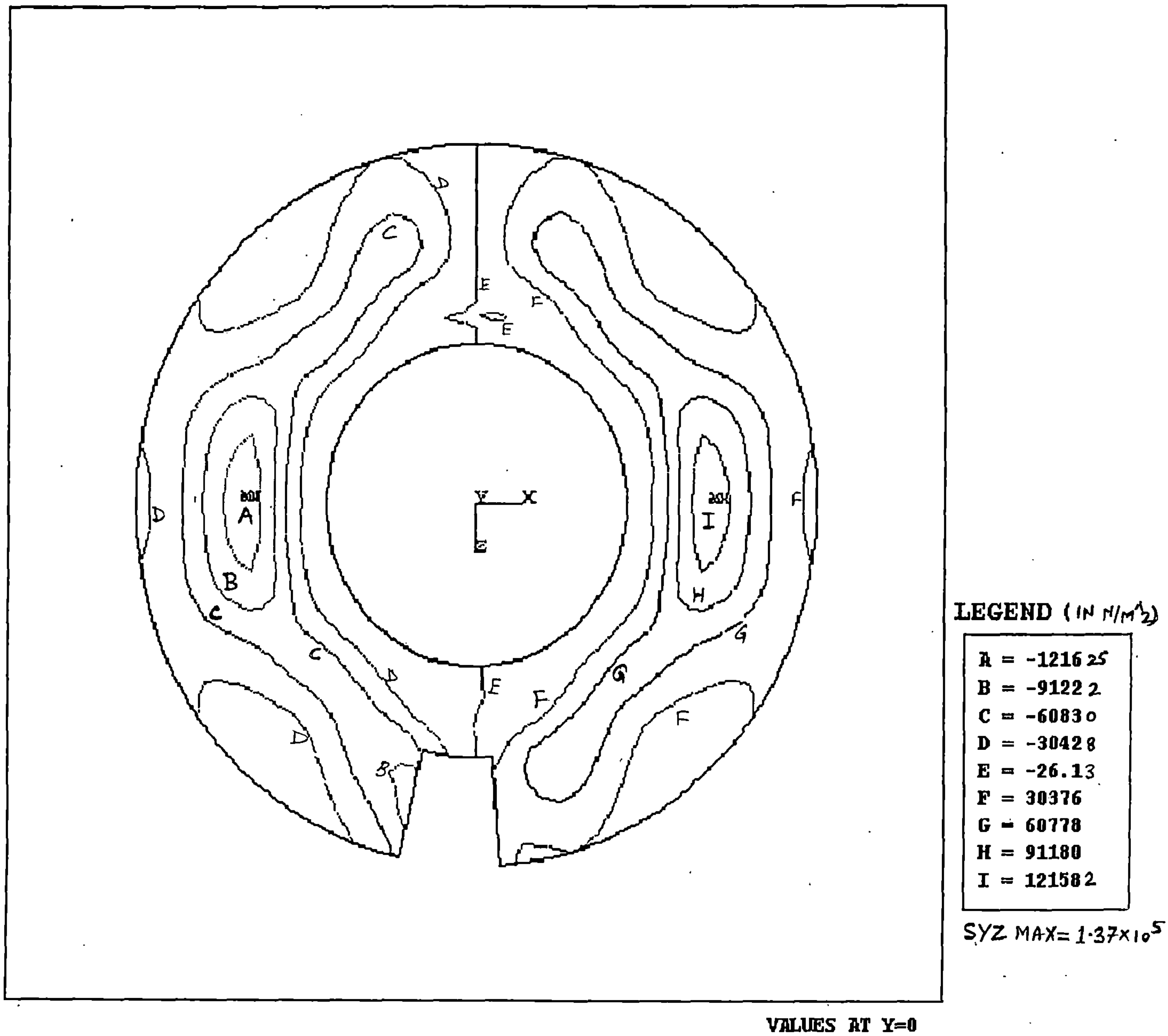


FIG. 6·10 CONTOUR OF SYZ FOR MODEL CHILA39F1
(ONLY TANGENTIAL LOAD ACTING)

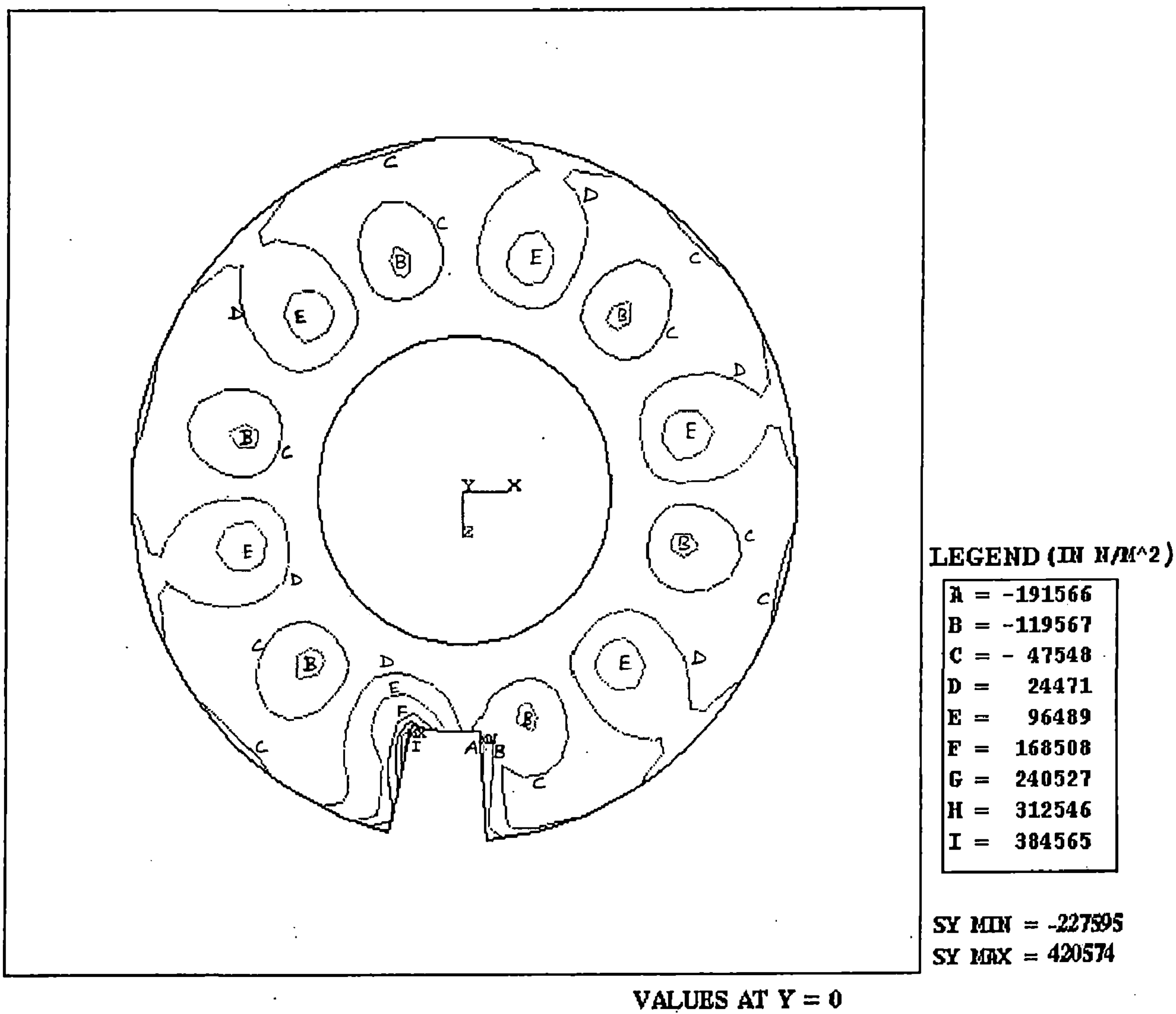
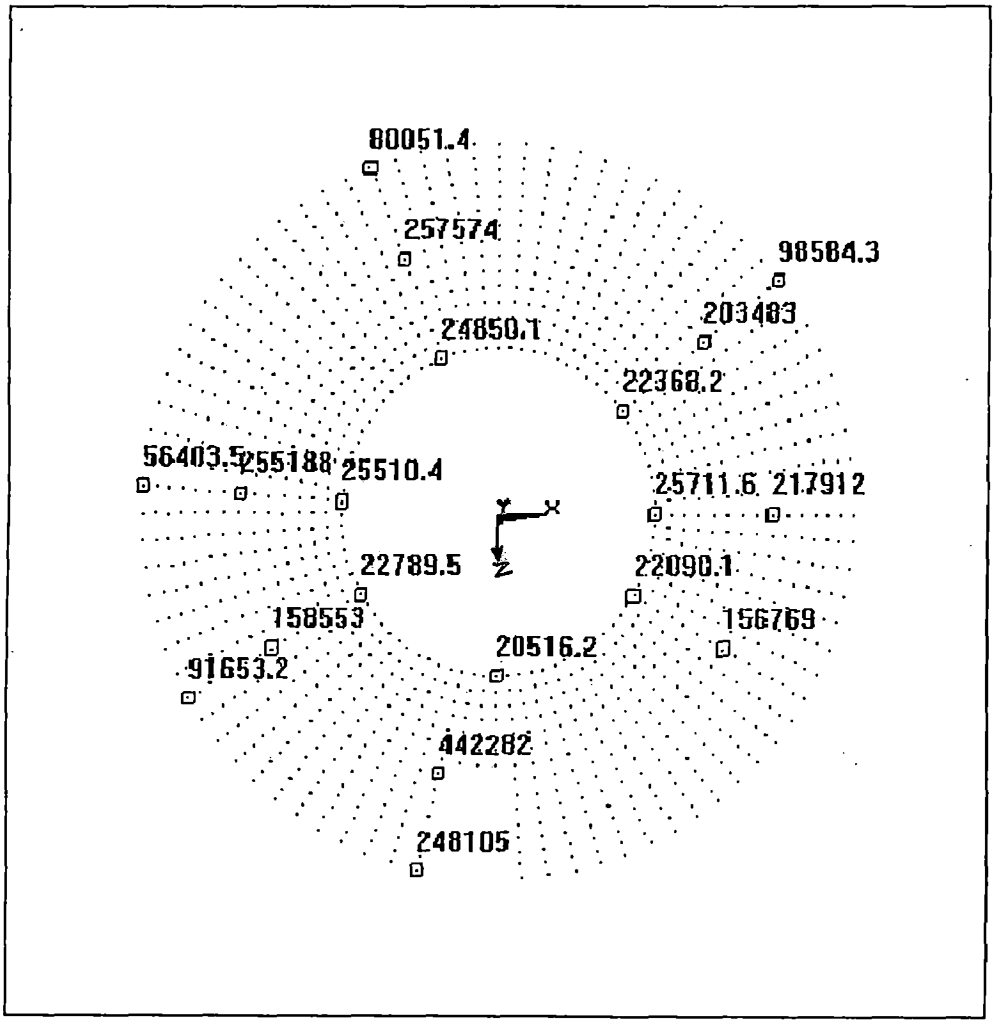


FIG. 6-11 CONTOUR OF SY FOR MODEL CHILA39F1
(ONLY TANGENTIAL LOAD ACTING)



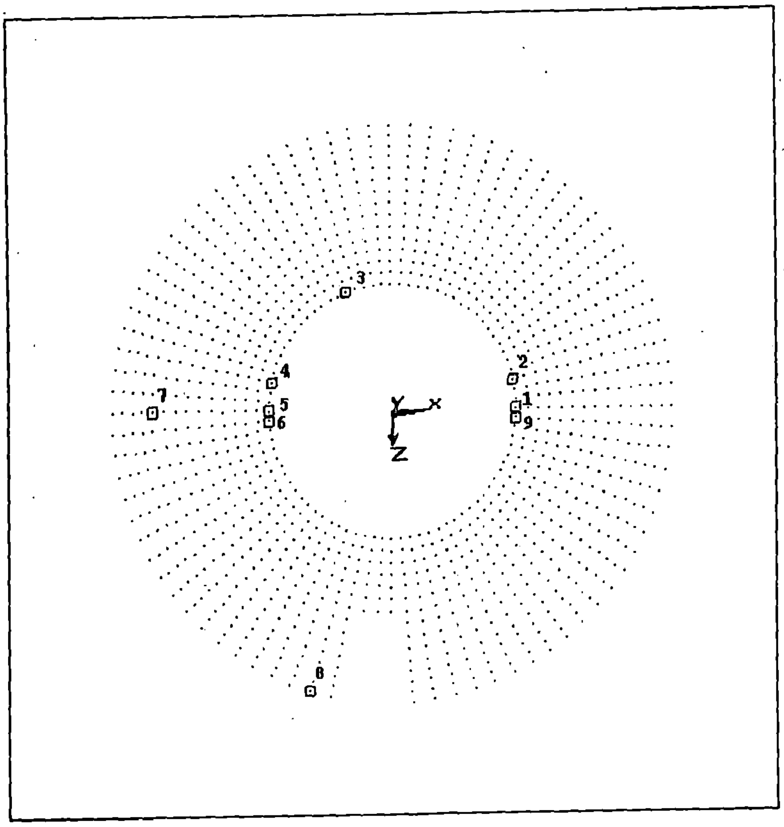
VALUES AT Y = 0

FIG. 6.12 DISTRIBUTION OF SINT FOR MODEL CHILA39F1
(ONLY TANGENTIAL LOAD ACTING)

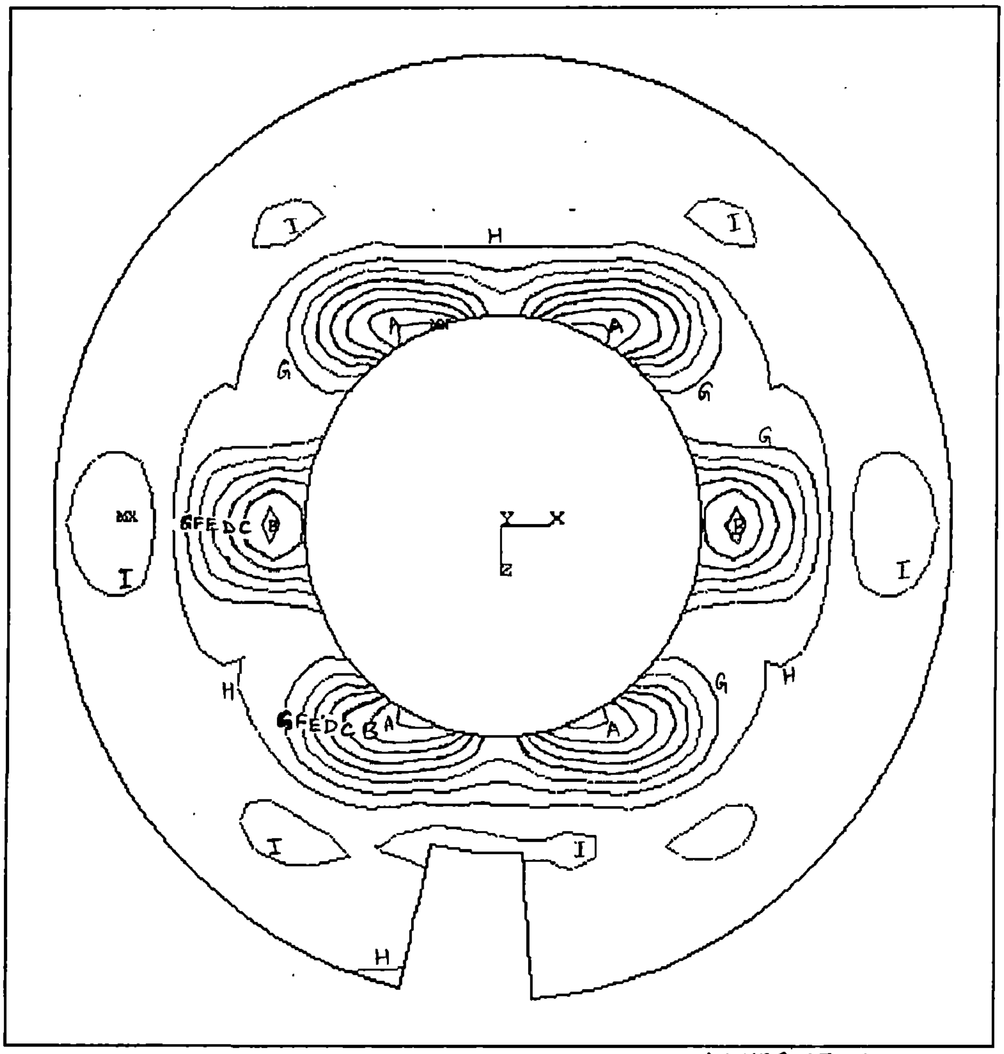
TABLE 6.6 NODAL STRESS COMPONENTS FOR MODEL CHILA39F2

(ONLY RADIAL LOAD IS ACTING)

SL. NO.	NODE	COORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	85	2.45, 0, 0	-1.50E+06	-2.48E+05	-2.7909	-1.73E+05	-1.55E+06	1.37E+06
2	205	2.39,0, -0.55	-8.80E+05	-1.81E+05	-2.61E+05	-60167	-1.00E+06	9.44E+05
3	4575	-0.90, 0, -2.28	7.12E+05	-3.81E+05	83334	9.14E+05	-40478	9.55E+05
4	6760	-2.39, 0, -0.55	8.80E+05	-1.81E+05	2.61E+05	1.00E+06	60167	9.44E+05
5	7487	-2.45, 0, 0	1.50E+06	-2.48E+05	8.9147	1.55E+06	1.73E+05	1.37E+06
6	7488	-2.44, 0, 0.18	1.47E+06	-2.44E+05	-1.01E+05	1.53E+06	1.74E+05	1.35E+06
7	7640	-4.75, 0, 0	78874	82803	34.772	1.37E+05	-38659	1.76E+05
8	10761	-1.64, 0, 5.3	646.52	1580.6	1674	2193.6	-2800.2	4993.8
9	14748	2.44, 0, 0.18	-1.47E+06	-2.44E+05	1.01E+05	-1.74E+05	-1.53E+06	1.35E+06
	MINIMUM VALUE							
	NODE		85	4575	205	14748	85	10761
	VALUE		-1.50E+06	-3.81E+05	-2.61E+05	-1.74E+05	-1.55E+06	4993.8
	MAXIMUM VALUE							
	NODE		7487	7640	6760	7487	7488	85
	VALUE		1.50E+06	82803	2.61E+05	1.55E+06	1.74E+05	1.37E+06



NODES LOCATION FOR TABLE 6.6



VALUES AT Y=0

LEGEND (IN N/M^2)

A =	-355515
B =	-303948
C =	-252381
D =	-200814
E =	-149248
F =	-97681
G =	-46114
H =	5453
I =	57020

SXY MAX = 381298

FIG. 6·13 CONTOUR OF SXY FOR MODEL CHILA39F2
(ONLY RADIAL LOAD ACTING)

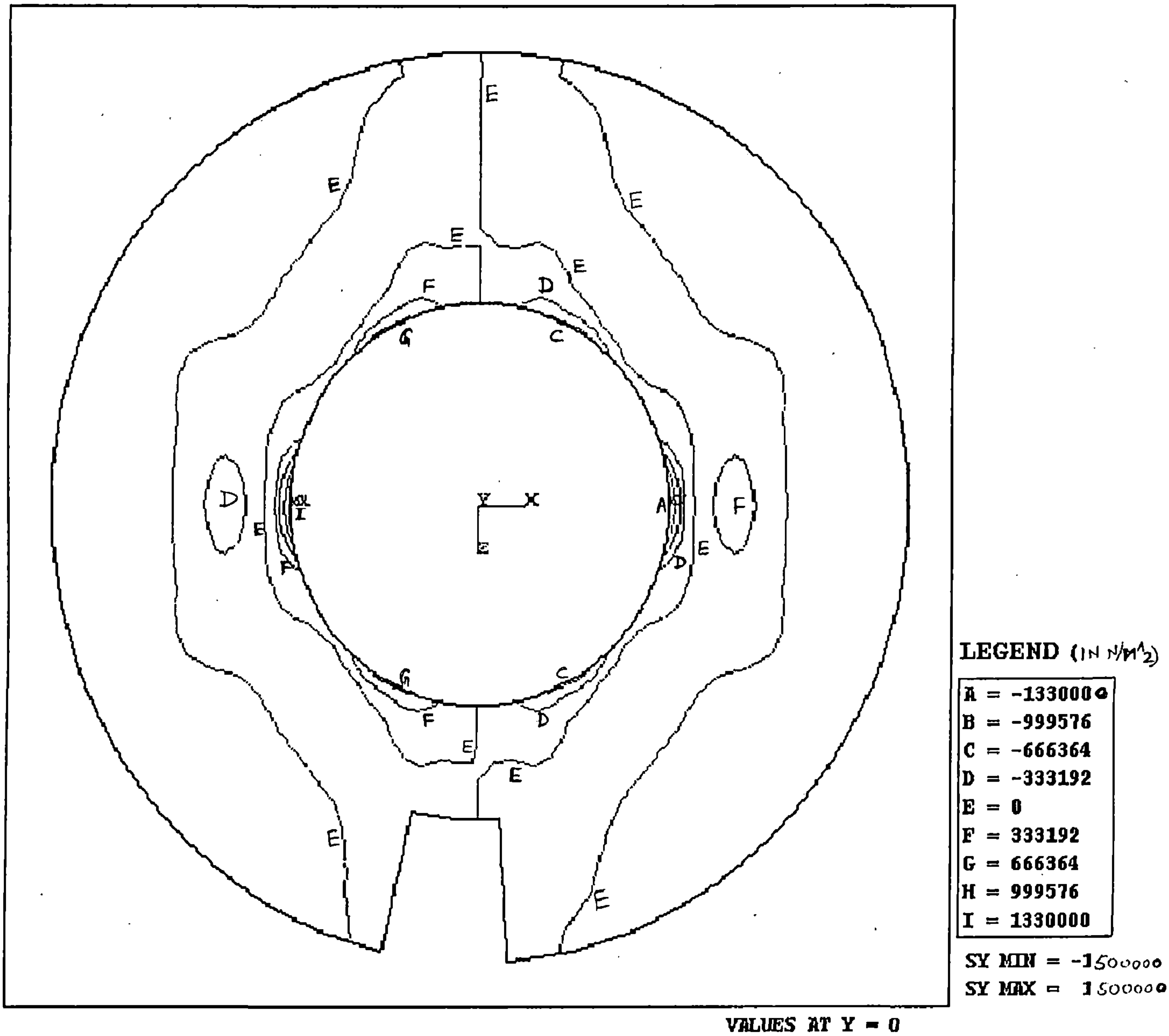
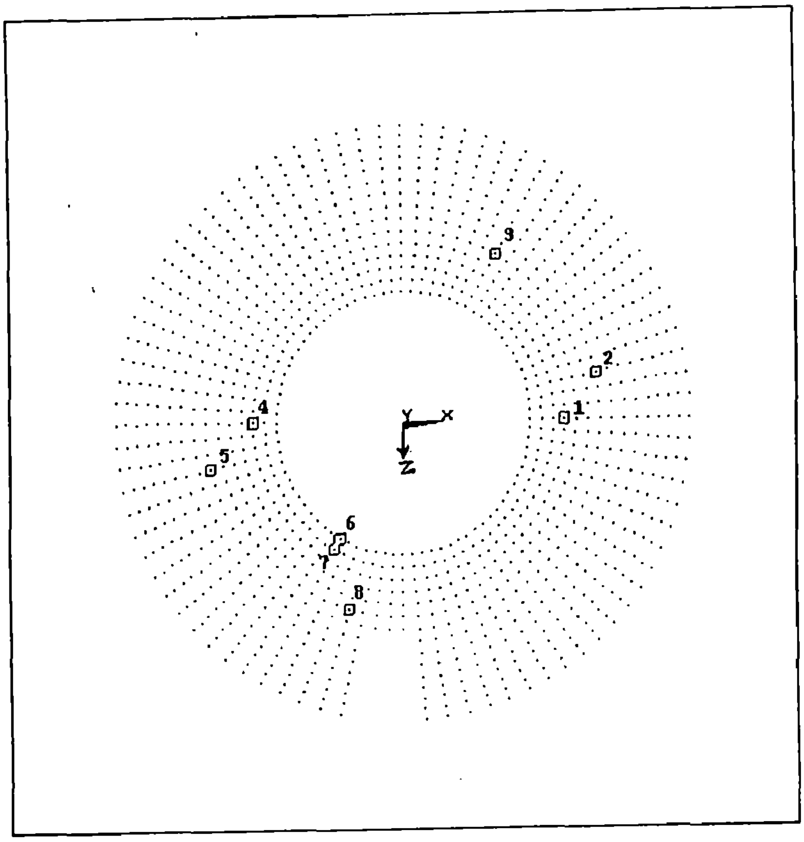


FIG. 6·14 CONTOUR OF SY FOR MODEL CHILA39F2
(ONLY RADIAL LOAD ACTING)

TABLE 6.7 NODAL STRESS COMPONENTS FOR MODEL CHILA39F3
(ONLY VERTICAL LOAD ACTING)

SL. NO.	NODE	COORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	86	3.13, 0, 0	-2.31E+05	-96436	3.9954	-19277	-2.75E+05	2.55E+05
2	273	3.72, 0, -0.85	-3.30E+05	1749.7	-93069	-50999	-3.61E+05	3.10E+05
3	2462	1.79, 0, -3.10	-6.50E+05	-10771	18655	-1.50E+05	-6.51E+05	5.01E+05
4	7499	-2.9, 0, 0	-46425	57221	10.617	25552	-91914	1.17E+05
5	8279	-3.72, 0, 0.85	-3.30E+05	-1700.2	93151	-50938	-3.61E+05	3.10E+05
6	9648	-1.23, 0, 2.12	-4802.7	2570.4	-4133.9	2983.3	-7846.3	10830
7	9651	-1.34, 0, 2.32	-400.99	9078.1	-15096	15976	-19349	35324
8	10471	-1.06, 0, 3.43	-3.67E+05	99405	18171	-58112	-4.00E+05	3.42E+05
	MINIMUM VALUE							
	NODE		2462	86	273	2462	2462	9648
	VALUE		-6.50E+05	-96436	-93069	-1.50E+05	-6.51E+05	10830
	MAXIMUM VALUE							
	NODE		9651	10471	8279	7499	9648	2462
	VALUE		-400.99	99405	93151	25552	-7846.3	5.01E+05



NODES LOCATION FOR TABLE 6.7

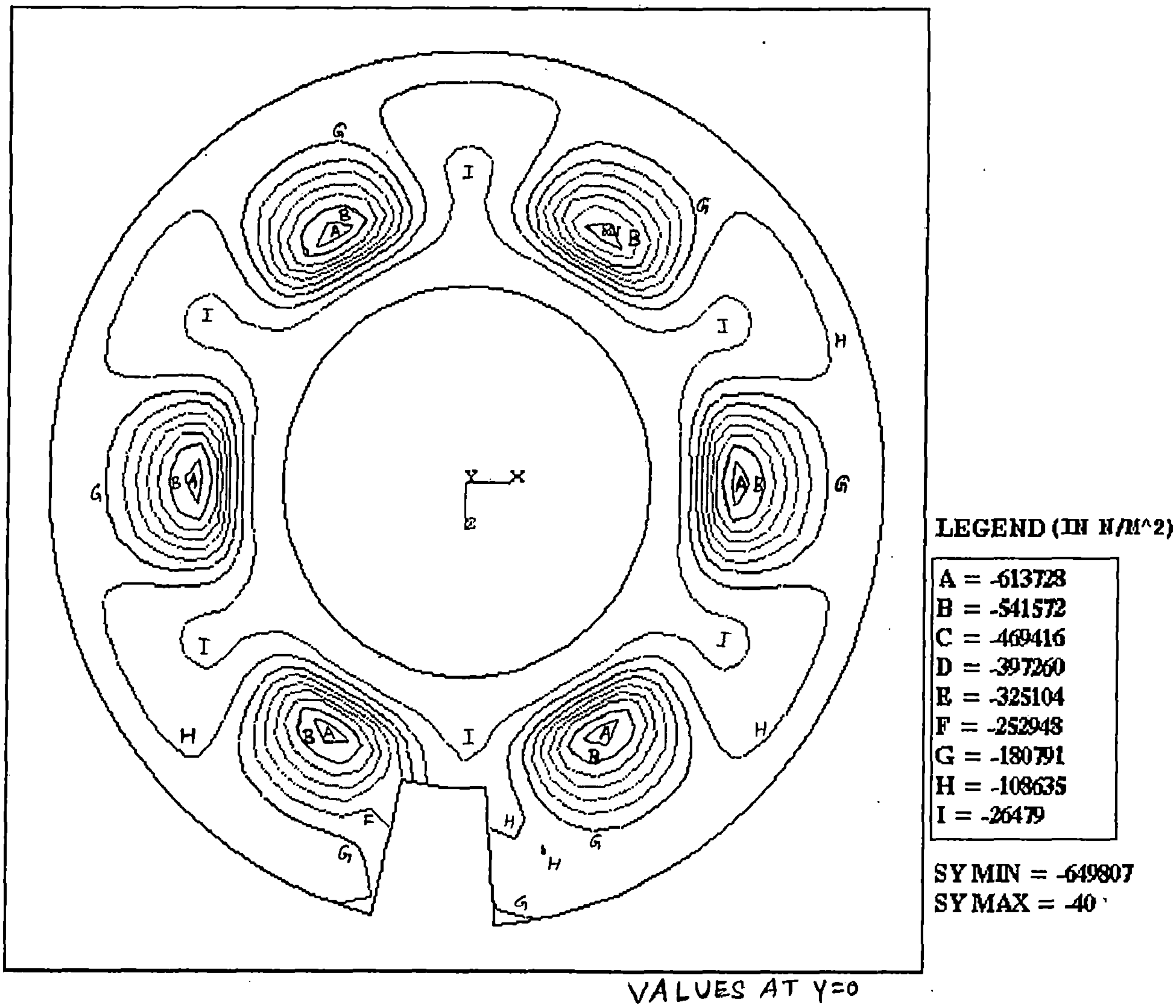
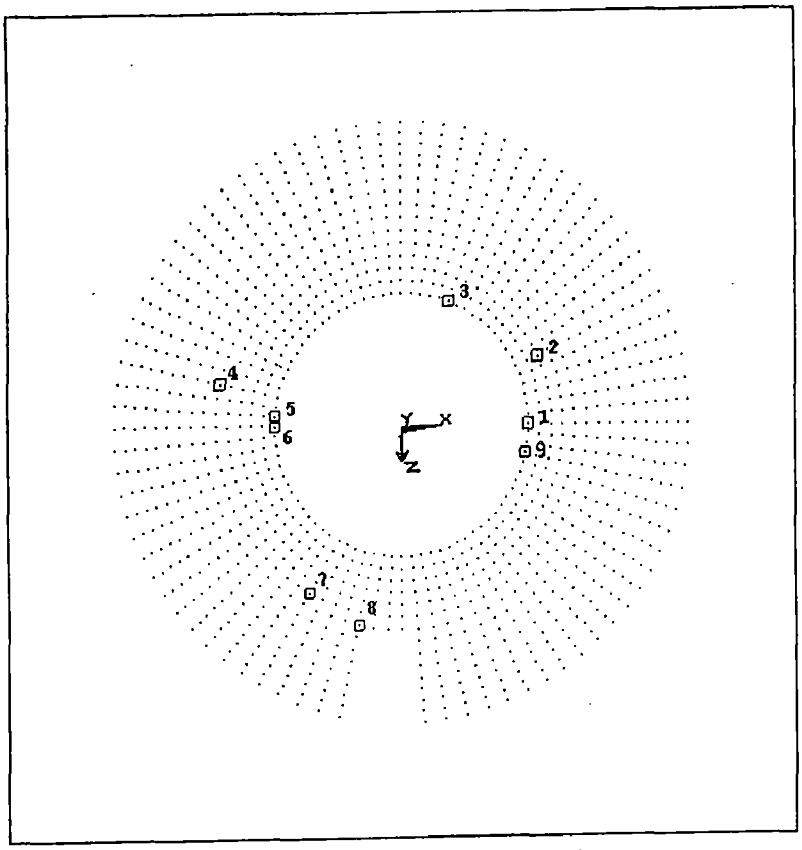


FIG. 6·15 CONTOUR OF SY FOR MODEL CHILA39F3
(ONLY VERTICAL LOAD ACTING)

TABLE 6.8 NODAL STRESS COMPONENTS FOR MODEL CHILA39F4
(ALL THREE LOADS ACTING)

SL. NO.	NODE	COORDINATE	SY	SXY	SYZ	S1	S3	SINT
1	85	2.45,0,0	-1.50E+06	-2.54E+05	14752	-1.71E+05	-1.55E+06	1.38E+06
2	947	2.61,0,-1.26	-7424.5	-8895.8	1601.3	3861.4	-14796	18657
3	2368	0.9,0,-2.28	-7.43E+05	-3.92E+05	-67034	34056	-9.46E+05	9.80E+05
4	6831	-3.35,0,-.8	-6.54E+05	-19948	-2.89E+05	-25445	-7.88E+05	7.62E+05
5	7486	-2.44,0,-.18	1.47E+06	-2.38E+05	86861	1.52E+06	1.76E+05	1.34E+06
6	7487	-2.45,0,0	1.49E+06	-2.43E+05	-14742	1.54E+06	1.75E+05	1.36E+06
7	9728	-1.79,0,3.1	-9.05E+05	-30027	-1474.9	-2.08E+05	-9.06E+05	6.98E+05
8	10455	-0.85,0,3.72	-3.61E+05	1.58E+05	15700	-14584	-4.34E+05	4.19E+05
9	14746	2.39,0,0.55	-8.89E+05	-1.88E+05	2.72E+05	-54299	-1.02E+06	9.67E+05
	MINIMUM VALUE							
	NODE		85	2368	6831	9728	85	947
	VALUE		-1.50E+06	-3.92E+05	-2.89E+05	-2.08E+05	1.55E+06	18657
	MAXIMUM VALUE							
	NODE		7487	10455	14746	7487	7486	85
	VALUE		1.49E+06	1.58E+05	2.72E+05	1.54E+06	1.76E+05	1.38E+06



NODES LOCATION FOR TABLE 6.8

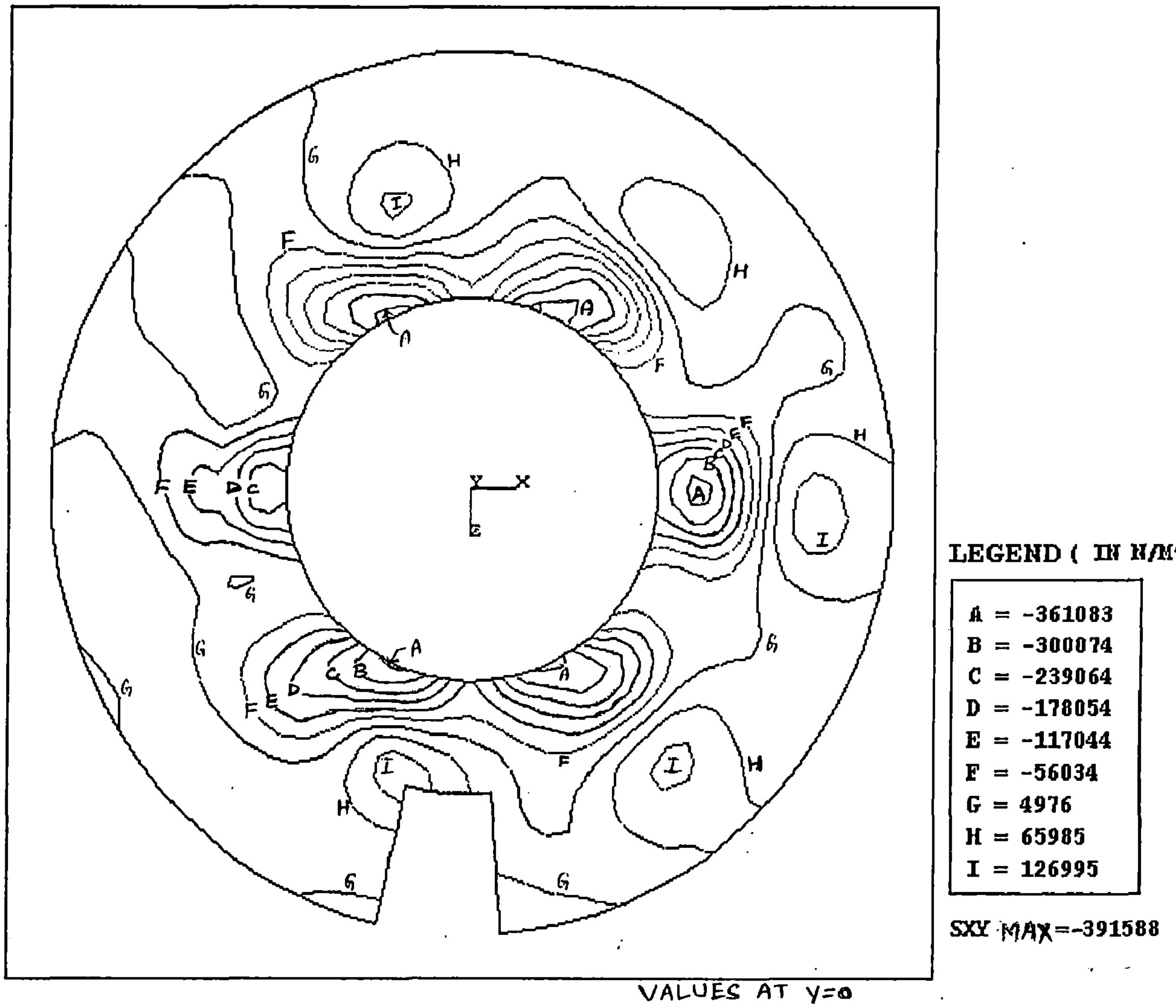
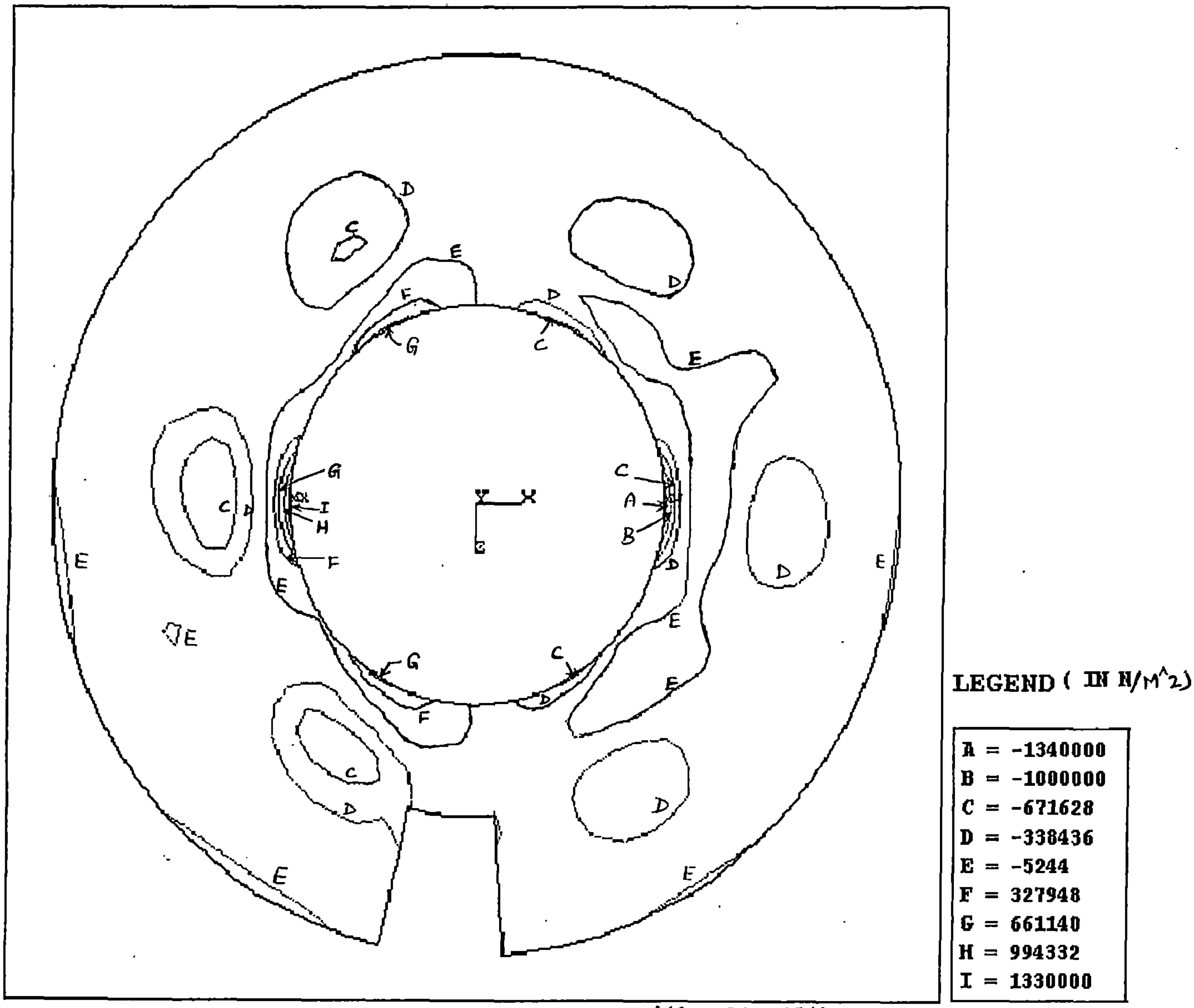


FIG. 6·16 CONTOUR OF SXY FOR MODEL CHILA39F4

(ALL THREE LOADS ACTING)



VALUES AT Y=0

SY MIN = -1500000
SY MAX = 1490000

FIG. 6·17 CONTOUR OF SY FOR MODEL CHILA39F4
(ALL THREE LOADS ACTING)

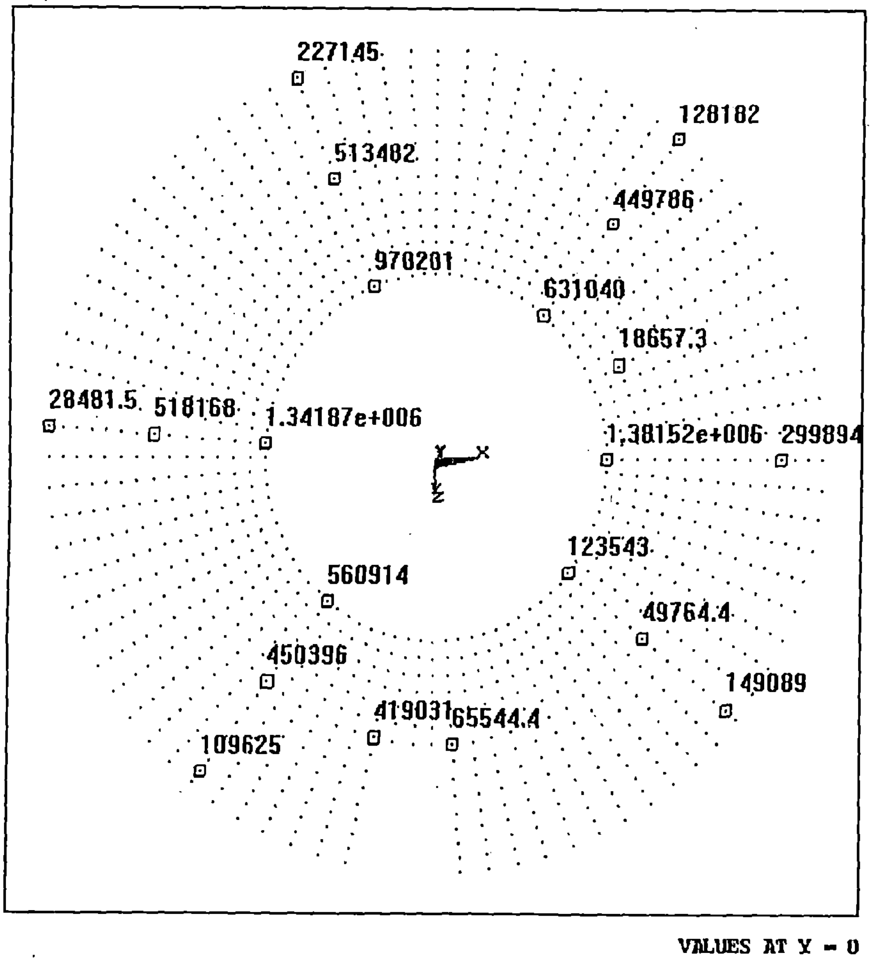


FIG. 6.18 DISTRIBUTION OF SINT FOR MODEL CHILA39F4
(ALL THREE LOADS ACTING)

TABLE 6.9 VARIATION OF NODAL STRESSES IN RADIAL DIRECTION FOR MODEL CHILA39E1
(ONLY TANGENTIAL LOAD ACTING)

NODE	X	Y	Z	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
85	2.45	0	0	0	0	0	0	12849	-126	12850	1.24E-07	-12850	25699
88	2.675	0	0	0	0	0	0	18096	-233.96	18097	1.75E-07	-18097	36195
87	2.9	0	0	0	0	0	0	33624	-128.93	33624	3.25E-07	-33624	67248
86	3.125	0	0	0	0	0	0	62815	191.28	62816	6.07E-07	-62816	1.26E+05
84	3.35	0	0	0	0	0	0	99085	385.45	99086	9.58E-07	-99086	1.98E+05
105	3.585	0	0	0	0	0	0	1.28E+05	215.2	1.28E+05	1.24E-06	-1.28E+05	2.56E+05
104	3.82	0	0	0	0	0	0	1.37E+05	74.988	1.37E+05	1.32E-06	-1.37E+05	2.74E+05
127	4.0525	0	0	0	0	0	0	1.28E+05	126.85	1.28E+05	1.24E-06	-1.28E+05	2.56E+05
126	4.285	0	0	0	0	0	0	1.09E+05	177.35	1.09E+05	1.05E-06	-1.09E+05	2.18E+05
125	4.5175	0	0	0	0	0	0	86230	192.03	86230	8.34E-07	-86230	1.72E+05
124	4.75	0	0	0	0	0	0	64636	196.12	64637	6.25E-07	-64637	1.29E+05
156	4.95	0	0	0	0	0	0	49517	173.73	49518	4.79E-07	-49518	99035
155	5.15	0	0	0	0	0	0	37949	170.1	37949	3.67E-07	-37949	75899
170	5.35	0	0	0	0	0	0	28862	312.71	28864	2.79E-07	-28864	57728
169	5.55	0	0	0	0	0	0	21356	128.16	21356	2.06E-07	-21356	42713
MINIMUM VALUE				0	0	0	0	12849	-233.96	12850	1.24E-07	-1.37E+05	25699
MAXIMUM VALUE				0	0	0	0	136760	3.85E+02	136760	1.32E-06	-1.29E+04	273520

TABLE 6.10 VARIATION IN NODAL STRESSES IN RADIAL DIRECTION FOR MODEL CHILA39F1
(ONLY TANGENTIAL LOAD ACTING)

NODE	X	Y	Z	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
85	2.45	0	0	0.35814	0.36261	0.15209	-1.2836	12855	-126.08	12856	0.33297	-12856	25712
88	2.675	0	0	0.44828	2.3429	0.56896	-1.945	18103	-233.97	18106	0.39833	-18103	36210
87	2.9	0	0	0.50388	2.0436	0.52385	-3.1573	33633	-128.91	33634	0.4797	-33632	67266
86	3.125	0	0	0.4628	1.3649	0.38427	-4.1155	62827	191.31	62828	0.48787	-62827	1.26E+05
84	3.35	0	0	0.79451	2.5134	0.69238	-5.0601	99101	385.47	99103	0.8339	-99100	1.98E+05
105	3.585	0	0	1.5802	6.52	1.6698	-6.6865	1.28E+05	215.21	1.28E+05	1.6026	-1.28E+05	2.56E+05
104	3.82	0	0	2.4308	10.276	2.6101	-9.0435	1.37E+05	75	1.37E+05	2.4408	-1.37E+05	2.74E+05
127	4.0525	0	0	2.9609	12.075	3.0898	-11.261	1.28E+05	126.85	1.28E+05	2.9832	-1.28E+05	2.56E+05
126	4.285	0	0	3.1982	12.712	3.273	-12.693	1.09E+05	177.33	1.09E+05	3.2395	-1.09E+05	2.18E+05
125	4.5175	0	0	3.3743	13.186	3.4109	-13.316	86256	192	86265	3.4336	-86248	1.73E+05
124	4.75	0	0	3.6809	14.318	3.7109	-13.358	64664	196.09	64673	3.7621	-64655	1.29E+05
156	4.95	0	0	4.2927	16.481	4.2877	-13.069	49546	173.7	49557	4.3845	-49536	99093
155	5.15	0	0	5.4316	20.803	5.4168	-12.762	37980	170.08	37994	5.5462	-37968	75961
170	5.35	0	0	8.537	28.015	7.5649	-12.033	28897	312.62	28916	8.7996	-28881	57797
169	5.55	0	0	10.618	57.82	13.993	-11.406	21395	128.3	21431	10.756	-21360	42791
MINIMUM VALUE				0.35814	0.36261	0.15209	-13.358	12855	-233.97	12856	0.33297	-136780	25712
MAXIMUM VALUE				10.618	57.82	13.993	-1.2836	136780	385.47	136790	10.756	-12856	273570

TABLE 6.11 DISTRIBUTION OF SHEAR STRESS IN A VERTICAL SECTION OF A BARREL

An imaginary barrel with greater L/D ratio was considered and analysed to see the shear stress distribution pattern under tangential loading. Dimensions assumed are

Outer radius = 3.4 m   Inner radius = 1m   Height = 5m

Loads are applied at four locations only and 3 nodes per location . Load per node=5000 N AT DIST.. 2.2M FROM CENTRE

From conventional method shear stress at outer and inner surfaces are 2154.2 and 633.6 N/m^2.

Considering X as radial direction and Y as axial direction and centre of the base at x=0,y=0 results are tabulated below:

	Shear stress (in N/m^2) at X =								
Y	1	1.3	1.6	1.9	2.2	2.5	2.8	3.1	3.4
0	**665.12**	866	1064.6	1263	1460.8	1659	1858.1	2059	**2260.14**
0.5	664.27	866	1064	1261.4	1458.5	1655.8	1854	2053.6	2256.57
1	664	865.5	1062.1	1257.1	1451.4	1645.8	1841.4	2039.7	2242.5
2	666.7	868.7	1058.7	1243	1423.3	1601.3	1779.9	1962.4	2149.5
3	680.6	890.4	1065.6	1219	1369.4	1507.7	1642.3	1762.4	1844.7
3.5	685.7	981.9	1041.1	1225.3	1338.1	1465.3	1539.5	1611.8	1560.4
4	610.6	882.8	1219	1120	1421.2	1489.8	1617.3	1439.9	1165.4
4.5	366	522.3	271.7	4936	4722.2	4839.1	919	868.3	581.7
5	162.4	104.9	-994.4	8965.8	7996.6	8246.76	100.73	400.7	223.62

6.2 DISCUSSION OF RESULTS

Results obtained from the analysis in previous chapter are discussed in the following three groups.

6.2.1 Effect of Opening in 3-D Barrel Model

A comparision of results of the analysis of solid barrel and the barrel with opening has indicated vertical stress concentration at the sharp corners of the opening with the application of tangential load. Under other loads and all loads acting together there has been no change in the distribution of stresses and the value of maximum and minimum stress.

6.2.2 Comparison of Results with Conventional Results

i) Tangential Loading

In conventional method generator barrel is mainly analysed for tangential loading as it induces large shear stress exceeding permissible shear stress in concrete. Hence for comparison of results conventional analysis has been done for tangential load only. In conventional analysis (Chapter 5.3) maximum shear stress has occurred at outer surface while minimum shear stress at inner surface. The results obtained from FEM analysis given above have shown maximum shear stress in a central annular ring in which stator pedestals are located. The shear stress distribution has not been in conformity with that of conventional analytical method. Variation of shear stresses in radial direction for model chila39E1 and chila39F1 are shown in table 6.9 & table 6.10 respectively.

$$\text{Maximum shear stress} = \frac{\sigma_1 - \sigma_3}{2} = \frac{SINT}{2}$$

From FEM, maximum shear stress = 2.21×10^5 N/m^2

Maximum shear stress calculated by conventional method is 2.62×10^5 N/m^2. Therefore, the shear stress distribution is found different in the two methods but the maximum shear stress value is quite close. In conventional method, it is assumed that longitudinal stresses (SY) due to torque (tangential load) are insignificant, but from FEM analysis in this case longitudinal stresses are quite considerable. The concentration of these stresses 4.21×10^5 N/m^2 tensile and 2.28×10^5 N/m^2 compressive (Table 6.5) has been observed at the sharp corners of the openings.

In conventional method it is assumed that tangential force is applied uniformly over the section and length/diameter ratio is quite large so that pure shear can develop. But for the case analysed, loading is not uniform over the section but the force acts through six pedestals, and each pedestal transfers the force on 15 nodes. Secondly length/diameter ratio in this case is very small (L/D < 1/10). Therefore pure shear condition could not developed in this case and applied load did not get enough length to even out. This is therefore, the reason to get different type of shear stress distribution by the two methods. The analysis of a solid barrel of large L/D ratio by FEM (results tabulated in Table 6.11) has shown that at greater depth the shear stress distribution across the radius follows the same pattern as obtained by conventional method.

ii) **Radial Loading**

In conventional method effect of radial loading is taken in X-Z plane only and it is checked for average shear stress in this plane. But results from FEM analysis reveal that in addition to shear stress there is considerable value of normal stress (SY) in longitudinal direction, though it is concentrated at the base plate edge on the inner surface

(Fig. 6.14). It is tensile or compressive depending on direction of force and has a value of 15×10^5 N/m^2.

Maximum normal stress in longitudinal direction = 1.50×10^6 N/m^2

The maximum shear stress is 6.85×10^5 N/m^2

iii) **Vertical Loading**

In conventional method vertical load is assumed to be dispersed at 45^0 and are considered uniformly distributed at the base of the barrel. The normal stress contours due to vertical loading are shown in Fig. 6.15 . From these stress contours it is seen that stresses are concentrated below stator pedestals only. The reason for this difference may be attributed to the small height of barrel due to which load distribution could not be effective at the base of barrel.

iv) **The all three loads acting simultaneously**

In conventional analysis effect of each loading is taken individually and stresses due to each are taken care of in design. But FEM analysis gives stresses for the combined loading also. It can help in developing an economical design.

6.2.3 Whether Stresses are Within Permissible Limits

As per BIS Code (IS:456-1978) permissible stresses for M 20 concrete are :

i) In direct tension = 2.8 N/mm^2 = 2.8×10^6 N/m^2 (when all the tensile stress will be taken by steel).

ii) Shear stress (considering nominal reinforcement in longitudinal direction) = 0.22 N/mm^2 = 0.22×10^6 N/m^2

iii) In direct compression, σ_{cc} = 5.0 N/mm^2 = 5×10^6 N/m^2

iv) Flexural strength $f_{cr} = 0.7\sqrt{f_{ck}} = 0.7 \times \sqrt{20}$ = 3.13 N/mm^2 = 3.13×10^6 N/m^2

Result from FEM under combined loading have shown that

(i) Maximum tension = 1.49 $\times 10^6$ N/m^2 < 2.8 $\times$ 10^6 N/m^2 (Hence reinforcement has to be provided for this stress.)

(ii) Maximum shear stress = (1.38$\times$ 10^6) / 2 = 0.69 $\times$ 10^6 N/m^2 > 0.22 $\times$ 10^6 N/m^2, hence not safe in shear and reinforcement has to be provided for shear stress.

(iii) Maximum direct compression = 1.50 $\times 10^6$ N/m^2 < 5.0 $\times$ 10^6 N/m^2, hence safe.

6.3 CONCLUSIONS

For the case (Chilla P.H. Generator barrel) analysed in this study by the two methods i.e. conventional and FEM, the following conclusions can be derived:

(i) The openings have little effect on the stress and the stress pattern for various loads and the load combination except the vertical stress concentration at the sharp corners of the opening which is inherent drawback of FEM analysis.

(ii) Because of very small L/D ratio of the barrel , load distribution could not be possible. Therefore the stresses and stress distribution by the two methods are not found comparable.

(iii) The results of analysis indicate that for small L/D ratio, the generator support should be designed as pedestals with adequate edge effect and not as a barrel, fixed at base and free at the top.

6.4 SUGGESTIONS FOR FURTHER STUDY

(i) The above conclusions can be generalised by analysing a number of cases with different L/D ratios and different opening sizes.

(ii) Further study can also determine the limit of L/D ratio for which analysis as a barrel will be applicable.

(iii) FEM analysis with refined mesh will be helpful in establishing quantitative relation between the stresses by the two methods of analysis.

(iv) The model can also be analysed for dynamic loads.

REFERENCES

1. Anonymous, IS: 456-1978, "Code of Practice for plain and reinforced concrete" Bureau of Indian Standard, New Delhi.
2. Anonymous, IS: 7207-1974, "Criteria for design of generator foundation for hydel power stations", Bureau of Indian Standard, New Delhi
3. Brown Gutherie, J. (1984), "Hydro- Electric Engineering practice, Vol. I", CBS publishers and distributors, Delhi
4. Chandrupatla, T.R. and Belegundu, A. (2000)- "Introduction to Finite Elements in Engineering", Prentice- Hill, Delhi.
5. Creager, William, P. and Justin, Joel D. (1950), "Hydro Electric Handbook", John Wiley and Sons, Inc. New York.
6. Desai, C.S. and Abel, J.F. (1987), "Introduction to Finite Element Method", CBS, Delhi
7. Kumar, Akhilesh (1978), "Economy of different type of generator", ME Dissertation ,WRDTC, University of Roorkee.
8. Nigam, P.S. (1985), "Handbook of Hydro Electric Engineering" Nem Chand and Bros. Roorkee
9. Masonyi, Emil, (1987), "Water Power Development" Vol-I and II Akademiai Kiado, Budapest.
10. Rao, S.S. (1982), "The finite Element Method in Engineering", Pergamon Press, Oxford.

11. Raynmond, J. Roark (1962), “Formulas for Stress and Strain”, McGraw-Hill Book company, Inc. New York.

12. Zienkiewicz, O.C. and Cheung, Y.K.(1968), "The Finite Element Method in Structural and Continuum Mechanics" , Mc Graw-Hill, London.