THREE DIMENSIONAL STRESS ANALYSIS OF RADIAL GATE USING FEM (ANSYS Software)

A DISSERTATION
Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT
(MECHANICAL)

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CANDIDATE'S DECLARATION

I do hereby declare that the dissertation entitled " THREE DIMENSIONAL STRESS ANALYSIS OF RADIAL GATE USING FEM (ANSYS Software)" is being submitted by me in partial fulfillment of requirement for the award of degree of "**Master of Technology** in **WATER RESOURCES DEVELOPMENT (MECHANICAL)**" and submitted in the Water Resources Development Training Centre, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from July, 2003 to June 2004 under the guidance of **Prof. Gopal Chauhan** Professor, **Prof. B.N. Asthana**, Visiting Professor, Water Resources Development Training Centre and **Dr. B.K. Mishra** Associate Professor, Mechanical and Industrial Engineering Department, Indian Institute of Technology, Roorkee.

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

22/06/04

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Dated: 22nd June, 2004
Place: IITR, Roorkee

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

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SYNOPSIS

The hydraulic gates are moving facilities provided in dams, barrages, hydropower projects, reservoir and, canal for flow control. Hydraulic gates are most important component of any water resources projects. Thus it needs specialized and expertise in regard to selection, planning and design, erection and maintenance. Any deviation in fulfilling the intended purposes can have devastating results, and sometimes may endanger the safety of the entire project. Mostly vertical lift gates and radial gates are used in water resources projects. These gates are designed as per guidelines followed in different Indian Standard Codes. These are based on mostly 2 D design approach. However in actual practice, structure behaves as 3 D structure. Hence displacements and stresses are developed in all three directions. The exact nature of stresses and displacement in different parts of gate, like joint between horizontal girder and vertical stiffener, horizontal girder & radial arm, radial arm & trunnion is quite complex and can be analyzed through 3 D analysis only.

In this dissertation an attempt has been made to study the stresses and displacement at critical part by the help of 3 D Model constructed through ANSYS 5.4 software. Also a comparative study between conventional approaches i.e. 2D approach and 3 D approach has been made to find out the effectiveness of 2D design procedure. This study is limited to skin plate, vertical stiffeners, horizontal girders and radial arms of an existing parallel arm radial gate fitted in a cross regulator on parallel Upper Ganga Canal at Jawalapur Haradwar.

A comparison of 2 D and 3 D analysis results have shown that the gate can be designed with confidence, reliability and cost effectively as a 3D structure as the 3 D results are generally less than 2 D analysis results indicating that 2 D analysis is conservative approach.

LIST OF NOTATIONS

	NOTATIONS	DETAILS
1.	UX	Displacement in X-direction
2.	UY	Displacement in Y-direction
3.	UZ	Displacement in Z-direction
4.	XROT	Rotation in X-direction
5.	YROT	Rotation in Y-direction
6.	ZROT	Rotation in Z-direction
7.	DOF	Degrees Of Freedom
8.	SX or σ_x	Bending stress in X-direction
9.	SY or σ_y	Bending stress in Y-direction
10.	SZ or σ_z	Bending stress in Z-direction
11.	SXY or τ_{xy}	Shear stress and membrane stress in X-Y Plane
12.	SYZ or τ_{yz}	Shear stress and membrane stress in Y-Z plane
13.	SXZ or τ_{xz}	Shear stress and membrane stress in X-Z plane
14.	S.F.	Shear Force
15.	B.M.	Bending Moment
16.	I_{xx}	Moment of Inertia in X-direction
17.	Iyy	Moment Of Inertia in Y-direction
18.	Izz	Moment of Inertia in Z-direction
19.	$S_{H.G.}$	Stiffness of Horizontal Girder
20.	$S_{R.A.}$	Stiffness of Radial arm
21.	cm .	Centimeter
22.	m	Meter
23.	kg.	Kilogram
24.	t	ton
25.	sq.	Square
16.	E	Young's Modulus
17.	ν	Poison's Ratio
18.	ρ	Density of steel

INTRODUCTION

1.1 GENERAL

The usual practice is to design a structure as a 2-D structure. However the exact behavior of the structure can not be visualized unless it is analyzed as 3-D structure. 2-D approach of design is more of a conservative nature rather than an accurate approach. Thus, a structure designed by 2-D approach often becomes uneconomical. Presently, 3D behavior of a structure can be studied with the help available softwares, which otherwise is not possible. In this study the design of hydraulic gate is taken as an example of comparison of 2-D and 3-D design approaches.

The hydraulic gates are movable devices used to regulate water for irrigation, power generation, flood control, navigation, industrial, water supply projects There are different types of gates which are used in water resources projects depending on type of structure and purpose to be served. Great attention for their selection, planning, design, manufacturing, erection operation and maintenance is needed because the failure of a gate may cause serious hazards and catastrophic situations that may result in loss of life, closuer of project requiring high expenditure in rehabilitation and replacement.Generally vertical lift gates and radial gates are used in water resources projects. This study is limited to radial gates.

1.2 RADIAL GATE

. Radial gates are widely used as spillway gates, intake gates and at cross regulators in canal due to (i) their relative simplicity in construction except in bearing, (ii) easy accessibility of main components for maintenance (iii) absence of grooves in piers which are unfavorable for smooth hydraulic flow condition (iv) absence of wheels and wheel assembly which reduces maintenance costs and (v) low hoisting capacity due to lever arm effects as compared to vertical lift gates.

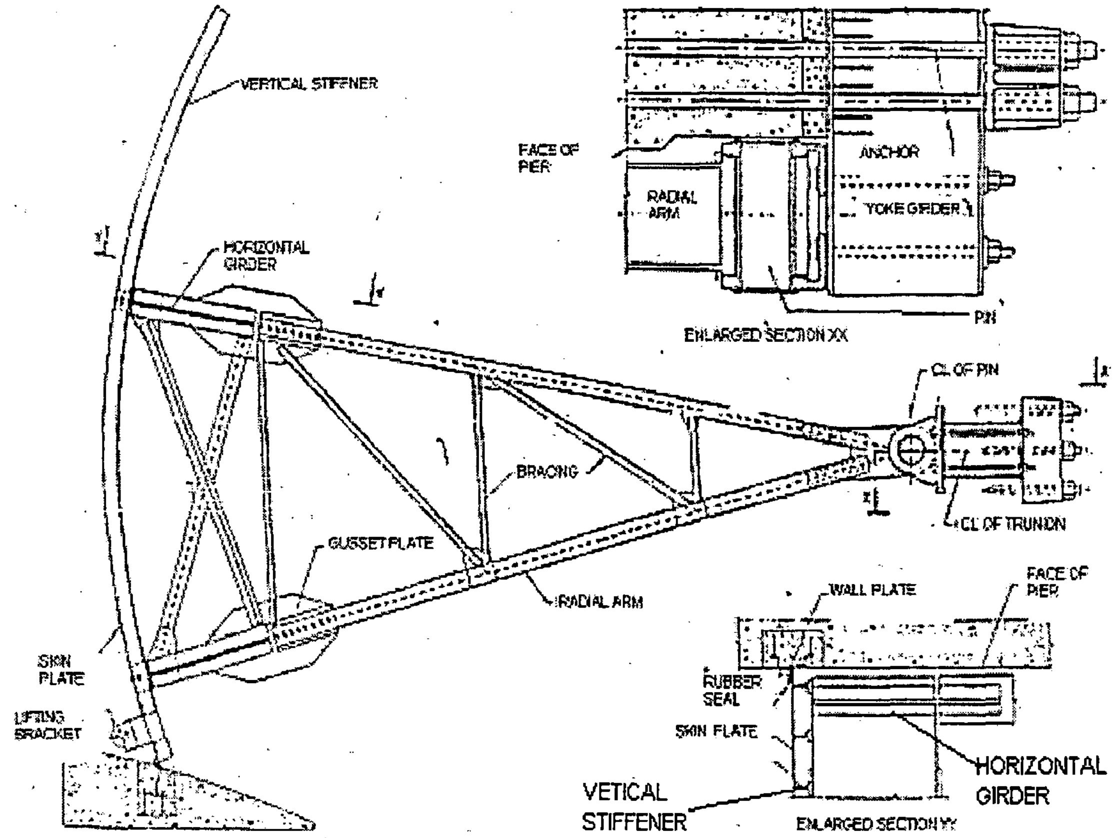


Figure 1.1

It consists of following parts which are shown in figure 1.1 and 1.2

1. Skin plate
2. Vertical stiffener
3. Horizontal girder
4. Radial arms which may parallel to each other as in fig 1.1 or inclined to each other as shown in fig1.2

5. Trunion hub ,pin,bush,and bracket
6. Load carrying anchors
7. Anchorage girders
8. Thrust block
9. Seal, seal seat, seal base and seal beam
10. Trunion tie
11. Guide roller
12. Anchor bolts

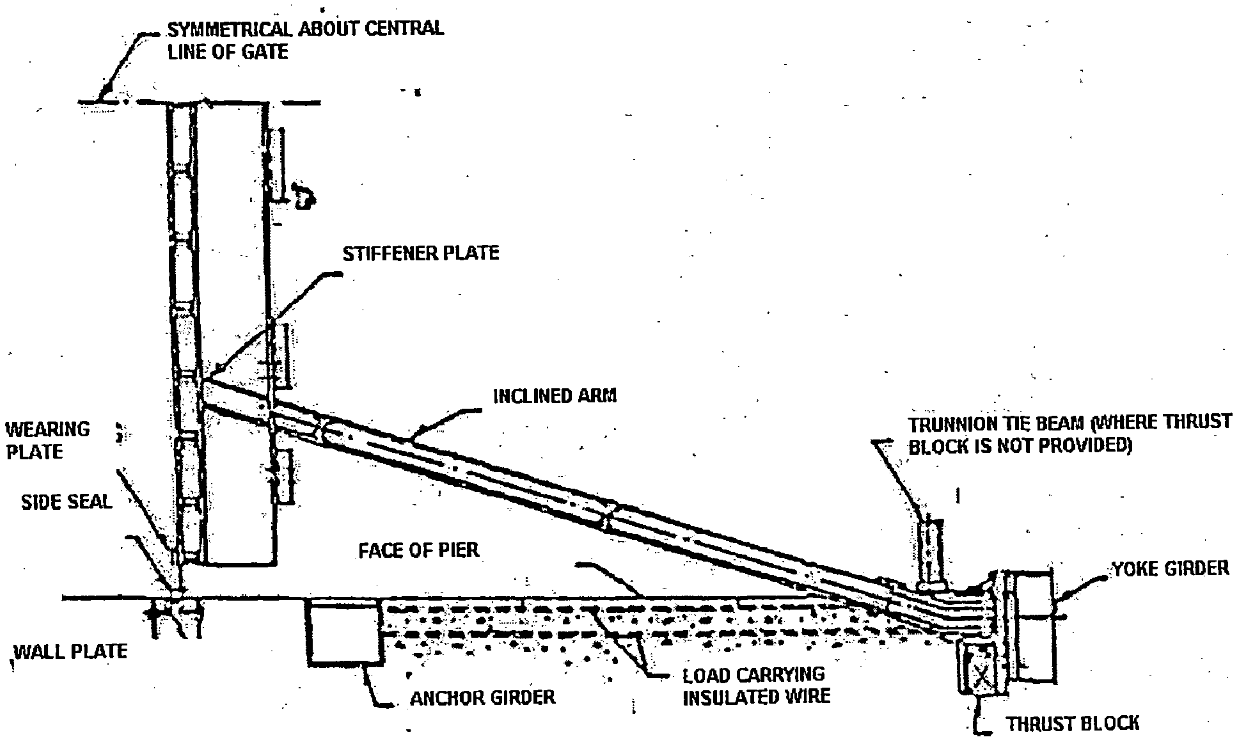


Fig- 1.2

When the gates are fully closed and rest on, sill following pressures act on it.

I. Hydrostatic pressure due to water

II. Silt pressure

III. Body weight due to gravity

When the gates are partially lifted following pressure act on it

I. Hydrostatic pressure due to water

II. Rope tension

III. Body weight due to gravity

IV. Hydraulic down pull

The pressures/ loads are transferred from skin plate to vertical stiffener to horizontal girder, radial arms, trunnion and finally to piers through anchor rods. Due to the pressure and loads, stresses are developed and displacement occurs in various parts of gate. Each side of trunnion pin carries half of the total pressure acting on gate. The vertical stiffeners transfer load to horizontal girders and horizontal girders transfer load to radial arms. Hence the joint between vertical stiffener and horizontal girder is a expected high stress zone. Similarly the joint between horizontal girder, and radial arm is also expected to be a high stress zone. Generally the gate is designed as per guide lines given in INDIAN STANDARDS 4623, 800, 2026 etc. which are based on 2D conventional approach. However these guidelines don't spell in clear terms about the stress conditions at the joints mentioned above. This can be analyzed by the help of 3-Dimensional analysis to make the design safe and economical.

The radial gate adopted for this study is provided at the regulator on Parallel Upper Ganga Canal at Jwalapur, Hardwar. It is a flow regulating gate of span 8 m, height 4.575m and parallel arm type as shown in Fig 1.3. The design of this gate is based on following IS codes.

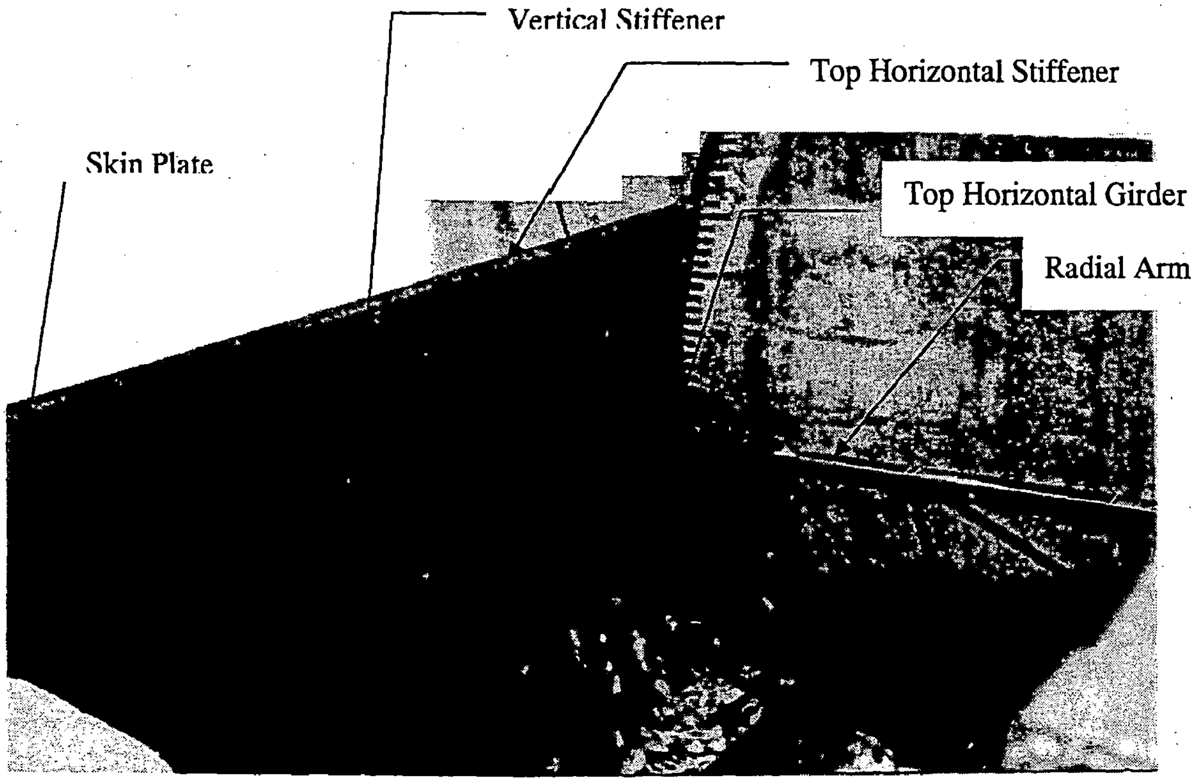


Fig 1.3 View of gate at Jawalapur, Haradwar

(a) IS – 4623 – 1984 : Recommendation for structural design of radial gates

(b) IS – 226 – 1975: Specification of structural steel standard quality.

(c) IS – 2062 – 1982.: Specification for structural steel for fusion welding quality

(d) IS – 800 – 1984: Code of practice for use of structural steel in general building construction.

(e) IS – 823 – 1964 : Code of practice for manual metal arc welding of mild steel

(f) IS-318- 1981 : Specification for leaded tin bronze ingots and castings

(g) IS-1030-1982: Carbon steel casting for general engineering purposes

(h) IS-1570(part V) :- 1985 Schedule for wrought steels for general engineering purposes

1.3 SCOPE OF STUDY

In this dissertation an attempt has been made to study the stresses and displacements that will occur in skin plate, vertical stiffener, horizontal girder, radial arm when analyzed as 3D structure using finite element method. Finite Element Software ANSYS is used. A comparison of results of conventional method with ANSYS Model results is made to establish effectiveness and utility of 3D analysis.

1.4 ORGANIZATION OF DISSERTATION

This dissertation consists of six chapters.

Chapter 1 covers introductory remarks.

Chapter 2 contains brief description about basic formulation of 3D finite element method.

Chapter 3 contains design data, loadings, design considerations of the gate, design criteria in general for skin plate, vertical stiffeners, horizontal girders, and radial arms, summary of conventional results. Details of design calculation for static condition is appended in APPENDIX – “A “.

Chapter 4 contains the basic formulation of finite elements modeling by ANSYS 5.4 version.

Chapter 5 contains results of ANSYS analysis and summary of comparison 2D analysis.

Chapter 6 contains conclusion and recommendations and scope of further work.

BASICS OF FEM

2.1. GENERAL

. Finite element method is a numerical procedure for analyzing structures, which permit the calculations of stresses and deflections. The most distinctive feature of the finite element method that it separates from other in the division of a given domain into a set of simple sub domains called finite elements. In finite element procedure many simultaneous algebraic equations are generated and solved on a digital computer. The results in general are accurate enough from engineering point of view.

Using such elements the structural idealization is obtained merely by dividing the original continuum into segments, all the material properties of the original system, are retained in the individual elements.. Instead of solving the problem for entire body in one operation the solutions are formulated at each constituent unit and combined to obtain the solution for the original structure.

2.2. DESCRIPTION OF METHOD

2.2.1. Discritization of continuum

The continuum is the physical body structure, or solid being analyzed. Discritization may be described as the process in which the given body in subdivided into equivalent system of finite elements. One must decide what number size, and arrangements of finite elements will give an effective representation of the given continuum for the particular problem considered. Continuum is simply zoned into small regions by imaginary planes in

3D bodies and by imaginary lines in 2D bodies. As general guidelines it can be said that where stress or strain grdients are expected to be comparatively flat i.e. the variation is not rapid, the mesh can be coarse to reduce the computation, where as zones in which stress or strain gradients are expected to be steep a finer mesh is indicted to get more accurate results. Theoretically speaking to get an exact solution the number of nodal points is infinite. So trade off has to be made between computation effort and corresponding accuracy.

2.2.2. Selection of Proper interpolation or displacement model

In finite element method we approximate a solution to a complicated problem by subdividing the region of interest into finite number of elements and representing the solution within each element by a relatively simple function of polynomials for ease of computation.

For the triangular element the linear polynomial

$$\phi = a_1 + a_2 x + a_3 y \qquad (3.1)$$

is appropriate

Where a_1, a_2, a_3 are constants which can be expressed in terms of ϕ at these nodes.

For the four nodded quadrilateral the bilinear function.

$$\phi = a_1 + a_2 x + a_3 y + a_4 xy \qquad (3.2)$$

is appropriate

Eight-node quadrilateral has eight a_i in its polynomial expansion and can represent a parabolic function.

Equation (3.1) & (3.2) are interpolations of function ϕ in terms of the position (x,y) within an element. It mesh of element is not too coarse and if ϕ_1 happened to be exact, and then ϕ would be a good approximation.

2.2.3. Convergence Requirements

In any acceptable numerical formulation the numerical solution must converge or tend to the exact solution of the problem. For this the criteria is as below.

a) Displacement model must be continuous within the element and the displacements must be compatible within the adjacent elements.

The first part is automatically satisfied if displacement functions are polynomials. The second part implies that the adjacent elements must deform without causing openings, overlaps or discontinuities between them. This can be satisfied if displacements along the side of an element depend only upon displacements of the nodes occurring on that side. Since the displacements of nodes on common boundary will be same, displacement for boundary line for both elements will be identical.

b) The displacement model must include rigid body displacement of the element.

Basically this condition states that there should exist such combinations of values of coefficients in displacement function that cause all points in the elements to experience the same displacement.

c) The displacement model must include the constant strain states of elements.

This means that there should exist such combinations of values of the coefficients in the displacement function that cause all points on the element to experience the same strain. The necessity of this requirement can be understood if we imagine that the continuum is divided into infinitesimally small elements. In such a case the strains in each element approach constant values all over the element. The terms a_3 and a_6 in the following equations

$$u(x) = a_1 + a_2 x + a_3 y$$

$$v(y) = a_4 + a_5 x + a_6 y \qquad (3.3)$$

provide for uniform strain in x and y directions. The elements, which meet first criterion, are called compatible or conforming. The elements, which meet second and third criteria, are called complete. For plain strain and plain stress and 3D elasticity the three conditions mentioned above are easily satisfied by linear polynomials.

2.2.4. Nodal Degree of Freedom

The nodal displacements, rotations and/or strains necessary to specify completely the deformation of finite elements are called degrees of freedom (DOF) of elements.

2.2.5. Element Stiffness Matrix

The equilibrium equation derived from principle of minimum potential energy between nodal loads and nodal displacements is expressed as

$$\{F\}^e = [K]^e \{\delta\}^e$$

Where $\{F\}^e$ = nodal force vector

$\{\delta\}^e$ = nodal displacement vector

$[K]^e$ = element stiffness matrix

The stiffness matrix consists of the coefficients of equilibrium equations derived from material and geometric properties of the element. The elements of stiffness matrix are the influence coefficients. Stiffness of a structure is an influence coefficient that gives the force at one point on a structure associated with a unit displacement at the same or a different point.

Local material properties as stated above are one of the factors, which determine stiffness matrix. For an elastic isotropic body, Modulus of Elasticity (E) and Poisson's Ratio (v) define the local material properties. The stiffness matrix is essentially a symmetric matrix, which follows from the principle of stationary potential energy, that "In an elastic structure work done by internal forces is equal in magnitude to the change in strain energy". And also from Maxwell Betti reciprocal theorem which states that: "If two set of loads $\{F\}_1$ and $\{F\}_2$ act on a structure, work done by the first set in acting through displacements caused by the second set is equal to the work done by second set in acting through displacements caused by first set.

2.2.6. Nodal Forces and Loads

Generally when subdividing a structure we select nodal locations that coincide with the locations of the concentrated external forces. In case of distributed loading over the body such as water pressure on dam or the gravity forces the loads acting over an element are distributed to the nodes of that element by principle of minimum potential energy. If the body forces are due to gravity only then they are equally distributed among the three nodes of a triangular element.

2.2.7. Assembly of Algebraic Equations for the Overall Discretised continuum

This process includes the assembly of overall or global stiffness matrix for the entire body from individual stiffness matrices of the elements and the overall or global force or load vectors. In general the basis for an assembly method is that the nodal interconnections require the displacement at a node to be the same for all elements adjacent to that node. The overall equilibrium relations between global stiffness matrix [K], the total load vector {F} and the nodal displacement vector for entire body {δ} is expressed by a set of simultaneous equations.

$$[K]\{\delta\} = \{F\}$$

The global stiffness matrix [K] will be banded and also symmetric of size of n x n where, n = total number of nodal points in the entire body. The steps involved in generation of global stiffness matrix are:

i) All elements of global stiffness matrix [K] are assumed to be equal to zero.

ii) Individual element stiffness matrices [K] are determined successively.

iii) The element k_{ij} of element stiffness matrix are directed to the address of element K_{ij} of global stiffness matrix which means

$$K_{ij} = \Sigma\, k_{ij}$$

Similarly nodal load $\{F_i\}^e$ at a node 'i' of an element 'e' is directed to the address of $\{F_i\}$ of total load vector i.e.

$$\{F_i\} = \Sigma\, \{F_i\}^e$$

2.2.8. Boundary Conditions

A problem in solid mechanics is not completely specified unless boundary conditions are prescribed. Boundary conditions arise from the fact that at certain points or near the edges the displacements are prescribed. The physical significance of this is that a loaded body or a structure is free to experience unlimited rigid body motion unless some supports or kinematics constraints are imposed that will ensure the equilibrium of the loads. These constraints are called boundary conditions. There are two basic types of boundary conditions, geometric and natural. One of the principal advantages of Finite Element Method is, we need to specify only geometric boundary conditions, and the natural boundary conditions are implicitly satisfied in the solution procedure as long as we employ a suitable valid variational principle. In other numerical methods, solutions are to be obtained by trial and error method to satisfy boundary conditions whereas in Finite Element Method boundary conditions are inserted prior to solving algebraic equations and the solution is obtained directly without requiring any trial.

2.2.9. Solution for the unknown displacements

The algebraic equations [K] {δ} = {F} formed are solved for unknown displacements {δ} wherein [K] and {F} are already determined. The equations can be solved either by iterative or elimination procedure. Once the nodal displacements are found, then element strains or stresses can be easily found from generalized Hooke's law for a linear isotropic material.

The assumption in displacement function, the stresses or strains are constant at all points over the element, may cause discontinuities at the boundaries of adjacent elements. To avoid this sometimes it is assumed the values of stresses and stains obtained are for the centers of gravity of the elements and linear variation is assumed to calculate them at other points in the body.

2.3. SUMMARY OF PROCEDURE

The principal computational steps of linear static stress analysis by Finite Element Method are now listed.

i) **Input And Initialization:** Input the number of nodes and elements, nodal co-ordinates, structure node numbers of each element, material properties, temperature changes, mechanical loads and boundary conditions. Reserve storage space for structure arrays [K] and {F}. Initialize [K] and {F} to null arrays. If array ID is used to manage boundary conditions, initialize ID and then convert it to a table of equation numbers.

ii) **Compute Element Properties:** For each element compute element property matrix [k] and element load vector {f}.

iii) **Assemble The structure:** Add [k] into [K] and {f} into {F}. Go back to step 2, repeat steps 2 and 3 until all elements are assembled. Add external loads {P} to {F}. Impose displacement boundary conditions (if not imposed implicitly during assembly by use of array ID).

iv) Solve the Equations: $[K]\{\delta\} = \{F\}$ for $\{\delta\}$

v) **Stress Calculation:** For each element extract nodal D.O.F. of element $\{\delta\}^e$ from nodal D.O.F. of structure $\{\delta\}$. Compute mechanical strains, if any and convert resultant stains to stresses.

2.4. MATHEMATICAL MODEL

2.4.1. General

Most Engineers and Scientists studying physical phenomena are involved with two major tasks:

1. Mathematical formulation of the physical process.
2. Numerical analysis of the mathematical model.

Development of the mathematical model of a process is achieved through assumptions concerning how the process works. In a numerical simulation, we use a numerical method and a computer to evaluate the mathematical model. While the derivation of the governing equations for most problems is not unduly difficult, their solution by exact methods of analysis is a formidable task. In such cases, approximate methods of analysis provide alternative means of finding solution. Among this finite element method is most frequently used.

Finite element method is endowed with three basic features.

1. a geometrically complex domain of the problem is represented as a collection of geometrically simple sub domains called finite elements.
2. over each element the approximation functions are derived using the basic idea that any continuous function can be represented by a linear combination of algebraic polynomials.
3. Algebraic relations among the undetermined coefficients (i.e. nodal values) are obtained by satisfying the governing equations over each element.

The approximation functions are derived using concepts from interpolation theory and are called interpolation functions. The degree of interpolation functions depends on the number of nodes in the element and the order of differential equation being solved.

2.4.2 Interpolation Function

The finite element approximation $U^e(x,y)$ of $u(x,y)$ over an element Ω^e must satisfy the following conditions in order for the approximate solution to be convergent to the true one.

1. U^e must be differentiable.
2. The polynomials used to represent U^e must be complete (i.e. all terms beginning with a constant term up to the highest order used in the polynomial, should be included in U^e).
3. All terms in the polynomial should be linearly independent.

The number of linearly independent terms in the representation of U^e dictates the shape and number of DOF of the element.

2.4.3. Displacement function

For a typical finite element 'e' defined by nodes i,j,k etc. the displacements {f} within the element are expressed as:

$$\{f\} = [N]\,\{\delta\}^e \qquad (3.4)$$

where $[N] = [N_i \;\; N_j \;\; N_m \ldots]$

and $\{\delta\}^e = \{\delta_i \;\; \delta_I \;\; \delta_m \ldots\}$ (3.5)

The components of [N] are in general functions of position and $\{\delta\}^e$ represents a listing of nodal displacements for a particular element.

For the three dimensional element

$$\{f\} = \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \qquad (3.6)$$

represents the displacements in x,y and z directions at a point within the element and

$$\{\delta_i\} = \begin{Bmatrix} u_i \\ v_i \\ w_i \end{Bmatrix} \qquad (3.7)$$

are the corresponding displacements of node i.

$[N_i]$ is equal to [IN'] where N_i is the shape function of node i and I is an identity matrix.

2.4.4. Strains

With displacements known at all points within the element, the strains at any point can be determined. Six strain components are relevant in three-dimensional analysis and the strain vector can be expressed as:

$$\{\in\}=\begin{Bmatrix}\in_x\\\in_y\\\in_z\\\in_{xy}\\\in_{yz}\\\in_{zx}\end{Bmatrix}=\begin{Bmatrix}\frac{\partial u}{\partial x}\\\frac{\partial v}{\partial y}\\\frac{\partial w}{\partial z}\\\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\\\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\\\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\end{Bmatrix} \qquad (3.10)$$

which can be further written as:

$$\{\in\}=[\mathbf{B}]\{\delta\}^e=[B_iB_jB_k\ldots\ldots]\{\delta\}^e \qquad (3.11)$$

in which $[B_j]$ is the strain displacement matrix.

$[B_j]$ is given by

$$[B_i]=\begin{bmatrix}\frac{\partial N_i}{\partial x} & 0 & 0\\ 0 & \frac{\partial N_i}{\partial y} & 0\\ 0 & 0 & \frac{\partial N_i}{\partial z}\\ \frac{\partial N_i}{\partial y} & \frac{\partial N_i}{\partial x} & 0\\ 0 & \frac{\partial N_i}{\partial z} & \frac{\partial N_i}{\partial y}\\ \frac{\partial N_i}{\partial z} & 0 & \frac{\partial N_i}{\partial x}\end{bmatrix} \qquad (3.12)$$

with other sub matrices obtained in a similar manner simply by interchange of subscripts.

For isoparametric elements

$$x=\sum_{i=1}^{n}N_ix_i,\ y=\sum_{i=1}^{n}N_iy_i,\ z=\sum_{i=1}^{n}N_iz_i$$

$$u = \sum_{i=1}^{n} N_i u_i, v = \sum_{i=1}^{n} N_i v_i, w = \sum_{i=1}^{n} N_i w_i \tag{3.13}$$

the summation being over total number of nodes in an element.

Because the displacement model is formulated in terms of the natural coordinates ξ, η and ς and it is necessary to related Eq. (3.12) to the derivatives with respect to these local coordinates.

The natural coordinates ξ, η and ς are functions of global coordinates x,y, z. Using the chain rule of partial differentiation we can write:

$$\frac{\partial N_i}{\partial \xi} = \frac{\partial N_i}{\partial x}.\frac{\partial x}{\partial \xi} + \frac{\partial N_i}{\partial y}.\frac{\partial y}{\partial \xi} + \frac{\partial N_i}{\partial z}.\frac{\partial z}{\partial \xi} \tag{3.14}$$

Performing the same differentiation with respect to the other two coordinates and writing in matrix form

$$\begin{Bmatrix} \frac{\partial N_i}{\partial \xi} \\ \frac{\partial N_i}{\partial \eta} \\ \frac{\partial N_i}{\partial \zeta} \end{Bmatrix} = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} & \frac{\partial z}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} & \frac{\partial z}{\partial \eta} \\ \frac{\partial x}{\partial \zeta} & \frac{\partial y}{\partial \zeta} & \frac{\partial z}{\partial \zeta} \end{bmatrix} \begin{Bmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial z} \end{Bmatrix} = [J] \begin{Bmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial z} \end{Bmatrix} \tag{3.15}$$

where [J] is given by:

$$[J]=\begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} & \frac{\partial z}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} & \frac{\partial z}{\partial \eta} \\ \frac{\partial x}{\partial \zeta} & \frac{\partial y}{\partial \zeta} & \frac{\partial z}{\partial \zeta} \end{bmatrix} \tag{3.16}$$

The matrix [J] is called the Jacobian matrix. The global derivatives can be found by inverting [J] as follows:

$$\begin{Bmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial z} \end{Bmatrix} = [J]^{-1} \begin{Bmatrix} \frac{\partial N_i}{\partial \xi} \\ \frac{\partial N_i}{\partial \eta} \\ \frac{\partial N_i}{\partial \zeta} \end{Bmatrix} \tag{3.17}$$

Substituting Eq. (3.13) into Eq. (3.16) the Jacobian matrix is given by

$$[J]=\begin{bmatrix} \sum \frac{\partial N_i}{\partial \xi} x_i & \sum \frac{\partial N_i}{\partial \xi} y_i & \sum \frac{\partial N_i}{\partial \xi} z_i \\ \sum \frac{\partial N_i}{\partial \eta} x_i & \sum \frac{\partial N_i}{\partial \eta} y_i & \sum \frac{\partial N_i}{\partial \eta} z_i \\ \sum \frac{\partial N_i}{\partial \zeta} x_i & \sum \frac{\partial N_i}{\partial \zeta} y_i & \sum \frac{\partial N_i}{\partial \zeta} z_i \end{bmatrix} \tag{3.18a}$$

$$[J]=\begin{bmatrix} \frac{\partial N_1}{\partial \xi} & \frac{\partial N_2}{\partial \xi} \cdots\cdots \\ \frac{\partial N_1}{\partial \eta} & \frac{\partial N_2}{\partial \eta} \cdots\cdots \\ \frac{\partial N_1}{\partial \zeta} & \frac{\partial N_2}{\partial \zeta} \cdots\cdots \end{bmatrix} \begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \\ . & . & . \\ . & . & . \\ . & . & . \end{bmatrix} \tag{3.18b}$$

2.4.5. Stresses

The stresses are related to the strains as:

$$\{\sigma\}=[D](\{\epsilon\}-\{\epsilon_0\}+\{\sigma_0\}) \qquad (3.19)$$

Where [D] is an elasticity matrix containing the appropriate material properties.

$\{\epsilon_0\}$ is the initial strain vector.

$\{\sigma\}$ is the stress vector given by

$\{\sigma\}=\{\sigma_x,\sigma_y,\sigma_z,\sigma_{xy},\sigma_{yz},\sigma_{zx}\}^T$ and

$\{\sigma_0\}$ is the initial stress vector.

For elastic, isotropic material the elasticity matrix is given by ;

$$[D]=\frac{E}{(1+v)(1-2v)}\begin{bmatrix} 1-v & v & 0 & 0 & 0 & 0 \\ v & 1-v & v & 0 & 0 & 0 \\ v & v & 1-v & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2v}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2v}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2v}{2} \end{bmatrix} \qquad (3.20)$$

Where E is the Young's modulus of elasticity and v is the Poisson's ratio of the material of the element.

2.4.6. Stiffness Matrix

The stiffness matrix of the element is given by the following relation

$$\{F\}^e=[K]^e\{\delta\}^e \qquad (3.21)$$

where $\{F\}^e$ is the element nodal load vector, $\{\delta\}^e$= nodal displacement vector and $[K]^e$ the element stiffness matrix given by:

$$[K]^e=\int\int[B]^T[D][B]dA \qquad (3.22)$$

where A refers to the area of the element.

The equivalent nodal forces are obtained as

i) Forces due to pressure distribution $\{p_x, p_y, p_z\}^T$ per unit area given by:

$$\{F^e\}_p = \int_v [N]^T \{p\} dA \qquad (3.23a)$$

For the complete structure relation of the form given below is obtained

$$\{K\}\{\delta\} = \{F\}$$

Where $\{\delta\}$ is the vector of global displacements, $\{F\}$ the load vector and [K] the stiffness matrix.

The global stiffness matrix [K] is obtained by directly adding the individual stiffness coefficients in the global stiffness matrix. Similarly the global load vector for the system is also obtained by adding individual element loads at the appropriate locations in the global vector.

The mathematical statement of the assembly procedure is :

$$[K] = \Sigma_{0-1}^{E} [K]^e$$

$$\{F\} = \Sigma_{0-1}^{E} \{F\}^0 \qquad (3.24)$$

where E is the total number of elements.

To transform the variable and the region with respect to which the integration is made the relationship.

$$dA = dxdy = \det[J] d\xi d\eta \qquad (3.25)$$

is used.

Writing explicitly

$$\int_A dxdy = \int_{-1}^{+1}\int_{-1}^{+1} \det[J] d\xi \, d\eta \qquad (3.26)$$

and the characteristic element stiffness matrix can be expressed as

$$[K]^e = [B]^T[D][B]\int_{-1}^{+1}\int_{-1}^{+1} \det[J]\, d\xi\, d\eta \qquad (3.27)$$

A2 x 2 x 2 integration has been used for the three dimensional analysis.

2.5. SIGN CONVENTION

The stress vectors are shown in Fig. 2.1. The sign convention for ANSYS programme is that tension is positive and compression is negative. Shear is positive when the two applicable positive axes rotate towards each other.

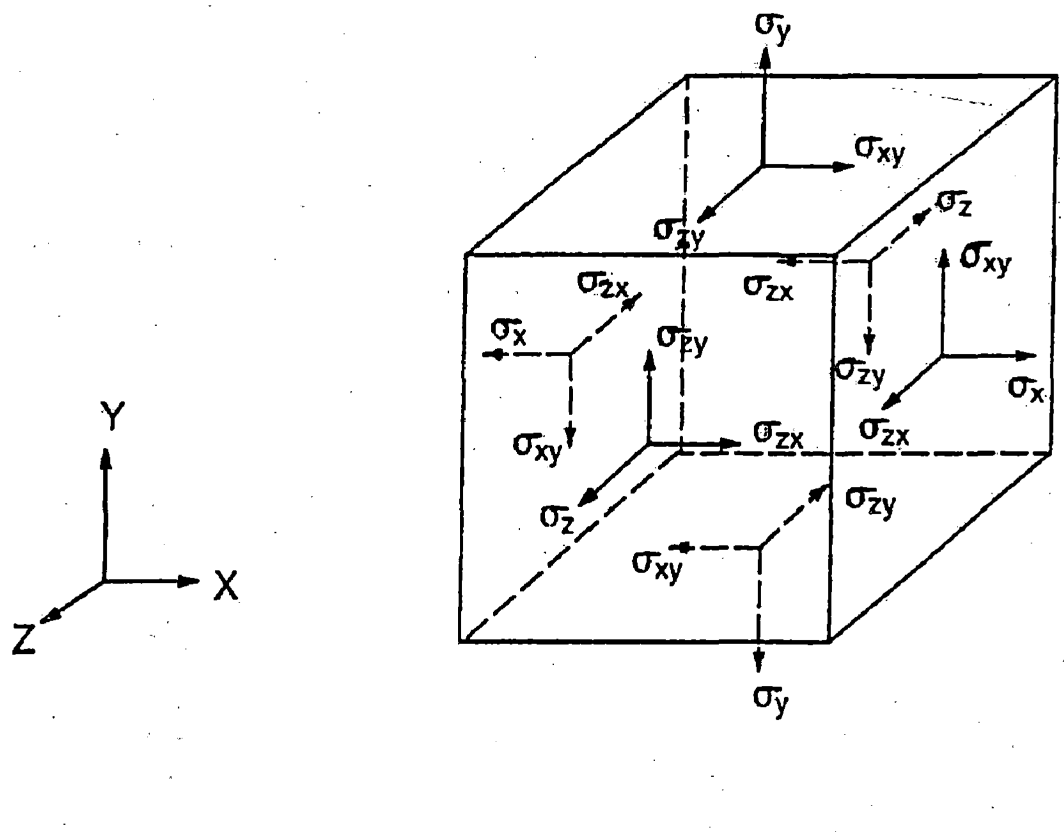


Fig 2.1

CONVENTIONAL DESIGN OF GATE

3.1 INTRODUCTION

The conventional design is carried out on the basis of guidelines given in various IS codes. Indian Standard 4623 provides general guidelines for structural design of radial gates. Normally the radial gate has an upstream skin plate bent to an arc with convex surface of the arc on the upstream side as shown in fig 1.1. The centre of the arc is at the centre of trunnion pins about which the gate rotates. The skin plate is supported by suitably spaced stiffeners either vertical or horizontal or both. If horizontal stiffeners are used, these are supported by suitably spaced vertical diaphragms which are connected together by horizontal girders transferring the load to the two end vertical diaphragms. The end beams are supported by radial arms emanating from the trunnion hubs located at the axis of the skin plate cylinder. If vertical stiffeners are used, these are supported by suitably spaced horizontal girders which are supported by radial arms. The arms transmit water load to the trunnion/yoke girder. Suitable seals are provided along the curved ends of the gate and along the bottom. Guide rollers are provided to limit the sway of the gate during raising and lowering. The gate under study is having vertical stiffeners, which are supported by suitably spaced horizontal girders.

3.2 GENERAL DESIGN CRITERIA

3.2.1 Skin Plate and Stiffeners

The skin plate and stiffeners is designed together in a composite manner.

The skin plate is designed for either of the following two conditions unless more precise methods are available:

(a) In bending across the stiffeners or horizontal girders as applicable, or

(b) As panels in accordance with the procedure and support conditions given in Annex C. of IS 4623

The minimum thickness of skin plate that should be used in gates is 8mm excluding corrosion allowance. However, in the case of large size crest gates because of the constant span under varying loading on the skin plate, it is economical to use two or more sizes of the plates at different sections. For smaller gates as in canals, tunnels and conduits the same thickness of plate should preferably be used throughout.

The stresses in skin plates are determined as follows:

(a) For determining the stresses for conditions in bending across stiffeners or horizontal girders as per the procedure in bending across the stiffeners or horizontal girders as applicable, bending moment shall be determined according to the conditions of supports.

(b) For calculating the stresses in skin plates for conditions in bending as panel in accordance with the procedure given in as panels in accordance with the procedure and support conditions given in Annex C. of IS 4623 and the stresses as given in Table A.2 and A.3 of Appendix -A should be used.

In either of the cases specified above while designing the stiffeners and horizontal girders the skin plate can be considered co acting with them.

(a) The co acting width of the skin plate of non-panel fabrication as per In bending across the stiffeners or horizontal girders as applicable is taken by restricting to the least of the following values:

1) 40t + B

where

t = thickness of skin plate, and

B = width of the stiffener flange in contact with the skin plate.

2) 0.11 span; and

3) Centre to center of stiffeners and girders.

(b) The width of the skin plate co acting with beam or stiffeners in panel fabrication as per panels in accordance with procedure and support conditions given in Annexure C of IS 4623 should be worked out as illustrated in Annex D of IS 4623 and stresses due to beam action calculated.

The stresses so computed shall be combined in accordance with the formula:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2}$$

where

σ_v = combined stress,

σ_x = sum of stresses along $x-$axis,

σ_y = sum of stresses along y-axis, and

τ_{xy} = sum of shear stresses in $x-y$ plane.

Note: the appropriate signs should be taken for σ_x, σ_y in the above formula.

The permissible value of mono-axial as well as combined stresses should not be greater than those specified in Table TA-2 and TA-3 of Appendix- A

Permissible value of stresses in welds shall be the same as permitted for the parent material. For site weld the efficiency should be considered 80 percent of shop weld.

To take care of corrosion, the actual thickness of skin plate to be provided shall be a least 1.5 mm more than the theoretical thickness computed based on the stresses specified in

Table A.2 and A.3 of appendix-A. The minimum thickness of the skin plate shall not be less than 8 mm, exclusive of corrosion allowance.

The stiffener's may, if necessary, be of a built-up section or of standard rolled section, that is, tees, angles, channels, etc.

3.2.1 Horizontal Girders

The number of girders used shall depend on the total height of the gate but shall be kept minimum to simplify fabrication and erection and to facilitate maintenance. As a general thumb rule the number of horizontal girders and correspondingly number of arms may be adopted as follows:

a)	For height of gate up to 8.5 m	2No.
b)	For height between 8.5 m and 12 m	3No.
c)	For heights above 12m	4 or more

In the case of the vertical stiffeners designed as a continuous beam the girders may be so spaced that bending moment in the vertical stiffeners at the horizontal girder are about equal.

When more than three girders are used, it may become necessary to allow the bending moment in the vertical stiffener at the top most girder, of a value higher than at the other girders, so as to adequately stress the skin plate,

The girders shall be designed taking into consideration the fixity at arms support. Where inclined arms are used, the girders should also be designed for the compressive stress induced.

The girders shall also be checked for shear at the points where they are supported by the arms. The shear stress shall not exceed the value specified in Table A 2 and A 3 of Appendix A

3.2.2 Stiffeners and Bracings for Horizontal Girders

The horizontal girder should also be suitably braced to ensure rigidity.

The spacing and design of the bearing and intermediate stiffeners shall be governed by relevant portion of IS 800.

3.2.4 Radial Arms

As many pairs of arms as the number of horizontal girders, shall be used, unless vertical end girders are provided.

The arms may be inclined or parallel. Inclined arms may conveniently be used to economies on the horizontal girders where other conditions permit.

The arms should be designed as columns for the axial load and bending moment transmitted by the horizontal girders and shall be in accordance with IS 800 taking into consideration the type of fixity to the girder.

The total compressive stress should be in accordance with IS 800 for various values of l/r where, l is the effective length, and r is the least radius of gyration. These stresses are further reduced by appropriate factor depending upon the permissible stresses as adopted from Annex B since the stresses in IS 800 are based on permissible stresses of 0.66 YP. For bending stresses, the stresses specified in Table TA-2 and TA-3 of Appendix-A shall apply.

The arms if inclined should be fixed to the horizontal girders at about one-fifth of the width of the gate span from each end of the girder consistent with the design requirements.

The joints between the arms and the horizontal girders should be designed against the side thrust due to the inclination of the arms, if inclined arms are used.

The arms are suitably braced by bracings in between the arms. The bracings connecting the arms that should be so spaced, that the l/r ratio of the arms in both the longitudinal and transverse directions is nearly equal.

In case of gates likely to be overtopped, the end arms and other components should suitably be protected by means of side shields to prevent direct impact of water on arms. A hood may also be provided to protect the horizontal girders and others downstream parts.

3.3 DESIGN CONSIDERATIONS OF THE GATE UNDER STUDY

1) Radius of the gate is kept as 1.25 times the maximum water depth.
2) The total height of the gate has been kept 0.3m more than the maximum water depth.
3) For simplicity of calculation design head has been taken as 4.5 m instead of 4.275m.
4) The location of the horizontal girder has been fixed as 0.123x L bottom end, and 0.491L between two [illegible]. Where L is length of skin plate.
5) Vertical stiffeners have been designed as continuous beam supported over the two horizontal girders. The vertical stiffener assumed to be either fixed or hinged at horizontal girder and has been designed for the maximum of the moments calculated in both the cases. For simplified analysis of the continuous beam, it has been assumed that the vertical stiffeners are straight having lengths equal to curved length of skin plate and section is half cut ISMB-400 with its web plate welded to the skin plate.
6) Skin plate has been designed as continuous plate supported over long parallel vertical supports. The combined stresses for bending in skin plate and bending of vertical stiffeners have been considered and found within permissible limit. 10 mm thick skin plate has been provided.
7) Horizontal girders have been designed as a "U" frame part. While U frame consists of two end arms or radial arms simply supported over the bush bearing and the arms are assumed to be fixed /hinged at their junction with the horizontal girders. After considering both the cases i.e fixed and hinged joint of end arms with horizontal girders bending stresses have been calculated. After analysis it is

found that bottom horizontal girder is under maximum load. Thus only the bottom girder, radial arms etc have been designed for maximum reaction calculated in the design of vertical stiffeners. The loadings on horizontal girder have been considered as uniformly distributed, since vertical stiffeners are closely spaced.

8) Radial arms have been designed for direct forces and bending moment calculated in analyzing as portal frame of horizontal girders, and designed for direct and bending stresses.

3.4 Design Data

1) Type of Gate: - Radial Gate
2) Clear Opening :- 8.0 m
3) Width of Pier :- 1.5 m
4) Sill Elevation:- 277.804m
5) F.S.L. :- 282.079
6) Height of Gate:- 4.575 m
7) Design Head :- 4.50m
8) Radius of Gate: - 1.25 x 4.5 = 5.625 m
9) Size of Gate :- 8.0m x 4.575m
10) Locality where gate is operating at present: - JWALAPUR

3.5 Pressures/ Loads

1. Water Pressure

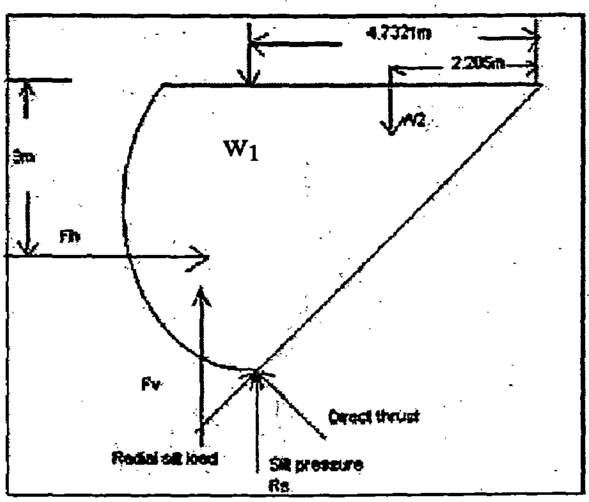


Fig 3.1 Water Pr. Body Weight and Sill Reaction

a) Horizontal = F_h= 81 t

b) Vertical $= F_v = 56.57$ t

2 Silt pressure

Horizontal = 1.33t

3. Weight of gate excluding arms and arm bracings $w_1 = 11.7$t

4. Weight arms arm bracings = 0.3435t

3.6 CONVENTIONAL RESULTS

Conventional design calculations are appended in Appendix –A. However summary of results of conventional calculations is given below.

3.6.1 Skin Plate

Maximum bending stress in skin plate occurs at bottom of skin plate.

$\sigma_{x(\text{skin plate})} = 724.5$ kg/sq.cm

Maximum bending stress in skin plate co acting with vertical stiffener at bottom horizontal girder is

$\sigma_{y(\text{skin plate co acting with vertical stiffener})} = 161.08$ kg/sq.cm

Deflection of skin plate co acting with vertical stiffener at top of the gate =0.05116 cm

Deflection of skin plate co acting with vertical stiffener at bottom of the gate =0.004592

cm

3.6.2 Vertical stiffener

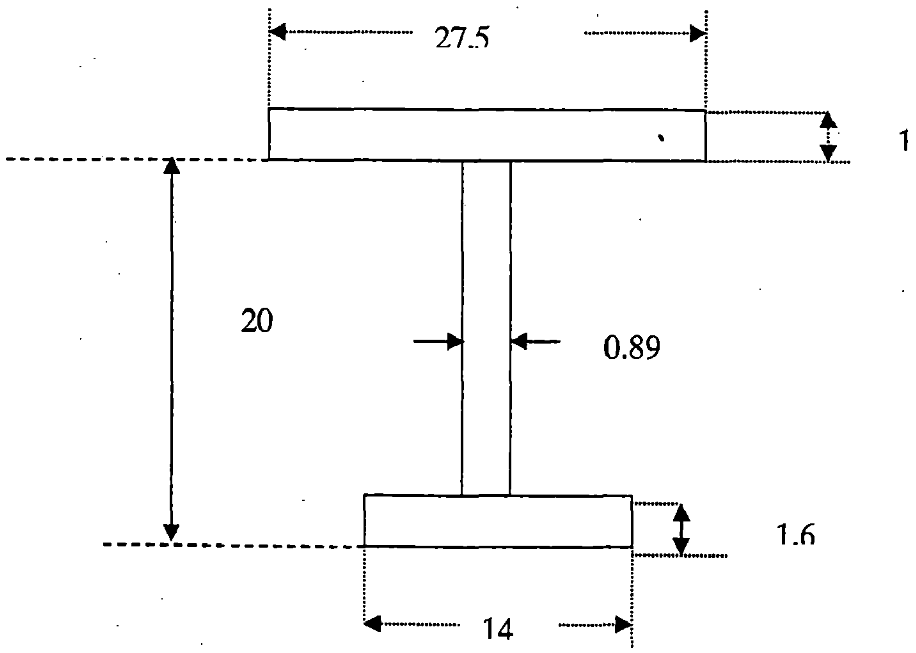


Fig 3.2 All values are in cm

Figure shown is the cross sectional view of vertical stiffener

Maximum bending stress at bottom horizontal girder skin plate bottom side

$\sigma_{y(\text{skin plate co acting with vertical stiffener})}$ = 161.08 kg/sq.cm

$\sigma_{y(\text{flange side vertical stiffener})}$ = 192.695 kg/sq.cm

Deflection at top end of vertical stiffener =0.05116cm

Deflection at bottom end of ertical stiffener =0.004592cm

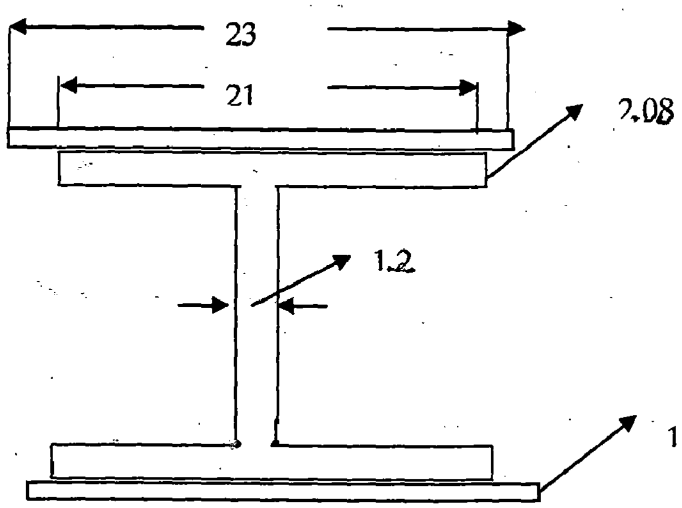


Fig 3.3 (All Values are in cm)

Cross sectional View : of Horizontal Girder

3.6.3 Horizontal girder

Maximum bending stress at bottom girder fixed end at radial arm

= 933.88 kg/sq.cm

Maximum stress (Considered hinged at radial arm,) middle of bottom horizontal girder = 1394.493 kg/sq.cm

Maximum deflection at middle of bottom horizontal girder = 1.3 cm (simple supported case)

Maximum deflection at middle of top horizontal girder = 0.8058 cm (simple supported case)

Maximum deflection at middle of bottom horizontal girder = 0.263cm (Fixed at both ends at joint of radial arm)

Maximum deflection at middle of top horizontal girder = 0.1564cm (Fixed at both ends at joint of radial arm)

3.6.4 Radial Arms

Maximum axial stress =699 kg/sq.cm

Maximum bending stress = 614.86 kg/sq.cm

3.6.5 Horizontal stiffener

Maximum bending stress in skin plate side = 185.2 kg/sqcm

Maximum bending stress in web side = 270.56 kg/sq.cm

3.7 SUMMARY OF CONVENTIONAL RESULTS

Table 3.1 Maximum value of Bending Stress and Axial stress

S.N.	Part Name	Maximum Bending Stress In kg/sq.cm	Maximum Axial Stress in kg/sq.cm
1	Skin Plate	724.5	-
2	Vertical Stiffener co-acting with skin plate	161.08	-
3	Vertical stiffener (flange side)	192.695	-
4	Horizontal girder	1394.493	-
5	Radial Arm	614.86	699
6	Horizontal Stiffener (web side)	270.56	-

Table 3.2 Maximum Value of Deflection of Horizontal Girder (Hinged at support)

S.N.	Part Name	Maximum Value of Deflection in cm
1	Middle of top Horizontal Girder	0.8058
2	Middle of Bottom Horizontal Girder	1.3

Table 3.3 Maximum Value of Deflection (Fixed Case)

Sl.no.	Position	Deflection by Conventional method (Fixed case) in cm
1	Middle of Top horizontal girder	0.1564
2	Middle of bottom horizontal girder	0.263
3	Top of skin plate co-acting with	0.05116

	vertical stiffener (x=25 cm)	
4	Bottom of skin plate co-acting with vertical stiffener (x=25 cm)	0.004592

3.8 RESULT OF DESIGN ORGANISATION

The gate has been designed by Irrigation Design Organization Utter Pradesh who have supplied the datas of gate and the maximum values of bending stresses in skin plate, vertical stiffener, horizontal girder, radial arm, axial stresses in radial arm, deflection in bottom horizontal girder (hinged case). Those values are matching with this study.

CHAPTER –4

FEM MODEL OF RADIAL GATE USING ANSYS SOFTWARE

4.1. GENERAL

There are various finite element softwares and ANSYS is one of such powerful tools in finite element analysis. Any complicated structure can be suitably analyzed using ANSYS. ANSYS is quite flexible and it has options to perform analysis in various fields like structural, thermal, fluid mechanics and electromagnetics, besides performing different types of analysis such as static, dynamic, transient, harmonic, etc.

The ultimate purpose of a finite element analysis is to create mathematically the behavior of an actual engineering system. In other words the analysis must be an accurate mathematical model of physical prototype. In the broadest sense this model comprises of all the nodes, elements, material properties, real constants, boundary conditions, and other system that are used to represent the physical system.

Beginning with modeling one should plan what should be objective, what basic form the model will be, what will be the elements types, what will be the mesh density etc?

The first step of analysis depends not on the ANSYS program, but relies, instead on our own experience and professional judgment. The objective that we establish at the start will influence the reminder of our choices as we generate the 2D and 3D model.

4.2 SELECTION OF ELEMENTS :

Selection of proper element is important in any software like ANSYS to find out desired result. Initially the model was prepared with volume form bottom to top operation. The radial gate was exactly in solid volume as that of original one. However, when it was mashed with free meshing in 3D 10node tetrahedral element it was found that software could not solve the problem. The computer was hanged after preparing 2-3 lakhes of elements. It was tried to mesh different other types of elements but it was in vain. Finally it was analyzed that minimum size of gate (web of vertical stiffener) was 8.9 mm where as maximum size of gate (length of span) is 8000mm. So while meshing number of elements was very high, this was beyond the capacity of software.

It was concluded that for skin plate 3 D Elastic Shell63 elements is most suitable one and for stiffener 3 D Beam4 element is suitable. Both the elements are having six degrees of freedom.

4.2.1. 3D Elastic Shell 63 elements

Shell 63 has been used for surface modeling of this shell structure. The element is defined by four nodes I J K and L having six degrees of freedom at each node: translations in the nodal x, y and z directions and rotations about the nodal x, y, and z axes. It has both bending and membrane capabilities. Stress stiffening and large deflection capabilities are included.

4.2.1.1. Input Data

The geometry, node locations, and the co-ordinate system for this element are shown in Figure 4.1. The element is defined by four nodes, four thicknesses, elastic foundation stiffness and the orthotropic material properties. Orthotropic material directions correspond to the element co-ordinate directions. The element co-ordinate system orientation is used for orthotropic material input directions, applied pressure directions, and under some circumstances, stress output directions. For these elements (Shell-63) the default orientation generally has x axis aligned with element i-j side, the z axis is normal to the shell surface and the y axis perpendicular to the x and z axes.

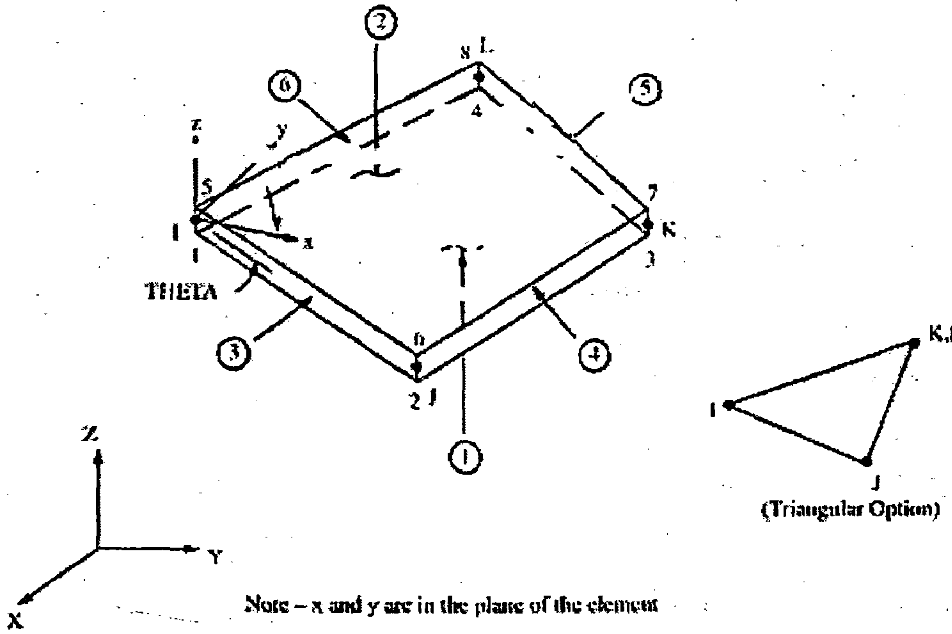


FIGURE 4.1 3 D Elastic shell 63 Elements

4.2.1.2. OUT PUT

The output associated with the element is in two forms: 1) nodal displacements included in the overall nodal solution and 2) additional element output stress output SX (Top), SX(Bottom), SY(Top), SY(Bottom) and moments output are shown in figure 4.2.

4.2.1.3. Assumptions and Retractions

Zero area elements are not allowed. This occurs most often whenever the elements are not numbered properly. Zero thickness elements are not allowed. The four nodes defining the element should lie in an exact flat plane; however a small out of tolerance in permitted so that the element may have slightly wrapped shape.

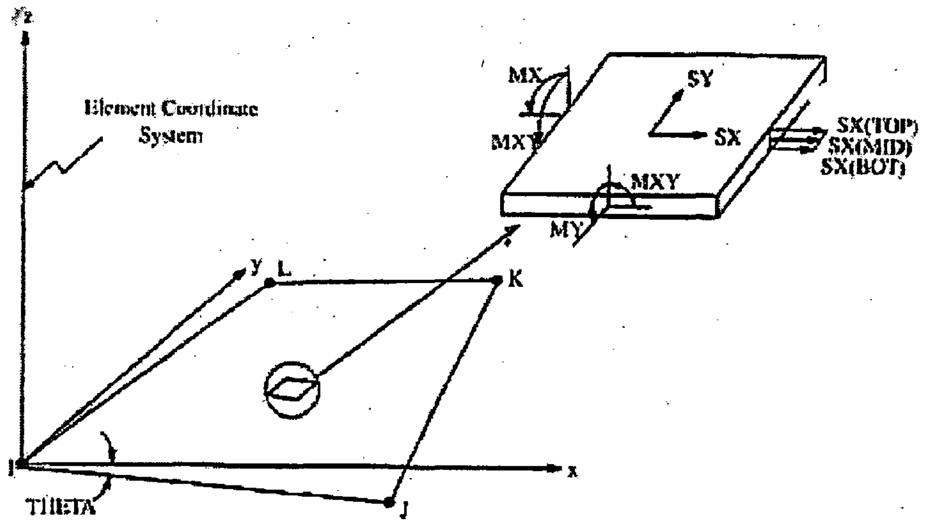


FIGURE 4.2 Shell 63 stress out put

4.2.1.4. Shape function for 3D4- Node quadrilateral shells

These shape functions are for 3D-node quadrilateral shell elements with RDOF's but without shear deflection and without extra shape functions, such as SHELL63 with KEYOPT(3)=0 when used as a quadrilateral:

$$u = \frac{1}{4}\left(u_1(1-s)(1-t) + u_j(1+s)(1-t) + u_K(1+s)(1+t) + u_L(1-s)(1+t)\right) \tag{4..1}$$

$$\mathrm{v} = \frac{1}{4}\left(\mathrm{v}_1(1-\mathrm{s}) \ldots \text{(analogous to u)}\right) \tag{4.2}$$

w = not explicitly defined. Four overlaid triangles (IJK, JKL, KLI, and LIJ) are defined as DKT elements (Batoz (56), Razzaque (57))

The shape function is as per figure no. 4.3.

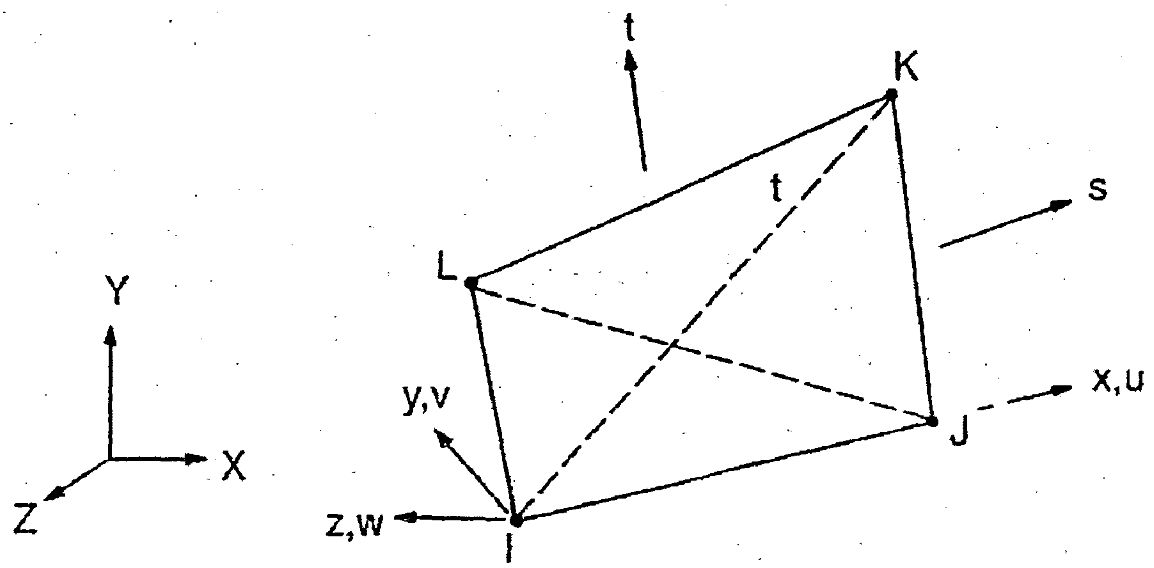


Figure 4.3

4.2.1.5. Stiffness matrix

The stiffness matrix vector for membrane stress having quadrilateral geometry the shape functions equations used are (4.1) and (4.2) having point of integration 2x2. For bending four triangles that are overlaid are used. There sub triangles are referred to equation (4.3) and point of integration in 3 (for each triangle).

4.2.1.6. NUMERICAL INTEGRATION

The numerical integration that ANSYS uses is given below.

1. 4-Noded Shell Element (2x2 or 3x3)

The numerical integration of shell element is given by

$$\int_{-1}^{1}\int_{-1}^{1} f(x,y)dxdy = \sum_{j=1}^{m}\sum_{i=1}^{l} H_j H_i f(x_i, y_j)$$

Gauss integration constants are given in Table below.

F(x) = Function to be integrated

Hi, Hj = weighting factor

1, m = number of integration (Gaussian Points)

Number of integration Points	Integration Point Locations (xi)	Weighting Factor (Hi)
1	0.00000 00000 00000	2.00000 00000 00000
2	$\pm$ 0.57735 02691 89626	1.00000 00000 00000
3	$\pm$ 0.77459 66692 41483 0.00000 00000 00000	0.55555 55555 55556 0.88888 88888 88889

4.2.2. 3D Elastic Beam4

Beam 4 is uniaxial element with tension, compression, torsion and bending capabilities. The element has six degrees of freedom at each node: translations in the nodal x, y and z directions and rotation about nodal x, y, and z axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection analysis.

4.2.2.1 Input Data

The geometry, node locations, and co-ordinate system for this element are shown in figure 4.3. The element is defined by two or three nodes, the cross sectional area, two area moments of inertia (IZZ, and IYY) two thickness (TKZ and TKY), an angle of orientation (θ) about the element x-axis in oriented from node I toward node J. For the two node option $\theta = 0^0$. The orientations are shown in figure 4.3. The third node (k), if, used, defines a plane (with i and j) containing the element x and z directions as shown in fig.4.4

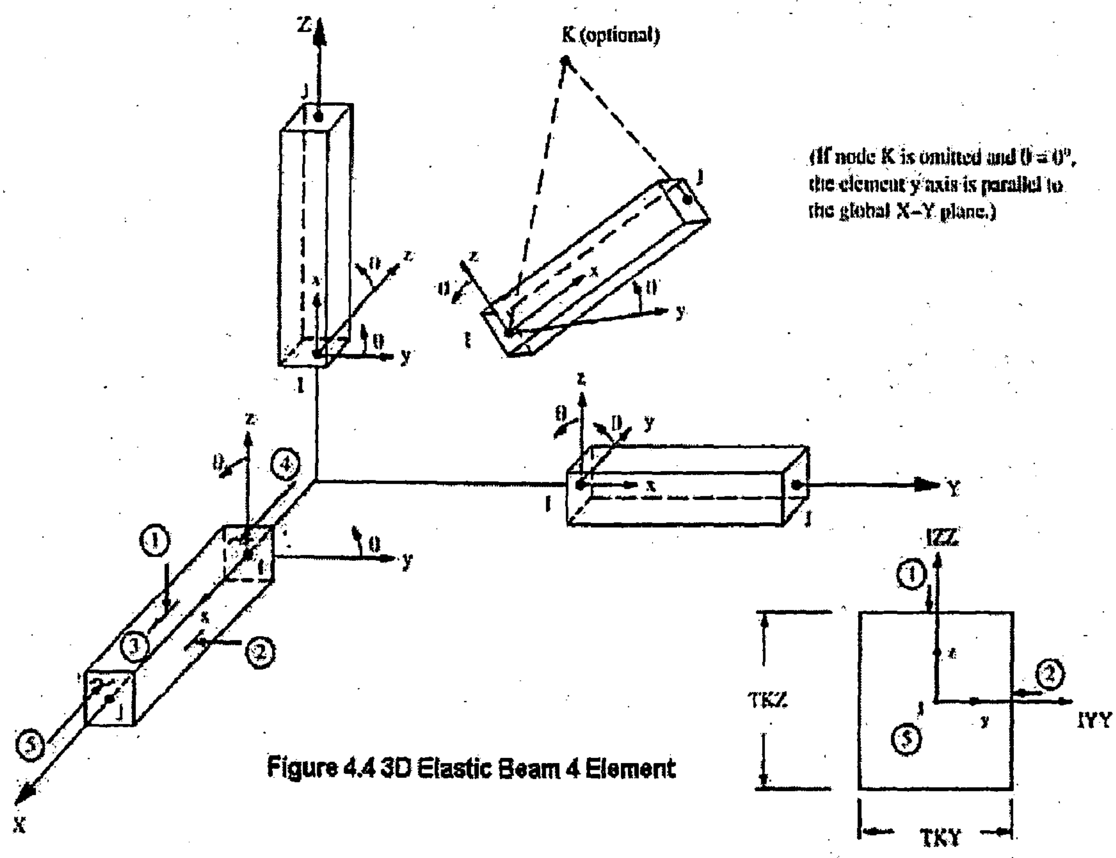


Figure 4.4 3D Elastic Beam 4 Element

4.2.2.2 Output data

The solution output associated with the element is in two forms; (1) nodal displacements included in overall nodal solutions and 2) additional element output in table 4.2. The maximum stress is computed as directed stress plus absolute values of both bending stresses. The minimum stress is the direct stress minus absolute value of both bending stresses. Figure 45 shows stress output of 3D Beam 4 element.

4.2.2.3 Assumptions and restrictions

The beam must not have zero length or zero area. The moments of inertia, however, maybe zero if large deflection are not used. The beam can have any cross sectional shape for which the moments of inertia can be computed. The stresses however will be determined as if the distance between the neutral axis and the extreme fiber is one half of the corresponding thickness.

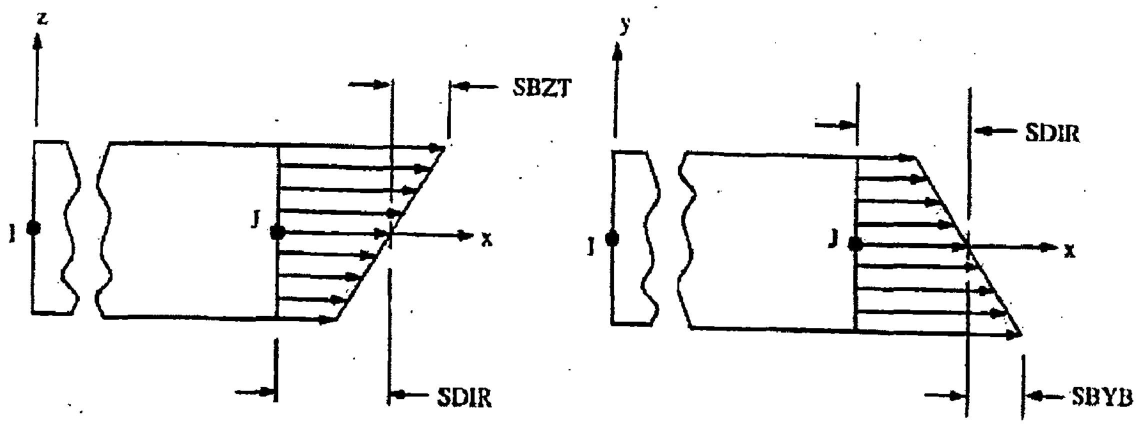


Figure 4.5 3D Elastic Beam4 Element Output Stress

4.2.2.4 Shape function

The shape functions for 3-D line elements with RDOFs, such as BEAM4 are

$$u = \frac{1}{2}\left(u_1(1-s)+u_j(1+s)\right) \tag{4.4}$$

$$v = \frac{1}{2}\left(v_1\left(1-\frac{s}{2}(3-s^2)\right)\right)+v_j\left(1+\frac{s}{2}(3-s^2)\right)$$

$$+\frac{L}{8}\left(\theta_{z,I}(1-s^2)(1-s)-\theta_{z,j}(1-s^2)(1+s)\right) \tag{4.5}$$

$$w = \frac{1}{2}\left(w_1\left(1-\frac{s}{2}(3-s^2)\right)+w_j\left(1+\frac{s}{2}(3-s^2)\right)\right)$$
$$-\frac{L}{8}\left(\theta_{y,I}(1-s^2)(1-s)-\theta_{y,j}(1-s^2)(1+s)\right) \tag{4.6}$$

$$\theta_x = \frac{1}{2}\left(\theta_{x,I}(1-s)+\theta_{x,J}(1+s)\right) \tag{4.7}$$

These shape functions are as per figure no 4.6

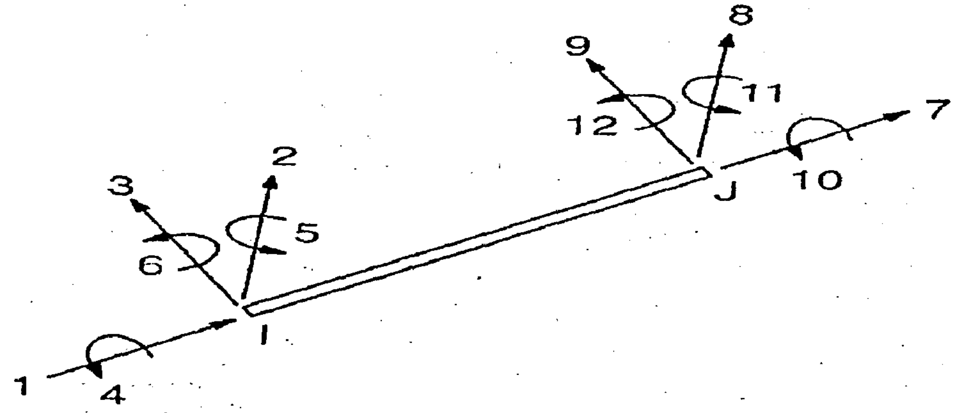


Figure no 4.6

The stiffness matrix vector is derived by the help of shape function equation (4.4.), (4.5), (4.6), (4.7) with integration points. Stress stiffness matrix is derived by the help of equation (4.5) and (4.6) and point of integration in 3 (for each triangle).

4.2.2.5 Stiffness Matrices

The order of degrees of freedom (DOFs) is shown below in matrix. The stiffness matrix in element coordinates is (Przemieniecki (28)).

$$
[K_l]=\begin{bmatrix}
AE/L & & & & & & & & & & & \\
0 & a_z & & & & & & & & & & \\
0 & 0 & a_y & & & & & & & & & \\
0 & 0 & 0 & GJ/L & & & & & \text{Symmetric} & & & \\
0 & 0 & d_y & 0 & e_y & & & & & & & \\
0 & c_z & 0 & 0 & 0 & e_z & & & & & & \\
-AE/L & 0 & 0 & 0 & 0 & 0 & AE/L & & & & & \\
0 & b_z & 0 & 0 & 0 & d_z & 0 & a_z & & & & \\
0 & 0 & b_y & 0 & c_y & 0 & 0 & 0 & a_y & & & \\
0 & 0 & 0 & -GJ/L & 0 & 0 & 0 & 0 & 0 & GJ/L & & \\
0 & 0 & d_y & 0 & f_y & 0 & 0 & 0 & c_z & 0 & c_y & \\
0 & c_z & 0 & 0 & 0 & f_z & 0 & d_y & 0 & 0 & 0 & c_z
\end{bmatrix}
$$

where A = cross-section area (input as AREA on R command)

E = Young's modulus (input as Ex on MP command)

L = element length

G = Shear modulus (input as GXY on MP command)

J = torsional moment of inertia = $\begin{Bmatrix} J_x & \text{if} & I_x & -0 \\ I_x & \text{if} & I_x & \neq 0 \end{Bmatrix}$

I_x = Input as IXX on RMORE command

J_x = polar moment of inertia = $I_y + I_z a$

$z = a(I_z, \phi_y)$

$a_y = a(I_y, \phi_z)$

$b_z = b(I_z, \phi_y)$

:

$f_z = f(I_z, \phi_y)$

$f_y = b(I_y, \phi_z)$

and where; $a(I,\phi) = \dfrac{12EI}{:L^3(1+\phi)}$

$$b(I,\phi) = \frac{-12EI}{L^3(1+\phi)}$$

$$c(I,\phi) = \frac{6EI}{L^2(1+\phi)}$$

$$d(I,\phi) = \frac{-6EI}{L^2(1+\phi)}$$

$$e(I,\phi) = \frac{(4+\phi)EI}{L(1+\phi)}$$

$$f(I,\phi)=\frac{(2-\phi)EI}{L(1+\phi)}$$

and where: $\phi_y = \dfrac{12EI_z}{GA_z^sL^2}$

$$\phi_z = \frac{12EI_y}{GA_y^sL^2}$$

I_i = moment of inertia normal to direction i (input as Iii on r command)

A_i^s = shear area normal to direction $i = A/F_i^s$

F_i^s = shear coefficient (input as SHEARi on RMORE command)

4.2.2.6 Stress Calculation for beam Elements

Centroidal stress at end i is:

$$\sigma_i^{dir} = \frac{F_{x,i}}{A}$$

Where: σ_i^{dir} = centroidal stress (output quantity SDIR)

$F_{x,i}$ = axial force (output quantity FX)

The bending stresses are

$$\sigma_{z,i}^{bnd} = \frac{M_{y,i}}{2I_y} t_z$$

$$\sigma_{y,i}^{bnd} = \frac{M_{z,i}}{2I_z} t_y$$

Where: $\sigma_{z,i}^{bnd}$ = bending stress in element x direction on the element +z side of the beam at end i (output quantity SBZ)

$\sigma_{y,i}^{bnd}$ = bending stress in element x direction on the element -y side of the beam at end i (output quantity SBZ)

$M_{y,i}$ = moment about the element y axis at end i

$M_{z,i}$ = moment about the element z axis at end i

t_z = thickness of beam in element z direction (input as TKZ on R command)

t_y = thickness of beam in element y direction (input as TKY on R command)

The maximum and minimum stresses are:

$$\sigma_i^{max} = \sigma_i^{dir} + \left|\sigma^{bnd}{}_{z,i}\right| + \left|\sigma_{y,i}{}^{bnd}\right|$$

$$\sigma_i^{min} = \sigma_i^{dir} - \left|\sigma^{bnd}{}_{z,i}\right| - \left|\sigma_{y,i}{}^{bnd}\right|$$

The presumption has been made that the cross section is a rectangle, sothat maximum and minimum stresses occur at the corners. If the cross-section is of the other form the user must replace above equations with other appropriate expressions.

4.3 PROCEDURES IN ANSYS

(i) Define element type

(ii) Define element real constants such as cross sectional area, moment of inertia, added mass per unit length, initial strain etc. thickness of element at different nodes etc.

(iii) Define material properties

(a). Isotropic, orthotropic or anisotropic

(b). Linear or nonlinear

(iv) Create the model geometry either by top to bottom or bottom to top procedure.

(v) Mesh the model with appropriate element chosen

(vi) Apply boundary conditions line, load, pressure, gravity load, degree of freedom constraints.

(vii) Solve for solution.

(viii) Go to the general post processor to review the results

4.3.1 Define Element Type

File Name: Radial Gate

File change title - Stress Analysis of Radial gates

Type of analysis :- Structural

h- Type

Add element: 1 Shell63

2 . Beam4

4.3.2 Define Real Constant

(a) Shell 63 Elements

Real constant is 1 cm thickness at each node i.e. i, j, k, l

(b) Beam 4 Elements

There are six types of real constants depending upon the cross sectional area, moment of inertia, thickness along Z axis and Y axis of element coordinate system.

(i) Real constant for vertical stiffener

Area = 66.276 cm^2

IYY = 5262.624 cm^4

IZZ = 2100.0205 cm^4

TKZ = Thickness along Z = 21 cm

TKY = 27.5

(ii) Real constant for Horizontal Girders.

Area = 202.21 cm2

IZZ = 4678.83 cm^4 / 11992.47

IYY = 134604.5 cm4

TKZ = 62 cm

TKY = 23 cm.

(iii) Real constant for radial arms

Area = 49.5 cm2

IZZ = 684.13 cm^4

IYY = 3187.3 cm4

TKZ = 19.5 cm

TKY = 16 cm.

(iv) Real constant for top and bottom horizontal stiffener

Area = 13.84 cm^2

IZZ = 43.763 cm^4

IYY = 168.04 cm^4

TKZ = 3.84 cm

TKY = 11 cm.

(v) Bracings in radial arm and middle of horizontal girder.

Area = 10.47 kg/cm^2

IZZ= 131.85 cm

IYY = 131.85 cm

TKZ = 9 cm

TKY = 9 cm

(vi) Area = 22.4 cm^2

IZZ= 1148.4 cm^4

IYY = 126.5 cm^4

TKZ= 7.5 cm

TKY= 17.5cm

4.3.3 Define Material Properties

Young's modulus = 2.01 x 10^6 kg/cm^2

Minor Poisson's ratio NUXY = 0.25

Density of material = 0.00785 kgf/cm^3.

4.3.4 Creation of Skin Plate

Key points

Main Menu: **Preprocessor → create → key points → in active co-ordinate system**

Enter Key point number in active co-ordinates x, y, z in respective box and apply as per followings

Key points No.	X	Y	Z	
1	0	7.5	562.45	Apply
2	0	-197.359	526.74	Apply
3	0	-384.6768	410.40	Apply
4	0	-408.765	386.415	Apply
5	0	-450	337.5	Apply
6	800	7.5	562.45	Apply
7	800	-197.359	526.74	Apply
8	800	-384.6768	410.40	Apply
9	800	-408.765	386.415	Apply
10	800	-450	337.5	Apply
11	0	0	0	Apply

12	800	0	0	OK

Creation Of Arc And Line

Main Menu→ **preprocessor →create → Arcs → through two nodes and radius→** Enter Key points, center of radius, and radius as per followings to create Areas.

Line No.	Key Points		Command	Centre of radius	Command	Radius	Command
1	1	2	Apply	11	Apply	562.5	Apply
2	2	3	Apply	11	Apply	562.5	Apply
3	3	4	Apply	11	Apply	562.5	Apply
4	4	5	Apply	11	Apply	562.5	Apply
5	6	7	Apply	12	Apply	562.5	Apply
6	7	8	Apply	12	Apply	562.5	Apply
7	8	9	Apply	12	Apply	562.5	Apply
8	9	10	Apply	12	Apply	562.5	OK.

Creating of Line

Main Menu → **Preprocessor → create →Lines→straight line → through key points.**

Line No	Key point no(1^{st})	Key point no(2nd)	Command
9	2	6	Enter
10	2	7	Enter
11	3	8	Enter

12	4	9	Enter
13	5	10	OK

Meshing of skin plate

Main Menu: **Preprocessor →Control size → picked lines**

Picked Line	Line Division	Spacing	Command
6, 7, 8,9,10	64	1	Apply
1,5	16	1	Apply
2,6	18	1	Apply
3,7	2	1	Apply
4,8	4	1	O.K.

Main Menu → **preprocessor → Define Attributes → All area**

→ 1 shell 63 → Real const set –1 → Material No.1.

→ Co-ordinate system O → straight line → O.K.

→ Mesh → Area → Free.

4.3.5 Creation of Vertical Stiffener

Main Menu: **Preprocessor →Create → Nodes → In active CS**

Co-ordinate systems as per followings.

Node No.	**X**	**Y**	**Z**	**Command**
1	0	0	0	Apply
2	25	0	0	Apply
3	7.5	0	0	Apply
4	125	0	0	Apply

5	175	0	0	Apply
6	225	0	0	Apply
7	275	0	0	Apply
8	325	0	0	Apply
9	375	0	0	Apply
10	425	0	0	Apply
11	475	0	0	Apply
12	525	0	0	Apply
13	575	0	0	Apply
14	625	0	0	Apply
15	675	0	0	Apply
16	725	0	0	Apply
17	775	0	0	Apply
18	800	0	0	OK

Creation of vertical stiffener element:

Vertical stiffeners are neither parallel x, y or z axis nor parallel to it. Hence to give the proper orientation of the element a third node i.e, k node is selected in addition of i,j, node. There are 16 numbers of vertical stiffeners having spacing 50 cm. Here each stiffeners having 40 numbers of beam elements having real constant set 2. 640 numbers of elements were created by selecting i,j , k.

Main menu → **Preprocessor** → **Create** → **Elements** → **Define** → **Attributes** →

Element No 2 Beams 4

Material No. 1

Real constant No. 2

Co-ordinate system –0

Straight Line

O.K.

→ Through nodes → Pick nodes → i, j, k → Enter.

Select j, i, k 640 times toe complete the vertical stiffeners elements.

4.3.6 Creationof Horizontal Girders

There are two horizontal girders. Each horizontal girder is having 17 beam elements. Here also the horizontal girders are neither in x, y, z, global direction nor parallel to it. So for each horizontal girder beam element i,j, k nodes were selected to give proper orientation to the element.

Main menu → **preprocessor** → **Create** → **Element** → **Define element Attributes** →

Element No.-1 Beam 4

Material No. 1

Real const No. –3

Co-ordinate system –0

Straight line

O.K.

→Through nodes → Pick, i,j,k nodes 34 times to create 34 elements. Here k node becomes the k node vertical stiffener as be orientation.

4.3.7 Creation of Horizontal Stiffener

There are two horizontal stiffeners in top and bottom. Each horizontal girder is having 65 elements here also k node is created to gives proper orientation to the beam elements.

Main Menu: **Preprocessor →Create → nodes → In active CS →** Also following data.

Node No.	X	Y	Z	Command
22	12.5	0	0	Apply
23	37.5	0	0	Apply
24	50	0	0	Apply
25	62.5	0	0	Apply
26	87.5	0	0	Apply
26	100	0	0	Apply
27	112.5	0	0	Apply
28	137.5	0	0	Apply
29	15	0	0	Apply
30	162.5	0	0	Apply
31	187.5	0	0	Apply
32	200	0	0	Apply
33	212.5	0	0	Apply
34	237.5	0	0	Apply
35	250	0	0	Apply
36	262.5	0	0	Apply
37	287.5	0	0	Apply
38	300	0	0	Apply

39	312.5	0	0	Apply
40	337.5	0	0	Apply
41	350	0	0	Apply
42	362.5	0	0	Apply
43	387.5	0	0	Apply
44	400	0	0	Apply
45	412.5	0	0	Apply
46	437.5	0	0	Apply
47	450	0	0	Apply
48	462.5	0	0	Apply
49	487.5	0	0	Apply
50	500	0	0	Apply
51	512.5	0	0	Apply
52	537.5	0	0	Apply
53	550	0	0	Apply
54	562.5	0	0	Apply
55	587.5	0	0	Apply
56	690	0	0	Apply
57	612.5	0	0	Apply
58	637.5	0	0	Apply
59	650	0	0	Apply
60	662.5	0	0	Apply
61	687.5	0	0	Apply

62	700	0	0	Apply
63	712.5	0	0	Apply
64	737.5	0	0	Apply
65	750	0	0	Apply
66	762.5	0	0	Apply
67	687.5	0	0	OK

Main Menu : **Preprocessor → Create →Elements → Define element attributes →**

Element No. 2 Beam 4

Material No.1

Real constant Set No. –5

Co-ordinate system –0

Straight line

O.K.

→ Though nodes → Enter i, j, k nodes for 130 times with proper picking nodes M top and bottom to create the required Horizontal stiffener elements.

4.3.8 Creation of Radial Arms

There are four radial arms which are connected to horizontal girder leaving aside 25 cm in both sides. For this we have to create four lines 6 key points as per followings.

Main Menu : **preprocessor →create →Key points →In active CS.**

Key point No.	X	Y	Z	
13	25	-197.359	526.74	Apply
14	25	-408.765	386.415	Apply

15	775	-197.359	526.74	Apply
16	775	-408.765	386.415	Apply
17	25	0	0	Apply
18	775	0	0	Apply

Main Menu : **Preprocessor →Create →Lines→Through key points** as per followings

Key points		Command	Line No. formed
13	17	Apply	14
14	17	Apply	15
15	18	Apply	16
16	18	O.K.	17

Meshing of Radial Arms

Main Menu: **preprocessor →control size →Pick lines** 14,15,16,17→ Division 4

Spacing 1

O.K.

→Define attributes →To picked Lines →pick line 14,15,16,17→Element No-2 beam 4

Material No-1

Real const set –4

Co-ordinate system –0

Straight Line

O.K.

4.3.9 Creation of bracings

4.3.9.1 Creation Of Bracings For Horizontal Girder

Main Menu : **Preprocessor →Create →Elements → Define element attributes**

→Elements No. 2 beam 4

Material No.1

Real const set No-6

Co-ordinate system –0

Straight Line.

O.K.

→ Through nodes →pick node i, j, k, as per following

Node No.			Command
I	J	K	Apply

Creat 8 elements of horizontal girders bracings.

4.3.9.2 Creation Of Bracing For Radial Arms

Main Menu: **Preprocessor → Create → Elements →Define attributes →Element** No.2

Beam 4

Material No.1

Real const set No-6

Co-ordiante system –0

Straight Line

ON

→Through nodes →Pick $i, j, k,$ Nodes→Apply

4.4 Boundary Condition

After various analysis (as per fixatation of boundary condition in chapter 5) following boundary conditions were decided.

Boundary condition 1(b)

- All bottom nodes UY DOF are zero.
- All nodes of shell elements ZROT DOF zero.
- All DOF at trunion nodes 2,17 are zero.

Commands for Boundary Condition

Select→Entities→ Nodes→ By Num pick

Select all bottom nodes→ O.K.

Main Menu: **Solution → Apply→ Displacement→ Nodes→Pick All(Selected all bottom nodes) → UY , 0→ O.K.**

Select→Entities→ Nodes→ attached to Element 1→O.K.

Main Menu: **Solution → Apply→ Displacement→ Nodes→Pick All (All selected Nodes of element 1) →O.K. → ZROT, 0 → O.K.**

Main Menu: **Solution → Apply→ Displacement→ Nodes→ By Num pick→ pick node 2,17 → ALL DOF , 0 → O.K**

The figure no 4.7 show the boundary condition of above model.

4.5 Applications of Pressure

The skin plate has been divided into four areas. First area is top of the gate till top horizontal girder. Second area is top horizontal girder till y = -384.6768 cm. Third area is from y = -354.6768 till y= -408.76cm fourth area in Y = -408.76 till y = -450cm.

Main Menu →**Solution:** →**Settings** →**Gradients** →**pressure** <-1.0e-3> →Y direction →Starting from –450 →O.K.

Main Menu: **Solution →Apply →Pressure →Areas →1,2, →O.K.** →Pressure value 0.3846768 →Load key 1 →O.K.

Main Menu →**Solution →Settings →Gradient →Pressure** →<-1.509e-3>→Y direction →Stanting from –384.6768 →O.K.

Main Menu →**Solution →Apply** →**Pressure** →**Area** →3,4 →O.K. →0.4833 →Key load 1 →O.K.

The above pressure is shown in figure 4.8

Main Menu →**Solution** →**Apply** → **Gravity → y=1 → OK**

4.6 Solutions of the problem

Main menu →**solution →current LS →Solve →O.K.**

To see the results commands

Main Menu: General **Post processor →Plot results →Nodal solution →**

After this in nodal solution one can see the contours of deflection in different directions

UX → deflection in X direction.

UY → deflection in Y direction.

UZ → deflection in Z direction.

In our case deflection in Z direction is matter of concern.

For different type of elements the command to see the results are different.

In case of shell 63 element the commands and its meaning are given below:

In shell elements stresses are shown at top and bottom at same node as shown in figure.

SX (Top), SY (Top), SZ Top, SXY (Top), SYZ (Top) SZX (Top)

= membrane stress +bending stress

SX (Bottom), SY (Bottom),SZ(Bottom), SYZ(Bottom), SZX (Bottom), SXY(Bottom)

SX (Top), SY (Top), SZ Top, SXY (Top), SYZ (Top) SZX (Top)

= membrane stress +bending stress

SX (Bottom), SY (Bottom),SZ(Bottom), SYZ(Bottom), SZX (Bottom), SXY(Bottom)

= membrane stress – bending stress.

In 3D Beam 4 element to get results one has to go to element table. It shows the element solution results.

3D Beam 4 element output definitions are given below

Name	Definition
SBYT	bending stress on the element +y side of the beam
SBYB	Bending stress on the element –y sides of the beam.
SBZT	Bending stress on the element +z side of the beam
SBZB	Bending stress on the elements -z side of the beam.
SDIR	Axial direct stress.
SMAX	Maximum stress (direct stress +bending stress)
SMIN	Minimum stress (direct stress –bending stress)

Command for beam 4 (key opt (9) =0) Item and sequence numbers of ETABLE and ESOL.

Table 4.1 Key opt (9) = 0

Name	Item	E	I	J
SDIR	LS		1	6
SBYT	LS		2	7
SBYB	LS		3	8
SBZT	LS		4	9

SBZB	LS	5	10
SMAX	NMISC	1	3
SMIN	NMISC	2	4

Through the ANSYS one can plot graphs contours and see the results at nodes and elements and can see direction of reactions.

For contour commands are:

Main Menu → General Post Processor →Plot results

→Nodal solution →SX/SY/SZ/UX/UY/UZ/SXY/SXZ/SZX.

To find nodal solution

Main menu: General **post processor →List results →DOF→O.K.**

Displacement in all direction UX, UY, UZ can be found out in all the nodes of shell element.

For beam element: Nodal displacement can not be verified. However element displacement can be seen by the help of element table.

Command

Main menu: **General Post Processor →Element table →Define table →Add**

→UX/UY/UZ.

Element stresses in beam elements can be find out as per following.

Command

Main Menu: General Post processor→Element Table →Define Table →Add→SBZT→LS, 4

→O.K. →List Element results

Then maximum stresses in beam element +z side in i node can be shown.

Similarly for other stresses for beam element can be seen by the help of command mentioned above. Figure 4.9 and 4.10 give the side view and down stream view of boundary condition and loading when initial model is descretized further. Figure 4.11 and 4.12 give the view of straight model and its boundary condition & loading respectively.

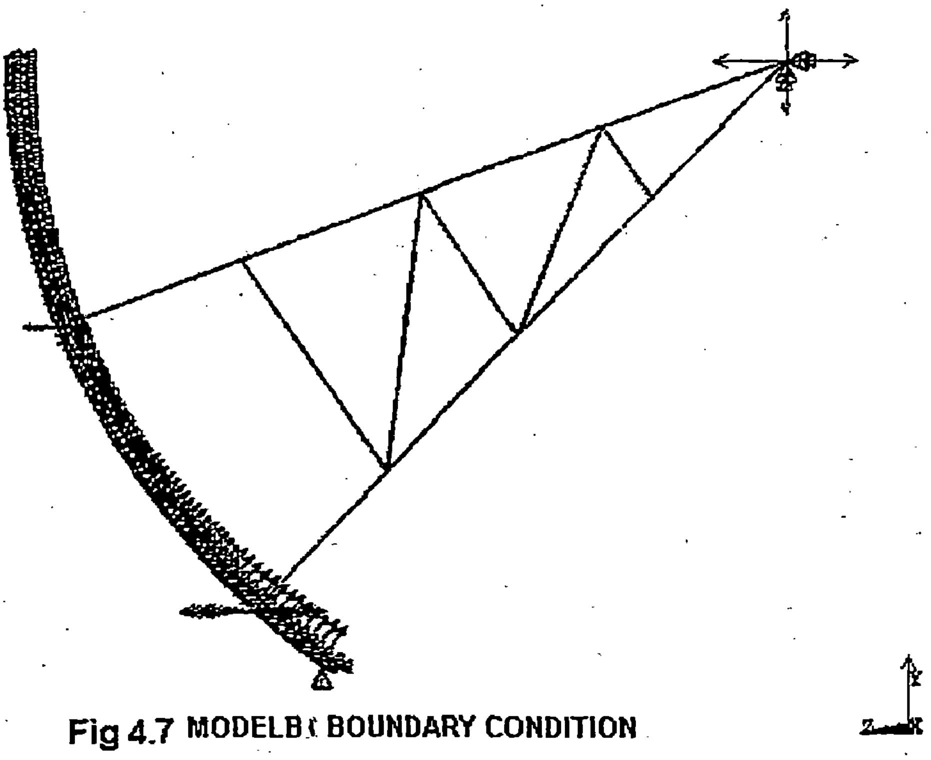


Fig 4.7 MODELB : BOUNDARY CONDITION

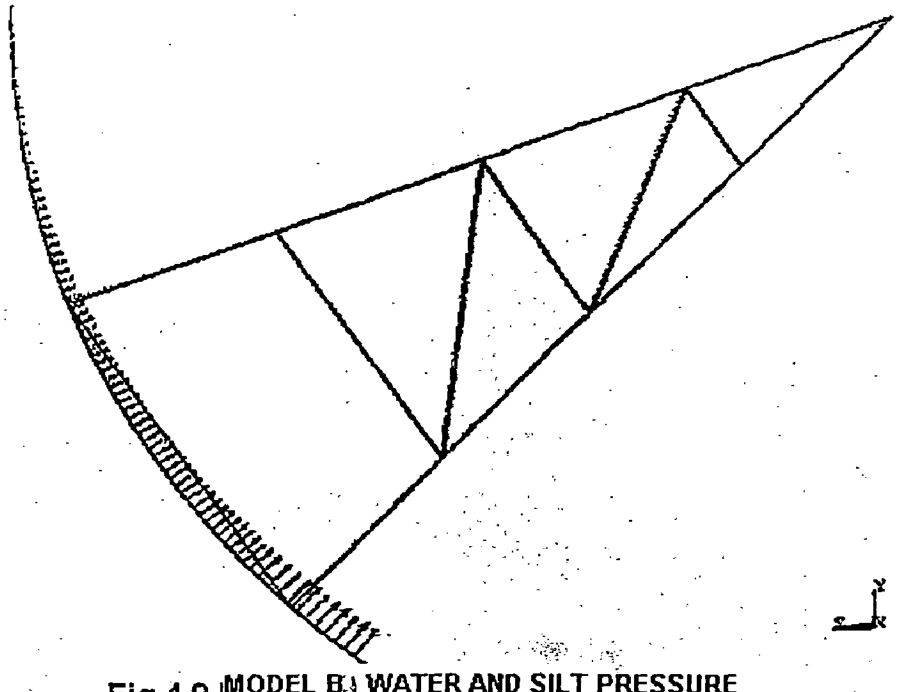


Fig 4.8 MODEL B : WATER AND SILT PRESSURE

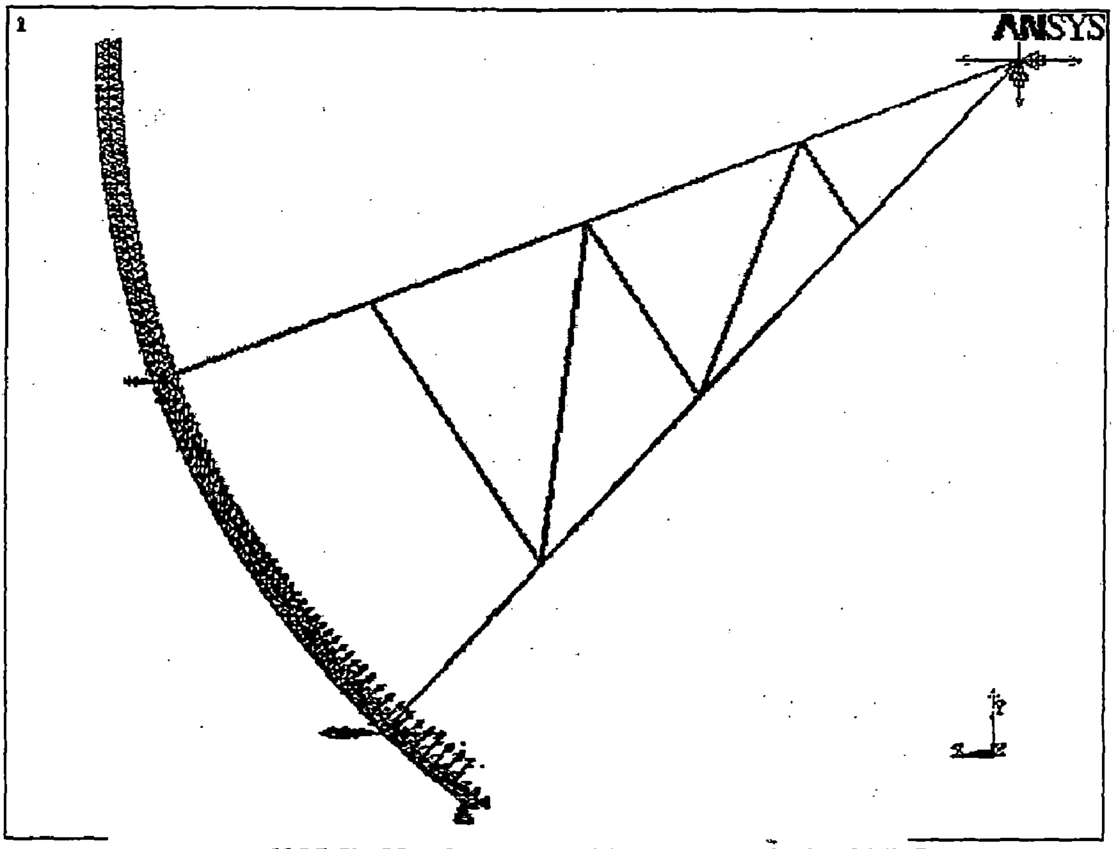


Fig 4.9 MODEL B2 BOUNDARY CONDITION AND LOADING

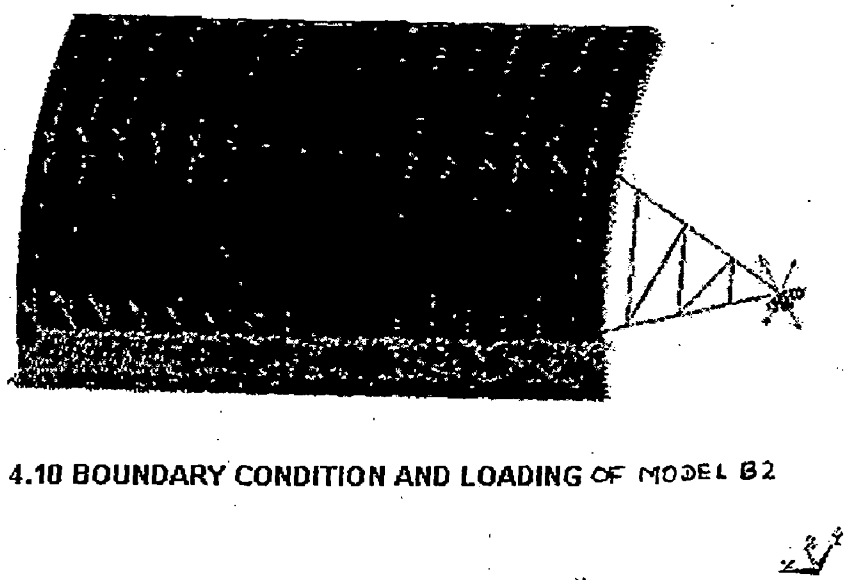


Fig 4.10 BOUNDARY CONDITION AND LOADING OF MODEL B2

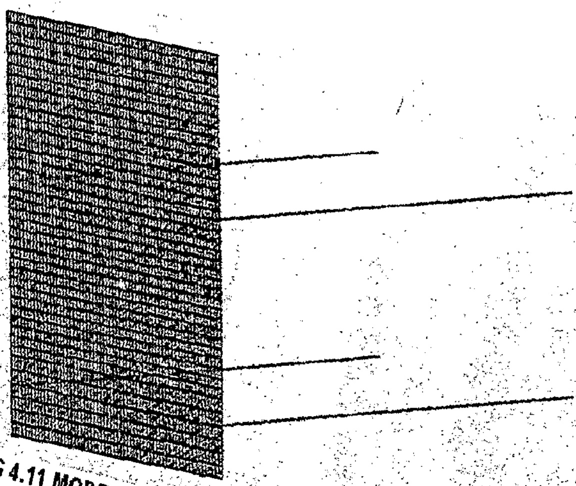


FIG 4.11 MODEL A1 DOWN STREAM VIEW

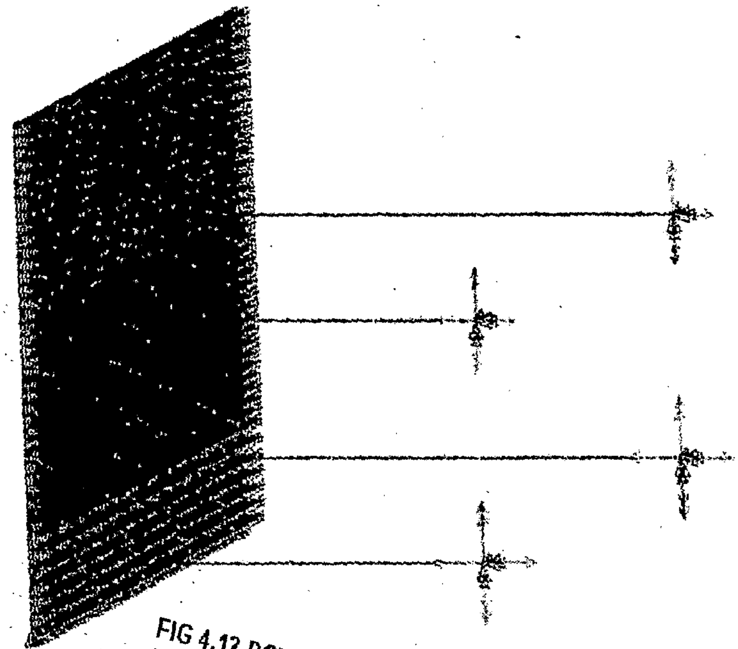


FIG 4.12 DOWN STREAM VIEW OF MODEL A1 WITH LOADING AND BOUNDARY CONDITION

CHAPTER – 5

VALIDATION, RESULTS AND ANALYSIS

5.1 GENERAL

For initial validation 2D analysis was done, for horizontal girders and vertical stiffeners of radial gate and it was found that the results (i.e. bending stress and deflection) are matching with conventional analysis results. Subsequently two types of models were developed through ANSYS features. One is straight skin plate model for validation with conventional results and the second is curved skin plate model. Further these two types of models were sub-divided in to two types depending upon number of divisions in skin plate which are mentioned below.

i) Model A1 (where straight skin plate along span divided into 64 divisions)

Model A2 (where straight skin plate along span divided in to 128 divisions)

ii) Model B1 (where curved skin plate along span is divided in to 64 divisions.)

Model B2 (where curved skin plate along span is divided into 128 divisions)

First Model A1 was considered for fixation of boundary condition with respect to conventional approach deflection. Then for convergence, model A1 and B1 have been compared with model A2 and model B2 respectively with same boundary condition and same load. The results of A2 were compared with conventional for validation. Finally the results of B2 analyzed and compared with model A2 and conventional.

5.2 FIXATION OF BOUNDARY CONDITION

The model of radial gate is a composite element structure. It is having two types of elements namely 3D shell63 and 3DElastic Beam4 type. These two types of elements are having six degrees of freedom. However directions of freedom in shell element of skin plate, and beam element of vertical stiffener, horizontal girder, and radial arm are different from each other. Hence it is important to find out the suitable boundary condition to get the actual results. The first phase of results and analysis is to choose boundary condition. The Model A1 tested with different boundary conditions under actual loadings. The different types of boundary conditions and their results through ANSYS are discussed below.

5.2.1 Boundary condition

Boundary condition 1(a)

- All bottom nodes UY DOF is zero.
- All nodes of shell elements ZROT DOF is zero.
- All DOF at four nodes where radial arms join with horizontal girder are zero.

Boundary condition 1(b)

- All bottom nodes UY DOF are zero.
- All nodes of shell elements ZROT DOF are zero.
- All DOF at trunion nodes 2, 17 are zero.

Boundary condition 2(a)

- All bottom nodes translation UY. XROT DOF is zero.
- All shell elements nodes ZROT are zero.
- All DOF at four nodes where radial arms join with horizontal girder are zero.

Boundary condition 2(b)

- All bottom nodes UY, XROT, DOF is zero.
- All shell elements nodes ZROT are zero.
- All DOF at trunion nodes 2, 17 are zero.

Boundary condition 3(a)

- All bottom nodes UY , ZROT,XROT DOF is zero
- All DOF at four nodes where radial arms join with horizontal girder are zero

Boundary condition 3(b)

- All bottom nodes UY , ZROT,XROT DOF are zero
- All DOF at trunion nodes 2,17 are zero

5.2.2 Loadings

I. Hydrostatic Gradient Pressure , maximum pressure 0.45 Kg/Sqcm at bottom Y= -521.4 and zero at Y= 0 is applied as surface pressure on skin plate

II. Silt pressure which is a gradient load having maximum value .0333 Kg/Sqcm at Y=--521.4cm and minimum 0 Kg/Sqcm at height of Y= -421.4cm

III. Gravity load due to body weight ie dead load 11.347ton

The results of displacement UZ of boundary condition 1(a), 2(a) and 3(a) were compared with fixed end deflection by conventional analysis and UZ of boundary condition 1(b), 2(b), and 3(b) were compared with simple supported end deflection by conventional analysis. The deflections on different boundary conditions and its maximum deflections positions are shown in Table no 5.1 and 5.2 for fixed end and Table no 5.3 and 5.4 for simple supported case.

Table 5.1

Sl.no.	Position	UZ by Conventional method in cm	UZ in cm as per B.C. 1(a)	UZ in cm as per B,C.2(a)	UZ in cm as per B.C. 2(b)
1	Middle of Top horizontal girder	0.1564	0.1863	0.186334	0.18633
2	Middle of bottom horizontal girder	0.263	0.2557	0.255763	0..25763
3	Top of skin plate co-acting with vertical stiffener (x=25 cm)	0.05116	0.1719	0.1719	0.171916
4	Bottom of skin plate co-acting with vertical stiffener (x=25 cm)	0.004592	0.2122	0.212698	0.212698

.Coordinates of maximum deflection with respect boundary condition 1(a), 2(a) and 3(a) are given in Table 5.2

Table - 5.2

Sl no	Boundary condition	Maximum deflection UZ in cm	X in cm	Y in cm	Z in cm
1	Boundary condition 1 (a)	0.257302	400	-396.967	562.5
2	Boundary condition 2 (a)	0.25723	400	-396.967	562.5
3	Boundary condition 3 (a)	0.25723	400	-396.967	562.5

Table- 5.3

Sl.no	Position	UZ as per conventional method simple supported case UZ in cm	Boundary condition 1(b) UZ in cm	Boundary condition 2(b) UZ in cm	Boundary condition 3(b) UZ in cm
1	Middle of Top horizontal girder	0.8058	0.9747	0.984694	0.984698
2	Middle of bottom horizontal girder	1.3	1.182	1.1729	1.17925

Coordinates of maximum deflection with respect boundary condition 1(b), 2(b) and 3(b) are given in table – 5.4

Table - 5.4

Sl.no.	Boundary condition	UZ in cm Maximum Deflection	X in cm	Y in cm	Z in cm

1	Boundary condition 1(b)	1.18773	400	-489.4	562.5
2	Boundary condition 2(b)	1.17421	400	-473.404	418.733
3	Boundary condition 3(b)	1.17421	400	-473.404	418.733

5.2.3 Analysis

In conventional analysis the skin plate was treated as plane skin plate of 521.4 cm. All loads act on it perpendicular to surfaces. However in actual practice pressure on curved surface act perpendicular to it. This has effect on all three directions. The Z component of pressure is more. So deflection in this direction was compared.

When the model results of boundary condition 1(a), 2(a), and 3(a) are compared with the conventional fixed end deflection then boundary condition 2(a) and 3(a) appears to be more appropriate compare to 1(a) boundary condition however when simple supported case is considered with boundary condition 1(b), 2(b) and 3(b) the deflection in boundary condition 2(b) and 3 (b) are more in top horizontal girder middle position compare to 1(b) boundary condition. But the boundary condition 1 is more appropriate if both the cases of fixed (a) and simple supported (b) cases will be considered. **As per design of IDO Roorkee the Maximum deflection in case of Bottom Horizontal Girder is permissible upto 2.46cm with reference to IS 800 1984.** The deflection calculated by conventional (simple supported) case is 1.3cm. The deflection as per model A2 at bottom horizontal girder middle point is 1.1873cm. Conventional design has been done taking into consideration the maximum value of simple supported and fixed case. However in actual practice it is neither simple supported nor fixed. In view of above study it was decided to study the stresses and deflection at different position basing upon boundary condition 1 (a) ie ZROT zero in all the shell nodes, all UY at bottom nodes zero and both trunion points ALL DOF are zero.

Further to strengthen the above boundary condition it is observed that Z direction in shell element is perpendicular to skin plate. ZROT of shell element when passes rotation to beam element it creates a twisting moment which is not desirable. Hence Z ROT zero should be appropriate boundary condition. On the other hand rotational

DOF in X and Y can not be constrained. Because these rotation create moment in Y and X direction.

5.3 CONVERGENCE OF MODEL

The boundary condition fixed up was applied to both types of model A1, A2 and B1, B2 along with pressures. The comparison of deflection of above two types of models are shown in Table 5.5

Table 5.5 Maximum Deflection of model A1, A2 and B1, B2

S.N.	Model no	UZ maximum deflection in cm	X in cm	Y in cm	Z in cm
1	Model A1	1.18773	400	-481.4	562.5
2	Model A2	1.18645	400	-481.4	562.5
3	Model B1	0.523128	400	-440.217	350.164
4	Model B2	0.516239	400	-450	337.5

5.3.1 Analysis

From above table it is evident that the difference in deflection between model A1 and A2 is only 0:00128 cm. and between model B1 and B2 is0.00689cm. If we further discretise the model A2 and B2 the difference may not be remarkable. Hence it is clear that the both types of model have converged. The colour displacement contour of model A1, A2 and B1, B2 are shown in figure 5.1, 5.2 and 5.3, 5.4 respectively. Deformed side view contour of model A1, A2 and model B1, B2 are shown in figure 5.5, 5.6 and 5.7, 5.8 respectively.

5.4 MODEL VALIDATION

It was decided to validate the results of modelA2 for stresses and displacements in skin plate, vertical stiffener, horizontal girder, and radial arm by comparing the results of 2D conventional approach.

5.4.1 RESULTS OF MODEL A2

Skin plate

Maximum deflection is -1.18645cm at x =400cm, y = -489.40cm and z = 562.5 cm. Fig 5.9 shows the maximum deflection graph.

Maximum bending stress σ_x = 603.41 kg/sqcm (Fig 5.10)

Shear stress τ_{xy} = 0

Vertical stiffener

Maximum bending stress = 197.94 kg/sqcm (fig 5.11) this occurs at joint of horizontal girder, vertical stiffener and radial arm.

Horizontal Girder

Maximum deflection is at middle of bottom horizontal girder = 1.1361 cm (fig. 5.12)

Maximum deflection in top horizontal girder = 0.974706cm (fig5.13)

Maximum bending stress at middle of bottom horizontal girder = 1045.8 kg/sqcm (fig. 5.14)

Radial arm

Maximum Axial stress= -579.34 kg/sqcm

Maximum Bending stress = -575.22 kg/sqcm

Horizontal stiffener

Maximum Bending stress = -222.02kg/sqcm (fig. 5.15)

5.4.2 VALIDATION OF MODEL A2 RESULTS WITH CONVENTIONAL

Table 5.6 Maximum Bending Stresses in kg/sqcm

S.N.	Part Name	Conventional results	Model A2 result
1	Skin plate	724	603.41
2	Vertical stiffener	192.695	197.94
3	Horizontal girder	1394:493	1046.2
4	Radial arm	614.86	575.46
5	Horizontal stiffener	276.56	219.39

Table 5.7 Maximum deflection in cm

S.N.	Part name	Conventional results	Model A2 result
1	top horizontal girder	0.8058	0.976595
2	bottom horizontal girder	1.3	1.1812

Table 5.8 Maximum Axial Stress in kg/sqcm

S.N	Part Name	Conventional Results	Model A2 result
1	Radial arm	699	579.26

From above results it is observed that all the model results are quiet close to conventional approach results and are generally less and difference may be considered as limitations of modeling a complicated multidimensional irregular structure.

5.5 RESULTS OF ANALYSIS OF MODEL B2 (curved skin plate 128 divisions)

5.5.1 SKIN PLATE

(i) Deflection

Skin plate of gate is made of Shell 63 elements. The displacement in shell 63 elements is in global direction. The displacement is shown in UX, UY, UZ, ROTX, ROTY and ROTZ. The maximum deflection absolute value and corresponding node is given below in Table 5.9

Table 5.9 Maximum Values of Deflection in Skin plate in cm

MAXIMUM ABSOLUTE VALUES						
	UX	UY	UZ	ROTX	ROTY	ROTZ
VALUE	-0.0058	-0.17815	-0.51624	-0.00165	-0.00169	0.000276

From the Table 5.9 it is evident that maximum deflection takes place in UZ (in flow direction) is -0.51624 cm at X= 400cm, Y= -450cm and Z= 337.5 cm. Where as maximum deflection in other direction is very small. Hence for analysis UZ is considered.

Deflection diagrams are plotted along the curvature and along the span of the gate at different positions in fig 5.16 to 5.28 as given in table in table 5.10

Table- 5.10 Fig, Deflection position and maximum value of deflection in cm

S.N.	Figure No.	X in cm	Y in cm	Z in cm	UZ Maximum Deflection in cm
1	5.16	0 to 800	- 450	337.5	-0.51624
2	5.17	0 to 800	- 408.76	386.42	-0.4978
3	5.18	0 to 800	-197.36	526.74	-0.32938
4	5.19	0 to 800	7.5	562.45	-0.16802
5	5.20	25, 775	7.5 to -450	362.45 to	-0.39952

				337.5	
6	5.21	75, 725	7.5 to -450	362.45 to 337.5	-0.4205
7	5.22	125, 675	7.5 to -450	362.45 to 337.5	-0.44884
8	5.23	175, 625	7.5 to -450	362.45 to 337.5	-0.47004
9	5.24	225, 575	7.5 to -450	362.45 to 337.5	-0.48781
10	5.25	275, 525	7.5 to -450	362.45 to 337.5	-0.50172
11	5.26	325, 475	7.5 to -450	362.45 to 337.5	-0.51119
12	5.27	375,425	7.5 to -450	362.45 to 337.5	-o.51598
13	5.28	400m	7.5 to -450	362.45 to 337.5	-0.51621

From the figure shown in 5.17 and 5.18 deflection is more at the beginning in both sides up to 25 cm then it decreases due to support of vertical stiffener, horizontal girder and radial arm. Again after 25 cm from both sides deflection increases and it is maximum at middle. Particularly where vertical stiffeners are welded deflection is less again between two vertical stiffeners but deflection is more which is clearly shown as kinks in the plot. In figure no 5.16 deflection is also increases towards center. The kinked deflection is not prominent due to presence of a horizontal stiffener at bottom most part of skin plate. In case of absence of vertical stiffener the pattern of deflection in skin plate between 25cm to 775 cm shall be parabolic and it is clear from figure 5.16. Figure no 5.19 shows little deviation compare to other figure. In this case deflection is more at X=250 cm and gradually decreases towards centre. Figure 5.20 to 5.28 shows one type of deflection. In this case deflection is less near top skin plate. Then the rate of deflection decreases near top horizontal girder. Rate of deflection is more between two horizontal girders. However it is less near both girders. Figure 5.29 shows the total deflection contour of skin plate.

If we compare the deflection with respect to conventional method simple supported deflection then deflection at middle of bottom horizontal girder is highest i.e. 1.3 cm. Deflection at bottom of skin plate co-acting with vertical stiffener is 0.00389 cm. Since skin plate vertical stiffener and horizontal girder acts as one structure in 3D analysis. Integrated deflection is reflected at bottom most middle part of the structure.

(ii) **Stresses**

The stresses in shell elements are in global direction. The output SX, SY and SZ, are bending stresses. The output SXY, SYZ, and SZX are combined bending and membrane stress. The maximum and minimum values of SX, SY, SZ, SZX, SZX, and SXY are given in table 5.11

Table 5.11

	SX	SY	SZ	SXY	SYZ	SXZ
MINIMUM	VALUES					
VALUE	-320.49	-168.01	-161.3	-123.92	-162.34	-101.52
MAXIMUM	VALUES					
VALUE	491.58	160.27	103.96	124.24	79.499	101.31

From above table maximum bending stress SX value is 491.58 kg/sqcm at X= 375,425cm Y= -435.19cm and Z= 356.19cm (fig 5.42)

Maximum Bending stress SY is 160.27 kg/sqcm. Here -168.01kg/sqcm is not considered as it is in both extreme sides of gate.

Bending stress in Z direction is also very small value as -161.3kg/sqcm stress is developed at extreme sides and it is a localized stress.

Maximum shear stress and membrane stress SXY is 124.24 kg/sqcm

From ANSYS global results

SXY (top) = 123.31 kg/sqcm

SXY (bottom) =124.24 kg/sqcm

Hence membrane stress $= \frac{(SXY(top) + SXY(bottom))}{2}$ = 123.775kg/sqcm

SXY shear stress =0.465 kg/sqcm.

Maximum absolute value of shear and membrane stress SYZ is -162.34kg/sqcm

From ANSYS global results SYZ (top) = -162.34 kg/sqcm

SYZ (bottom) =- 144.16 kg/sqcm

Membrane stress = $\frac{(SYZ(top) + SYZ(bottom))}{2}$ =-151.88 kg/sqcm

Hence shear stress at node 1888 =-162.34-(-151.88)= 10.46 Kg/sqcm

Maximum absolute value of shear and membrane stress SZX is 101.31kg/sqcm

From ANSYS global stress results SZX(top)= 101.31 kg/sqcm

SZX (bottom) = 80 kg/sqcm

Membrane stress = $\frac{(SZX(top) + SZX(bottom))}{2}$ =-90.655 kg/sqcm

Shear stress =101.31- 90.655= 10.655kg/sqcm

ANALYSIS

In a plane skin plate neutral axis lies in its middle surface. Hence its middle surface does not remain under stress. In case of curved skin plate its neutral axis is not its middle plane. Hence its middle surface remains under stress when load applied on it. This stress is treated as bending stress in skin plate. If we compare the bending stress in x direction conventional method the maximum bending stress at bottom (Y= -450 cm) is 724.5 kg/sqcm where as in model maximum bending stress is 491.58kg/sqcm (y=-435.19).

Maximum shear stress in case of conventional method is 18.105 kg/sqcm where as maximum shear stress in XY plane as per 3D analysis is 0.465 kg/sqcm

Bending stress y direction is 160.27 kg/sqcm.

Combined stress in skin plate as per 3D analysis $\sigma_u = (\sigma_x^2 + \sigma_y^2 + \sigma_x\sigma_y + 3\,\tau_{yz}^2)^{.5}$

$= (491.58^2 + 160.27^2 + 491.58 \times 160.27 + 3 \times 0.465^2)^{.5}$

=588.32kg/sqcm

Maximum permissible combined stress as per IS is 1560 kg/sqcm. Hence it is safe.

The graphs drawn at different location of skin plate combined bending and membrane stress in up stream (u/s) and down stream (d/s) surface and middle surface are mentioned in table 5.12

The membrane stress is nothing but stress developed at middle surface.

Table 5.12

Sl .no.	Figure no. and surface	X in cm	Y IN CM	Z in cm	Maximum value of absolute stress SX in Kg/sqcm
1	5.30 u/s surface	0 to 800	-450	337.5	344.167

2	5.31 d/s surface	0 to 800	-450	337.5	333.321
3	5.32 middle surface	0 to 800	-450	337.5	288.755
4	5.33 u/s surface	0 to 800	-408.76	386.42	369.028
5	5.34 d/s surface	0 to 800	-408.76	386.42	169.989
6	5.35 middle surface	0 to 800	-408.76	386.42	100.141
7	5.36 u/s surface	0 to 800	197.36	526.74	261.75
8	5.37 d/s surface	0 to 800	197.36	526.74	-252.96
9	5.38 middle surface	0 to 800	197.36	526.74	-69.4673
10	5.39 u/s surface	0 to 800	7.5	562.45	-91.2193
11	5.40 d/s surface	0 to 800	7.5	562.45	-83.2987
12	5.41 middle surface	0 to 800	7.5	562.45	-88.5838
13	5.42 u/s surface	0 to 800	-435.19	356.19	491
14	5.43 d/s surface	0 to 800	-435.19	356.19	288.931
15	5.44 middle surface	0 to 800	-435.19	356.19	226.35

From the graphs drawn in figure 5.30, 5.33, 5.36, 5.39, and 5.42 there are 16 crests and 16 troughs. The point of crest is the joint of vertical stiffener with skin plate where tensile bending stress occurs at upstream surface and point of all troughs are the middle position between two crests where only skin plate is there. At upstream the stresses in trough regions are compressive. Figure no 5.31, 5.34, 5.37, 5.40 and 5.43 are the graphs for down stream stress in skin plate where there is 16 crests and 16 troughs. All crests are the position of stress between two consecutive vertical stiffeners. All troughs are the position of joint between vertical stiffeners and skin plate. In this case tensile stresses are there in surface of skin plate between two vertical stiffeners. In case of troughs compressive stresses are there. In figure 5.32, 5.35, 5.38, 5.41 and 5.44 are the graphs of middle surface. Here all crests are the location of joint of vertical stiffener and skin plate where tensile stress occurs. All troughs are location of middle of skin plate between two consecutive stiffeners.

From above it is evident that if all crests or all troughs are only joined it will be a parabolic graph. Due to support of skin plate this type of spike shape graph is found. The maximum stress is occurring in figure no 5.26 at X=375,425, Y= -435.19 and Z=356.19 i.e.491 kg/sqcm.

5.5.2 VERTICAL STIFFENER

(i) Deflection

The deflection in beam element can be seen in element table in element solution. From the table 5.13 the maximum deflection is taking place in Z direction of element is -.51436cm. Deflection in UY and UX is very small

Table- 5.13

ELEM	UZ in cm	UY in cm	UX in cm
MINIMUM	VALUES		
VALUE	-.51436	-0.17814	-0.0385
MAXIMUM	VALUES		
VALUE	-0.15230	-0.0021	-0.00354

This element is connected at two points . The co-ordinate of those two points are shown in table 5.14

Table – 5.14

Sl.no.	X in cm	Y in cm	Z in cm
1	425	-445.15	-450
2	425	-450	337.5

From above table it is evident that maximum deflection in vertical stiffener is the nearest beam element to maximum deflection position of skin plate I.e. X= -400cm, Y= -450cm, Z= 337.5 cm. The figure no 5.12 shows the position of maximum deflection.

(ii) Stresses

The stress output in beam element is in element solution. The figure no 5.45 to 5.53 plots graph of beam stress in all 16 stiffener. Table 5.15 gives the clear picture of bending stress in element z direction.

Table 5.15

S.N.	Figure no	X in cm	Y in cm	Z in cm	Maximum stress (Kg/sqcm)
1	5.45	25, 775	7.5 to -450	562.45 to 337.5	-473.43
2	5.46	75, 725	7.5 to -450	562.45 to 337.5	-336.19
3	5.47	125, 675	7.5 to -450	562.45 to 337.5	-233.93
4	5.48	175, 625	7.5 to -450	562.45 to 337.5	-161.81
5	5.49	225, 575	7.5 to -450	562.45 to 337.5	-131.94
6	5.50	275, 525	7.5 to -450	562.45 to 337.5	-118.09
7	5.51	325, 475	7.5 to -450	562.45 to 337.5	-108.87
8	5.52	375, 425	7.5 to -450	562.45 to 337.5	-104.22
9	5.53	All 16 stiffeners	7.5 to -450	562.45 to 337.5	-473.13

From above graphs it is evident that maximum stress occurs at point where horizontal girder and vertical stiffener and radial arm join. Stress concentration gradually decreases towards centre. In figure no 5.45 to 5.52 where horizontal girder and vertical stiffener join together stress is more. It is highest at bottom horizontal girder. The highest stress is -473.43 kg/sqcm at x= 25 and 775 cm. Minimum stress is 104.22 kg/sqcm at x= 375 and 425 cm. The figure no 5.39 shows the distribution pattern of stress at nodes where horizontal girder and vertical stiffener join. The maximum stress graph is shown in figure 5.45 From the fig no 5.45 to 5.47 it is observed that there is sudden rise of stress where vertical stiffener and horizontal girder are joined together.

As per conventional method the maximum stress is 192.695 kg/sqcm in all the joints of vertical stiffener and bottom horizontal girder. However in actual practice stress is 473.43kg/sqcm at joint of radial arms horizontal girder and vertical stiffener. This zone of vertical stiffener is highly stressed zone. This stress decreases gradually towards centre. It is 104.22 kg/sqcm at centre. However allowable stress in this zone is 1170 kg/sqcm. Hence design is safe. If this maximum stress is considered as maximum bending stress of skin plate coacting with vertical stiffener then combined stress is

$$\sigma_c = (\sigma_x^2 + \sigma_y^2 + \sigma_x\sigma_y + 3\tau_{xy})^{.5}$$

$$= (491.58^2 + 473.43^2 + 491.58x\,473.43 + 3x\,0.465^2)^2$$

$$= 835.77 \text{ kg/sqcm}$$

Maximum permissible combined stress as per IS is 1560 kg/sqcm Actual stress is less than combined stress. Hence it is safe. Figure 5.54 displays the pattern of stress distribution in vertical stiffener at joint of horizontal girder and skin plate. This pattern of stress distribution is completely different from conventional method. Stress where vertical stiffener joins with horizontal girder in figure 5.45 is very high all on a sudden. This sort of result is not expected. If this sudden change is removed, actual stress will be within 200 kg/sq.cm.

5.5.3 Horizontal Girder

(i) Deflection

The maximum deflection in horizontal girder takes place in element no 11709 and its value is -0.48870. This element consists of two points whose co-ordinates are given below in table 5.17

Table – 5.16

ELEM	UZ	UY	UX
MINIMUM	VALUES		
VALUE	-.48870	-0.17123	-1.21E-02
MAXIMUM	VALUES		
VALUE	-.17550 -	.32818E-1	1.12E-01

The location of above maximum deflection of element is shown in following table. In which it is clear that maximum deflection occurs at the middle element of horizontal girder.

Table- 5.17

Sl.no.	X in cm	Y in cm	Z in cm
1	425	-445.15	-450
2	425	-450	337.5

As per conventional method maximum deflection in bottom horizontal girder is 1.3 cm. Hence in actual practice it is less.

(ii) Stresses

Figure 5.55, 5.56 shows the graphs of bottom horizontal girder bending stresses. Figure 5.57 and 5.58 gives the graph of bending stress in top horizontal girder. As per the graph the maximum stress in 3D analysis is 786.36 kg/sq.cm at X= 125 cm and 675 cm from both sides in bottom horizontal girder.

As per conventional method the maximum stress is 1394.493 kg/sqcm. The stress in 3D model is only 56.39 % of the bending stress calculated by conventional method.

5.5.4 RADIAL ARM

In radial arm maximum deflection in axial direction UZ e is -0.28404 cm.

The maximum axial compressive stress is 683 kg/sqcm. As per conventional method maximum axial stress is 699 kg/sqcm. Hence actual axial stress is less than conventional stress. Maximum bending stress is 151.11 kg/sqcm.. The conventional method maximum bending stress is 641.86 kg/sqcm. 3 D bending stress is less than conventional method bending stress.

5.5.5 HORIZONTAL STIFFENER

(i) Deflection

The maximum deflection occurs in horizontal stiffener element where maximum deflection of skin plate occurs.

Table 5.18

ELEM	UZ	UY	UX
MINIMUM	VALUES		
VALUE	-.51623	-0.17678	-0.0372
MAXIMUM	VALUES		
VALUE	-0.1499	0	-0.038

(ii) Stress

THE figure 5.59 shows the bending stress graph for bottom horizontal stiffener. The maximum bending stress as shown from the graph is 133.74 kg/sqcm. As per conventional method maximum stress is 276.56 kg/sqcm. Hence bending stress as per 3 D is less than 2D conventional analysis stress.

5.6, SUMMARY OF COMPARISON AMONG CONVENTIONAL, MODEL A2, AND MODEL B2 RESULTS

The results of conventional approach, B2 model and A2 model were compared and mentioned in Table 5.19, 5.20 and 5.21

Table 5.19 **Comparison of bending stress in kg/sqcm**

S.N.	Part Name	Conventional results	model B2 result	Model A2 result
1	Skin plate	724	491.58	603.41
2	Vertical stiffener	192.695	473.43	197.94
3	Horizontal girder	1394.493	786.36	1046.2
4	Radial arm	614.86	151.11	575.46
5	Horizontal stiffener	276.56	133.74	222.02

Table 5.20 **Comparison of Deflection UZ (along the direction of flow) in cm**

S.N.	Part name	Conventional results	model B2 result	Model A2 result
1	top horizontal girder	0.8058	0.3356	0.976595
2	bottom horizontal girder	1.3	0.5085	1.1812

Table 5.21 **Comparison of Axial stress in Radial arm**

S.N	Part Name	Conventional Results	model B2 result	Model A2 result
1	Radial arm	699	683	579.26

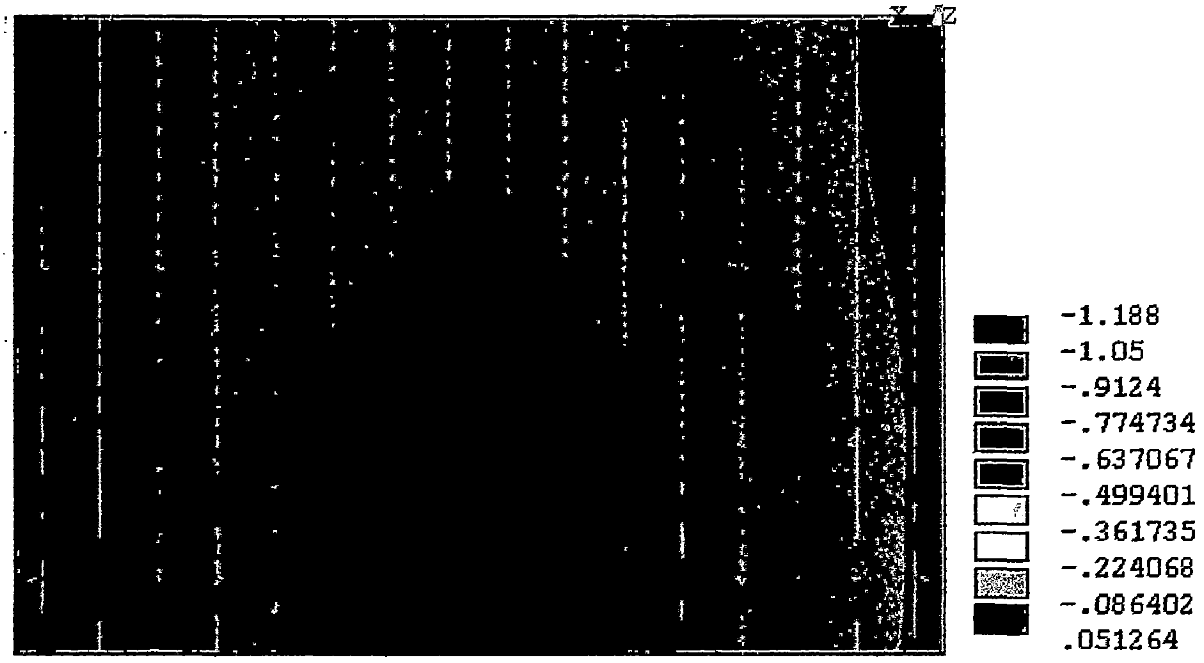


FIG- 5.1 MODEL A1 DEFLECTION CONTOUR ALONG FLOW

FIG- 5.2 MODEL A2 DEFLECTION CONTOUR ALONG FLOW

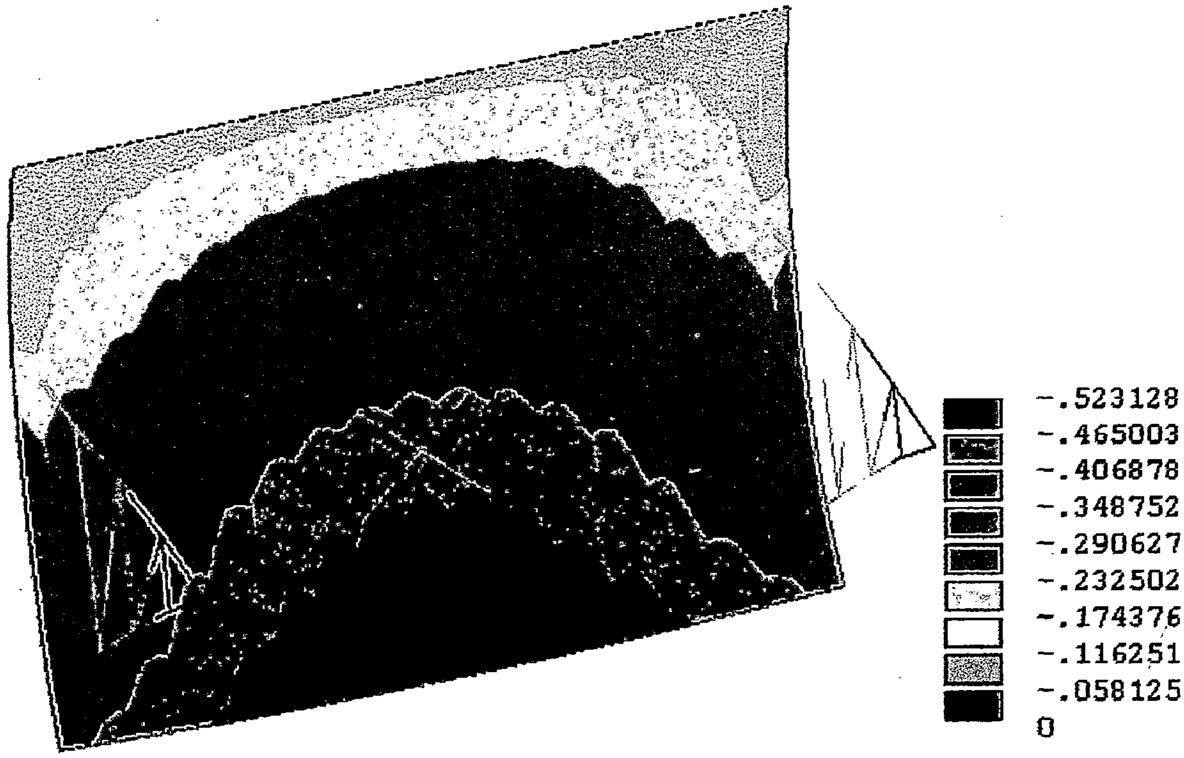


FIG- 5.3 MODEL B1 DEFLECTION CONTOUR ALONG FLOW

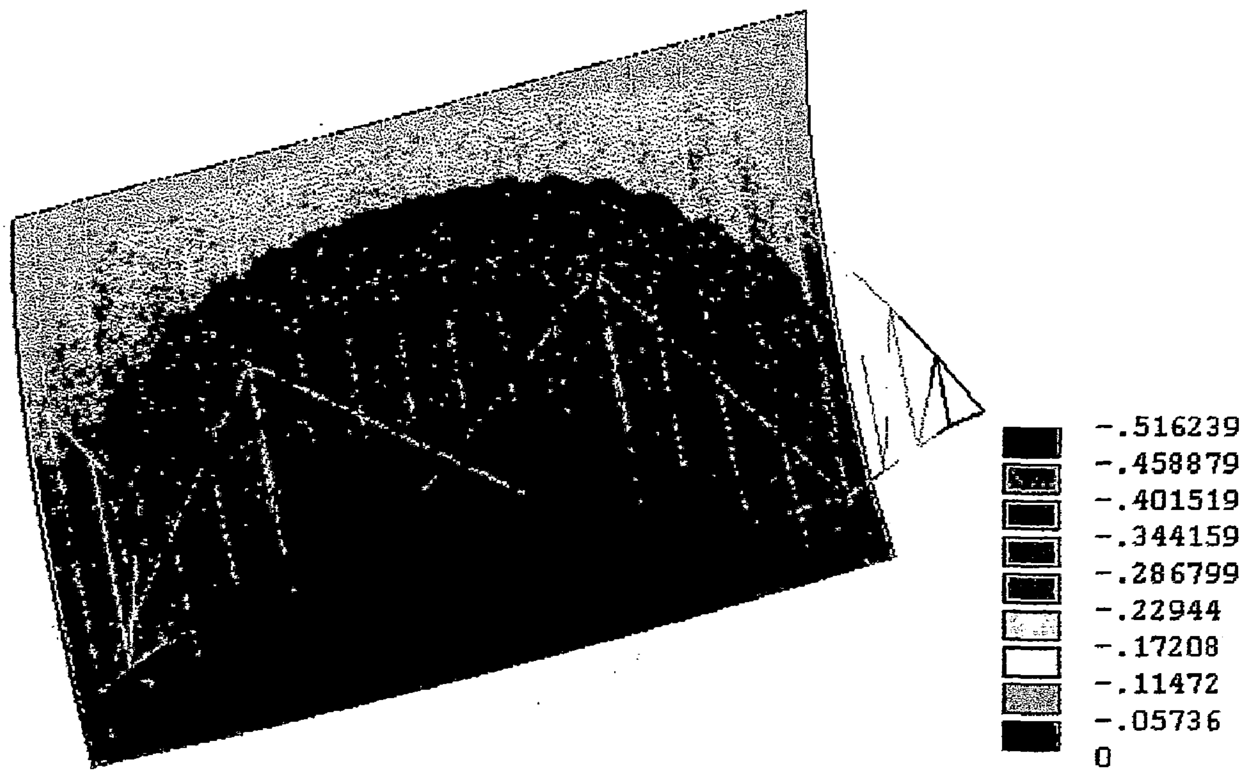


FIG- 5.4 MODEL B2 DEFLECTION CONTOUR ALONG FLOW

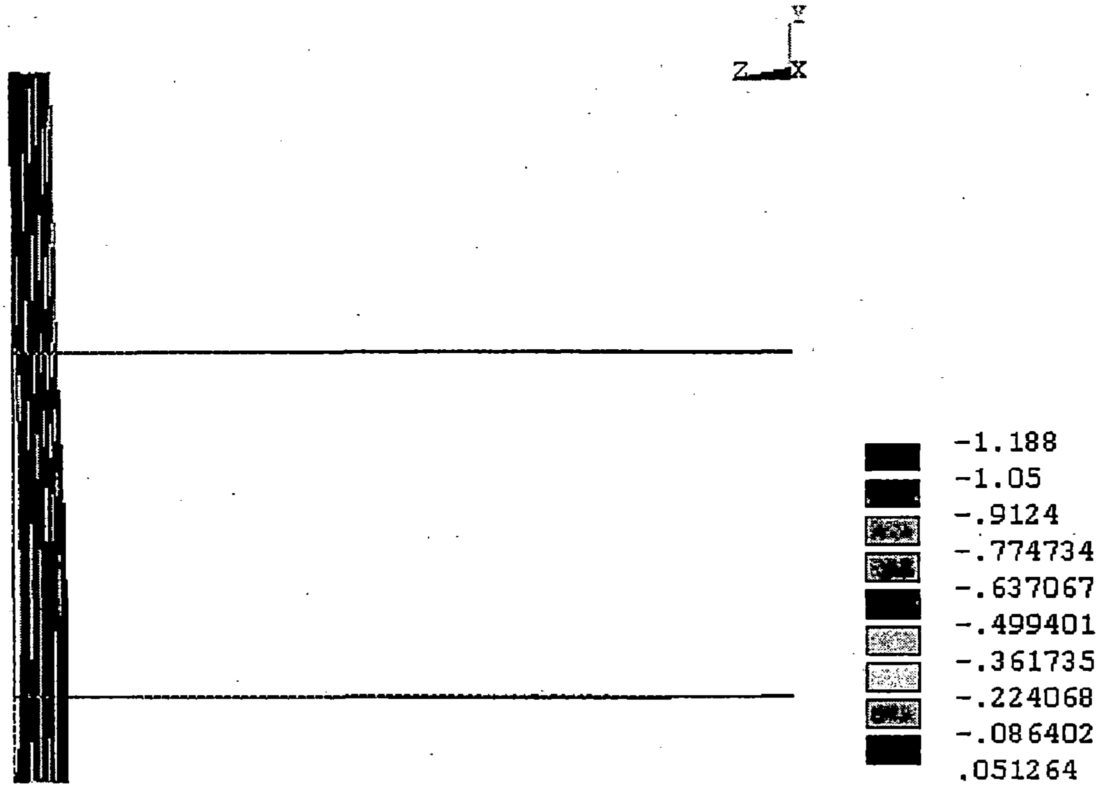


FIG- 5.5 MODEL A1 DEFLECTION CONTOUR ALONG FLOW

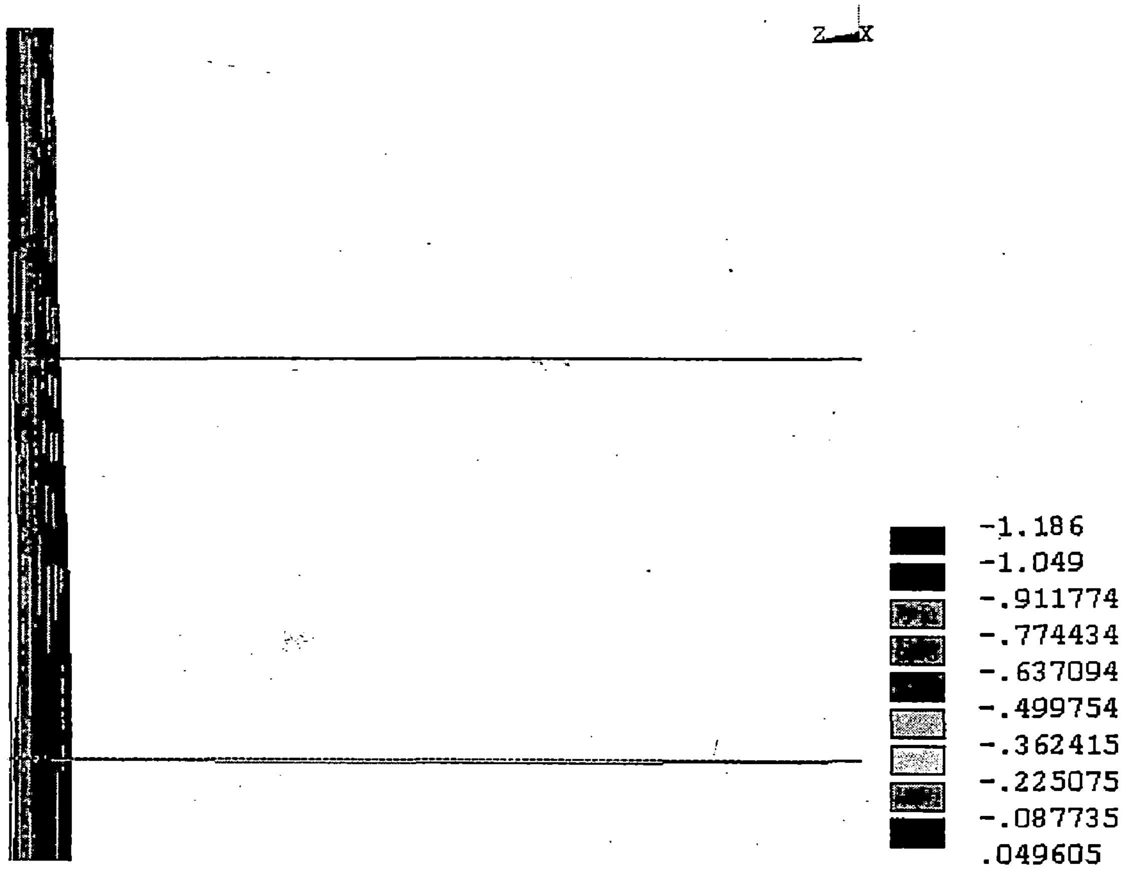


FIG- 5.6 MODEL A2 DEFLECTION CONTOUR ALONG FLOW

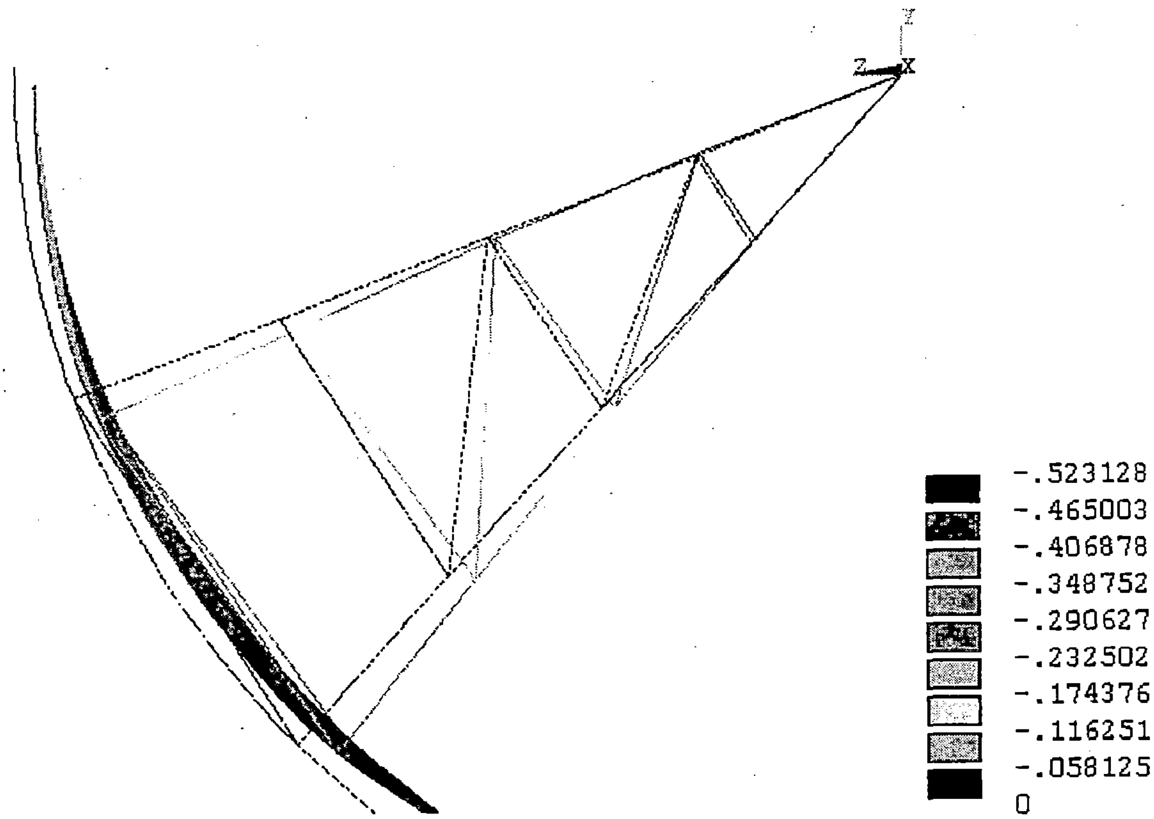


FIG- 5.7 MODEL B2 DEFLECTION CONTOUR ALONG FLOW

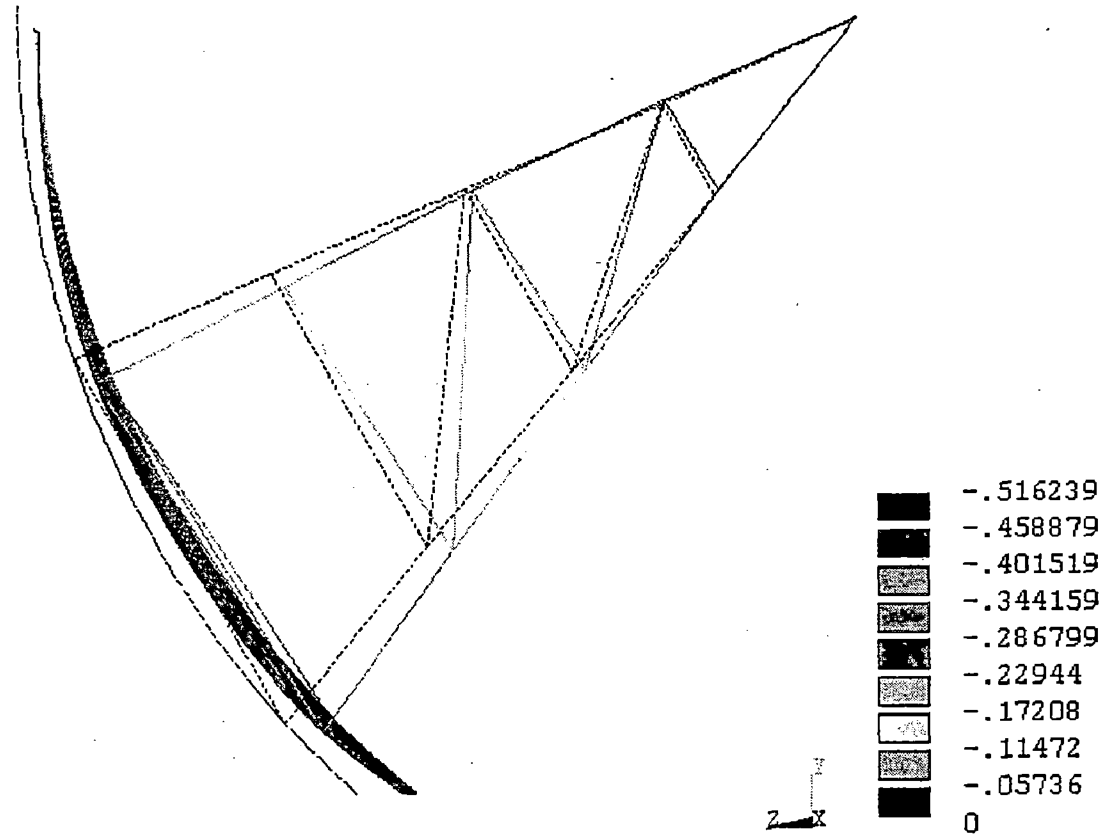


FIG- 5.8 MODEL B2 DEFLECTION CONTOUR ALONG FLOW

Fig.5.10 SX , U/S of Skin plate at bottom horizontal Girder

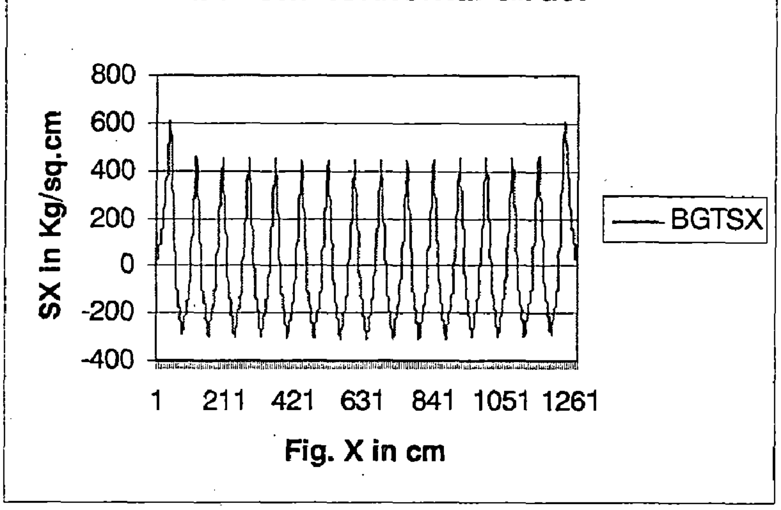


Fig. 5.9 UZ at bottom of skin plate

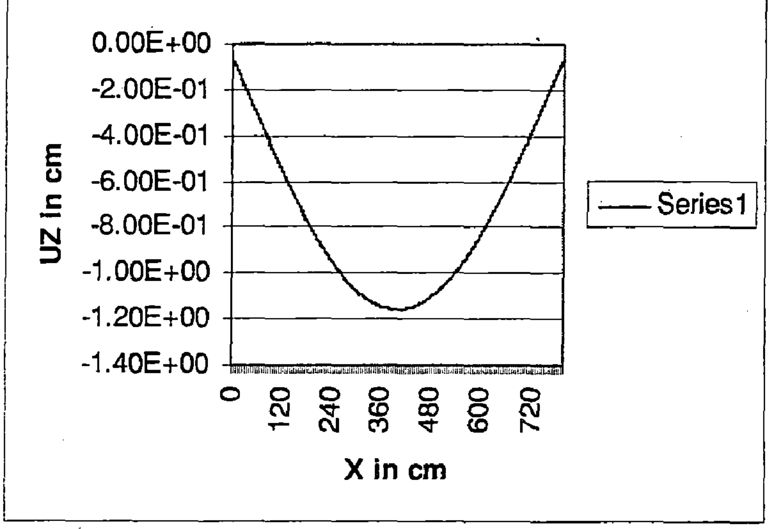


Fig 5.11 Bending Stress in vertical stiffner at distance 25cm from both sides of gate

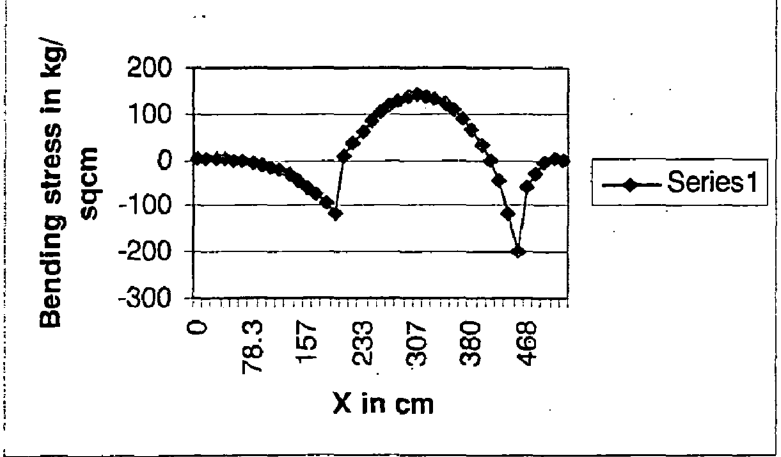


Fig 5.12 UZ of bottom Horizontal Girder

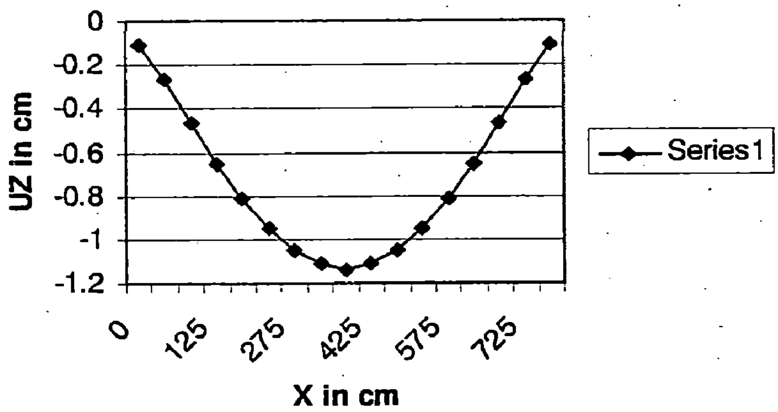


Fig 5.13 UZ in top horizontal girder

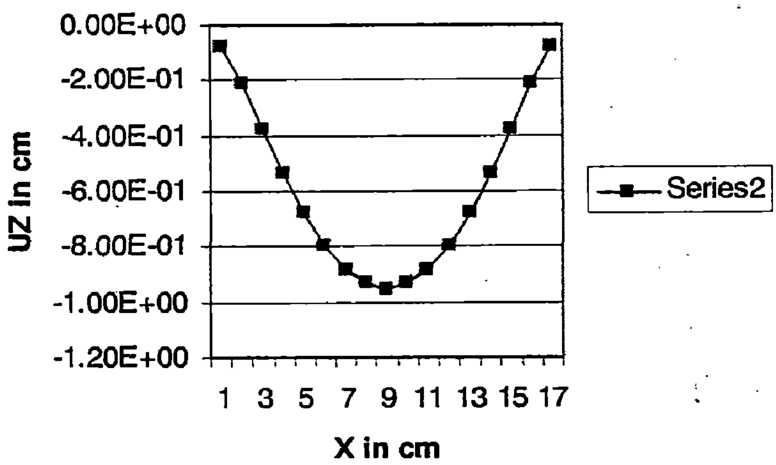


Fig 5.14 Bending stress in bottom horizontal girder

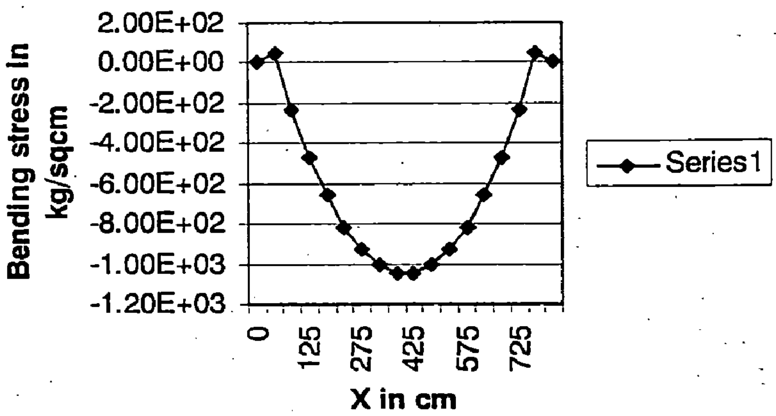


Fig 5.15 Bending stress in bottom horizontal stiffner

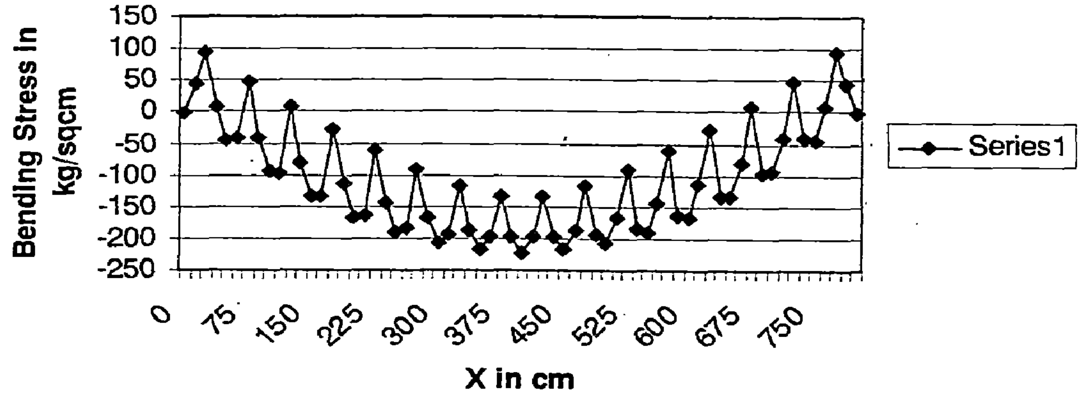
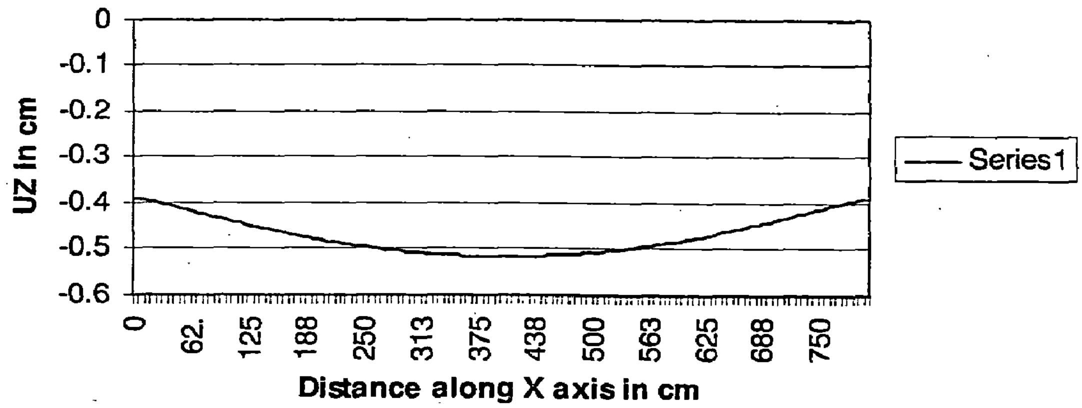
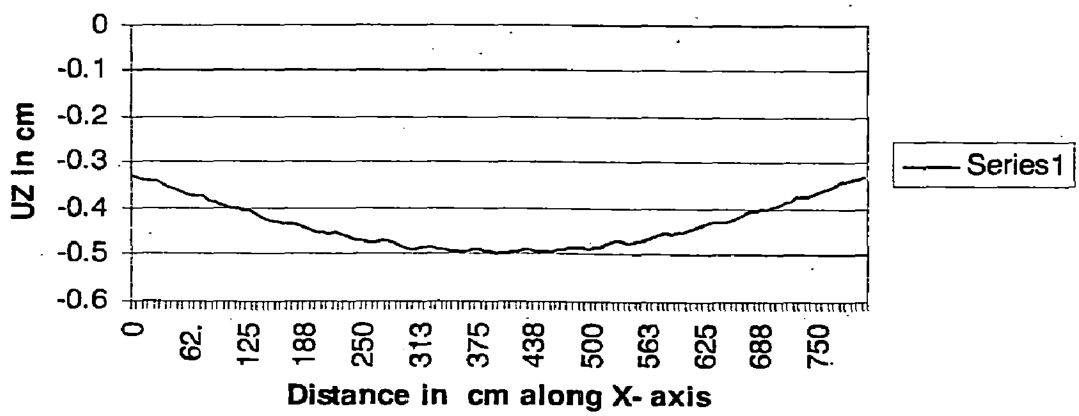


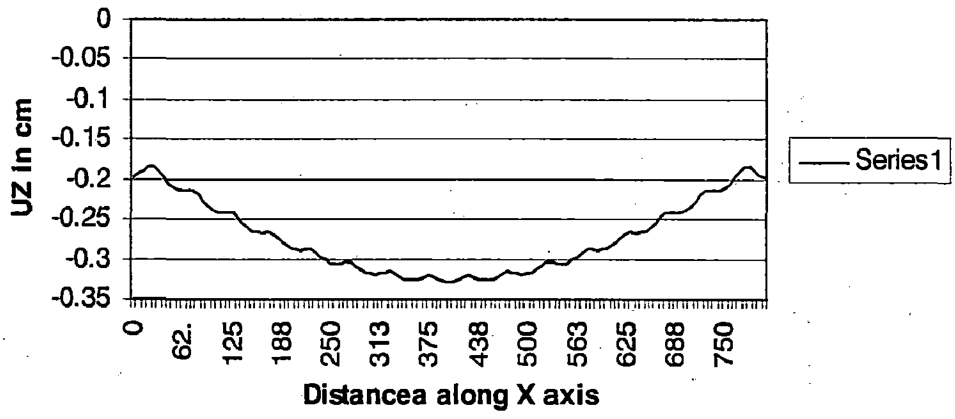
Figure no 5.16 Deflection of skin plate at bottom (y=-450)



Graph no.5.17 Deflection of skin plate at bottom horizontal girder(Y=-408.76cm)



Graph no 5.18, Deflection in skin plate at top horizontal girder (y=-197.36cm)



Graph no 5.19 Deflection in skin plate at top(Y =7.5 cm)

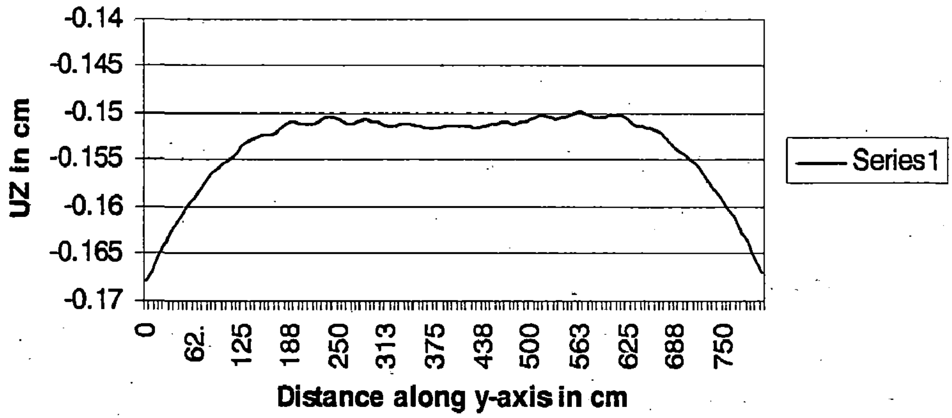
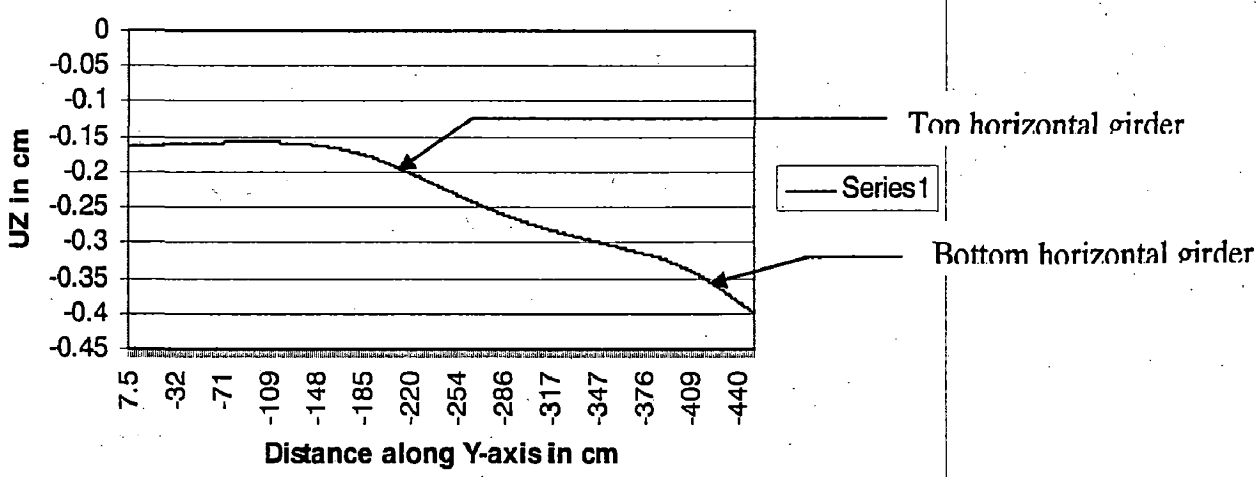


Fig 5.20 Deflection in skin plate (X=25, 775cm)



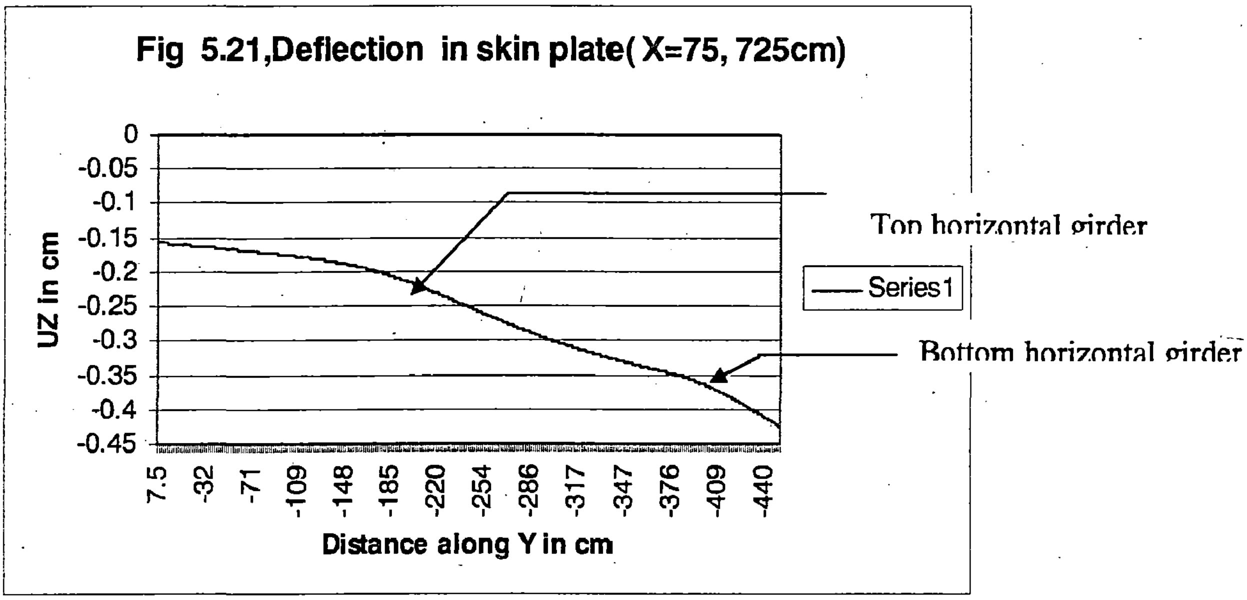


Fig 5.21,Deflection in skin plate(X=75, 725cm)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
UZ in cm
7.5
-32
-71
-109
-148
-185
-220
-254
-286
-317
-347
-376
-409
-440
Distance along Y in cm
Top horizontal girder
Series1
Bottom horizontal girder

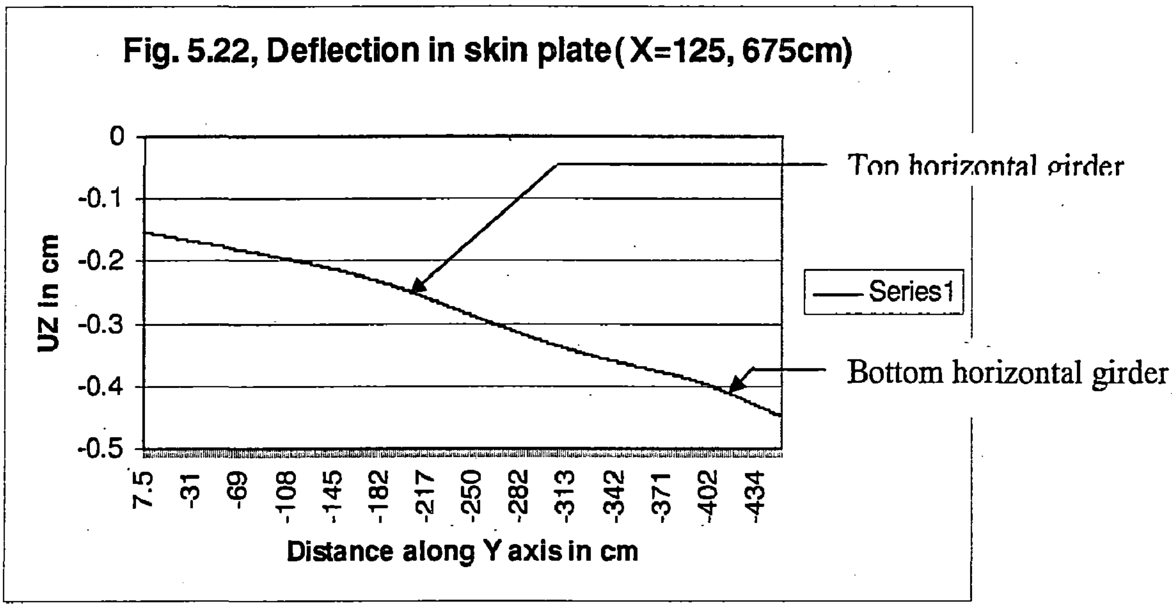


Fig. 5.22, Deflection in skin plate(X=125, 675cm)
0
-0.1
-0.2
-0.3
-0.4
-0.5
UZ in cm
7.5
-31
-69
-108
-145
-182
-217
-250
-282
-313
-342
-371
-402
-434
Distance along Y axis in cm
Top horizontal girder
Series1
Bottom horizontal girder

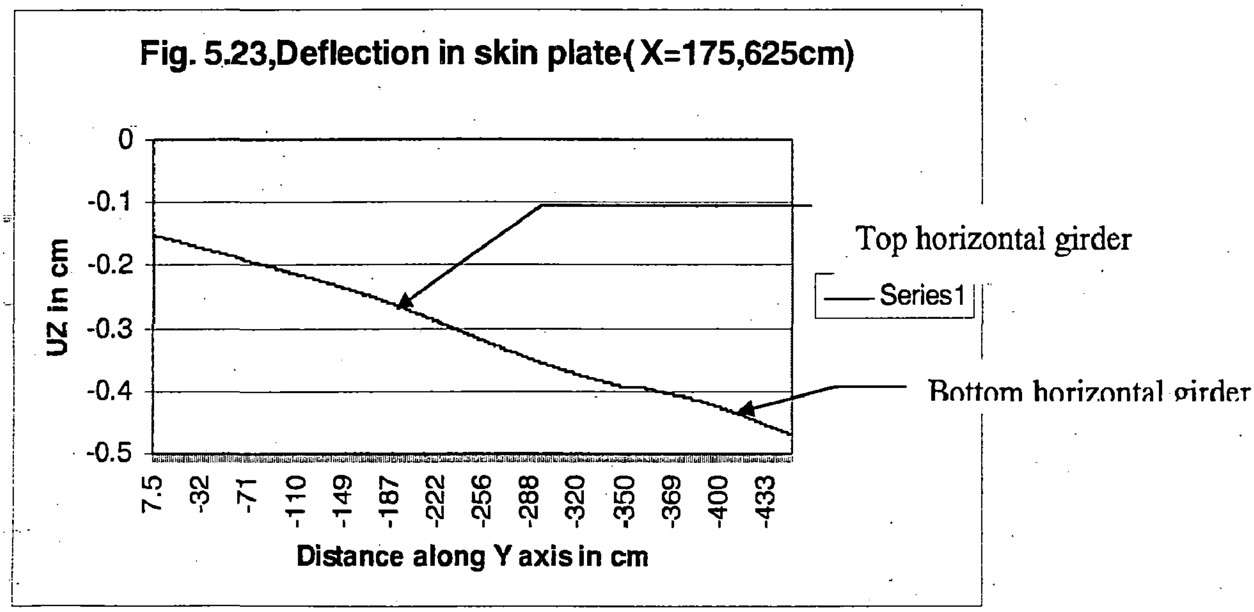


Fig. 5.23,Deflection in skin plate(X=175,625cm)
0
-0.1
-0.2
-0.3
-0.4
-0.5
UZ in cm
7.5
-32
-71
-110
-149
-187
-222
-256
-288
-320
-350
-369
-400
-433
Distance along Y axis in cm
Top horizontal girder
Series1
Bottom horizontal girder

Fig. 5.24 Deflection of skin plate(X=225, 575cm)

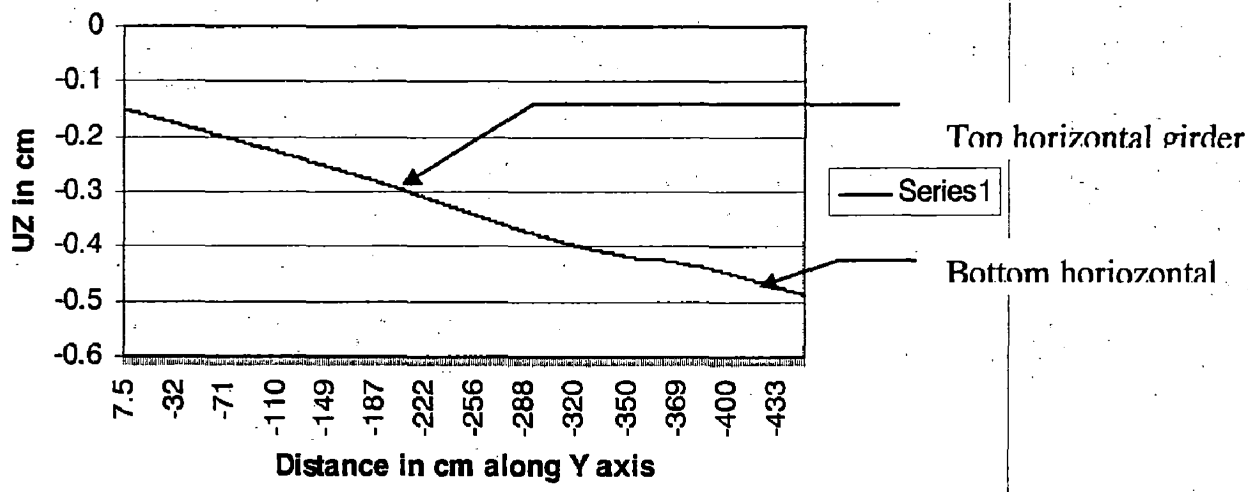


Fig. 5.25, Deflection in skin plate (x=275,525cm)

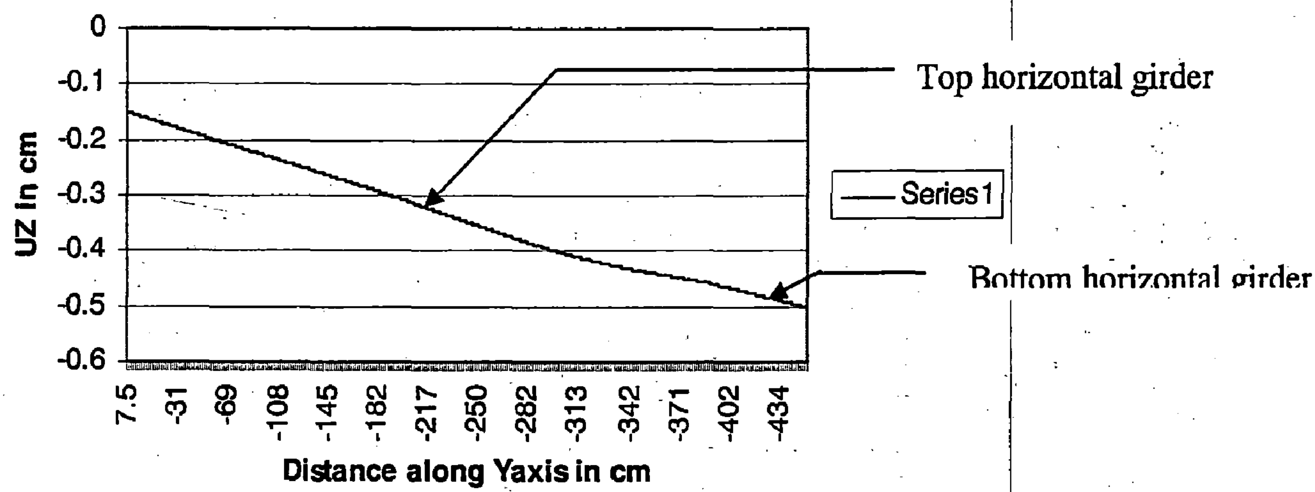


Fig.5. 26 Deflection of skin plate (X=325,475cm)

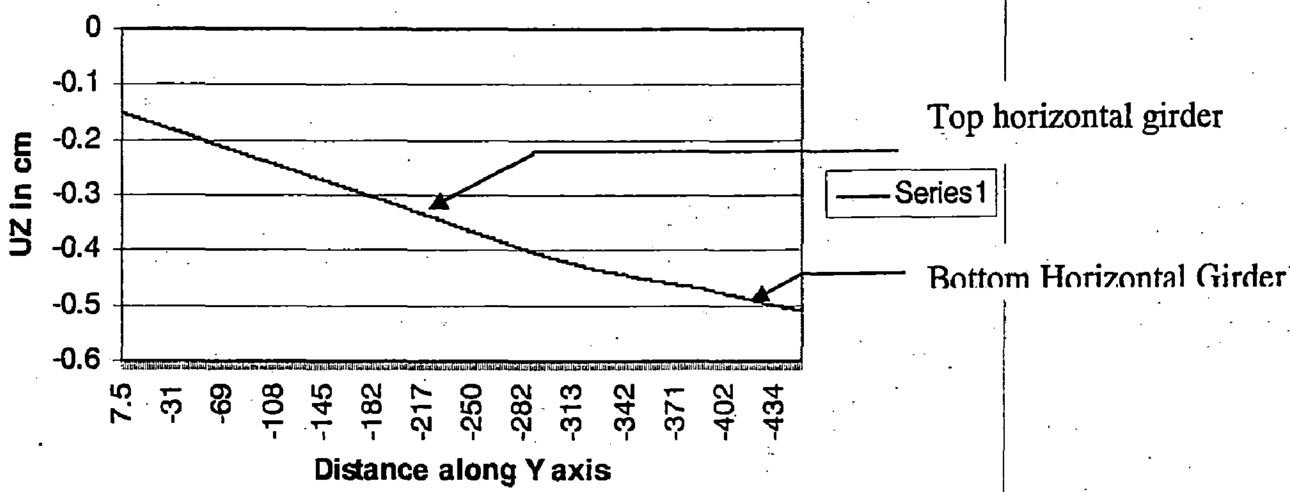


Fig. 5.27 Deflection in skin plate (X=375,425cm)

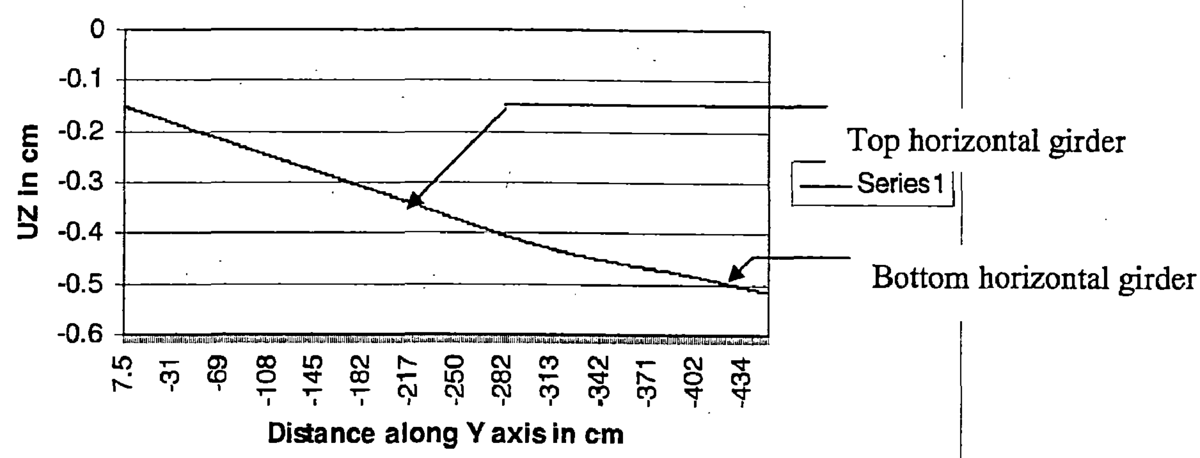
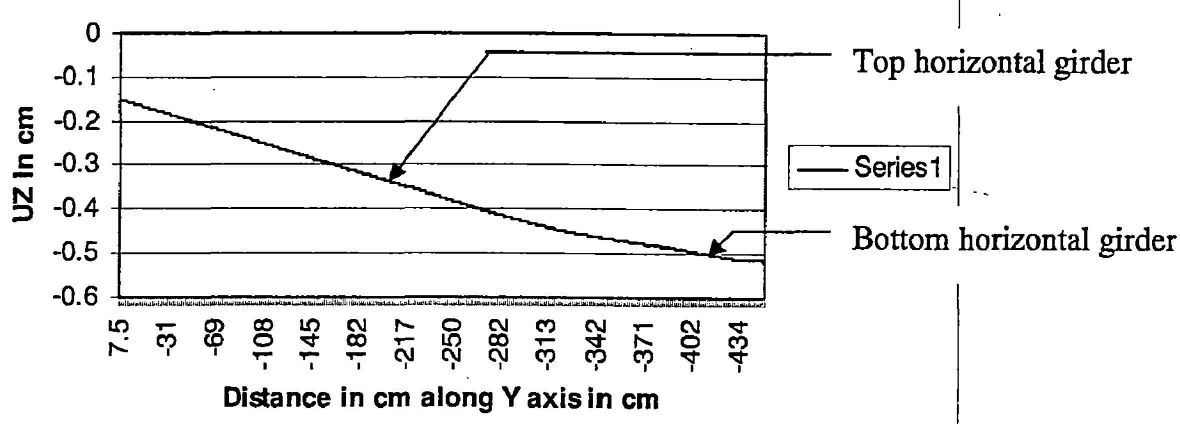
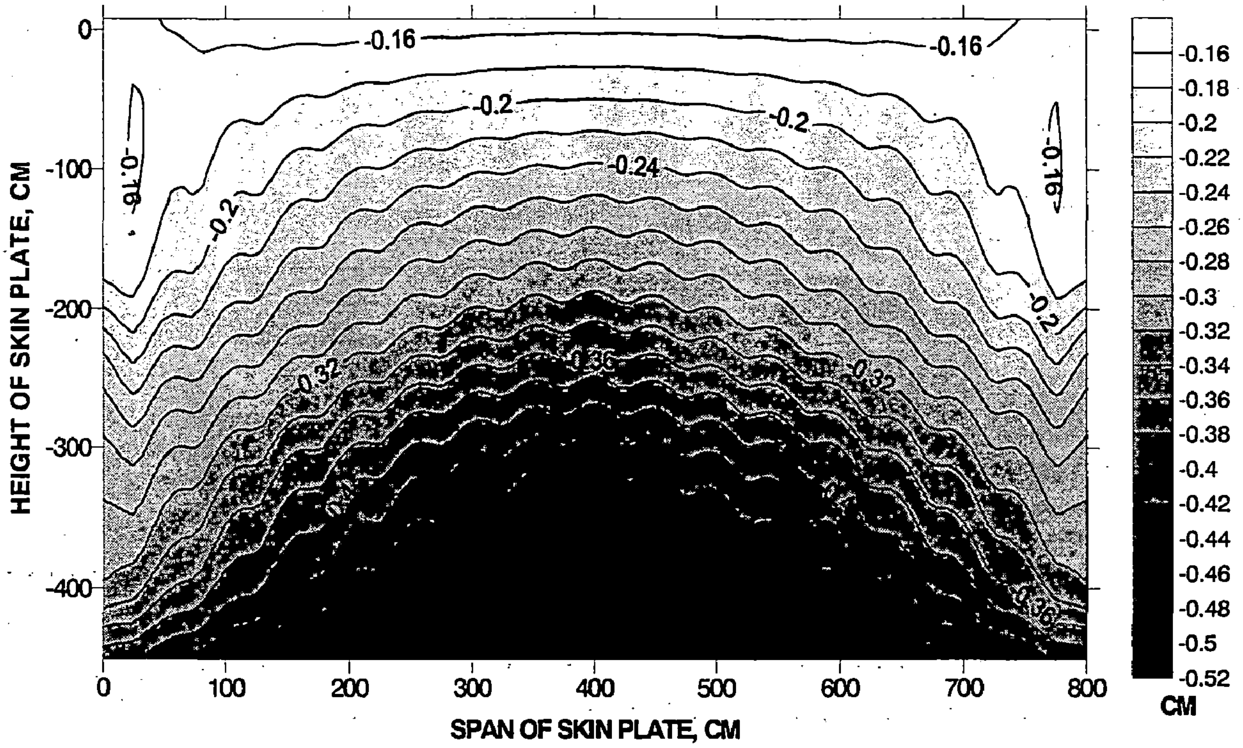


Figure 5.28. displacement of skin plate (X =400 cm)





DEFLECTION CONTOUR FOR UZ UNDER HYDROSTATIC,SILT, SILL AND DEAD LOAD

FIG. 5.29

Fig.5.30 SX U/S surface of skin plate at bottom

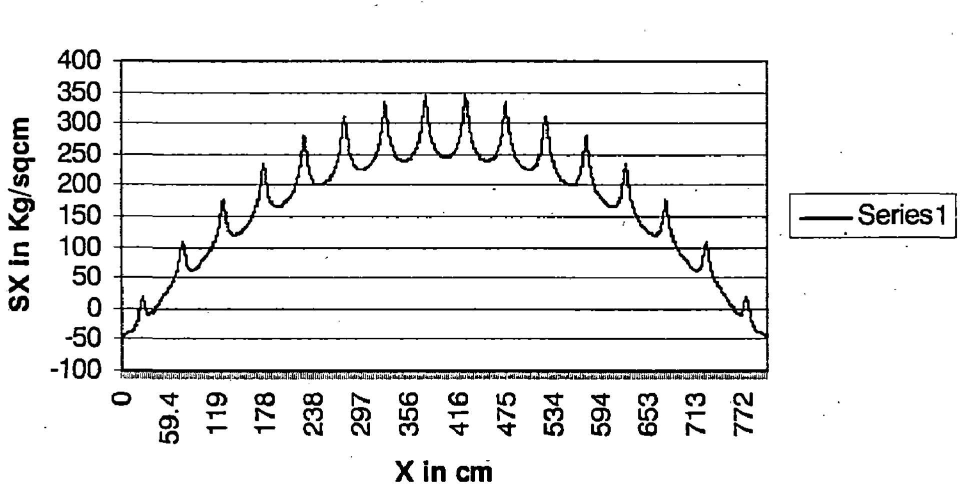


Figure 5.31 SX d/s of skin plate at bottom

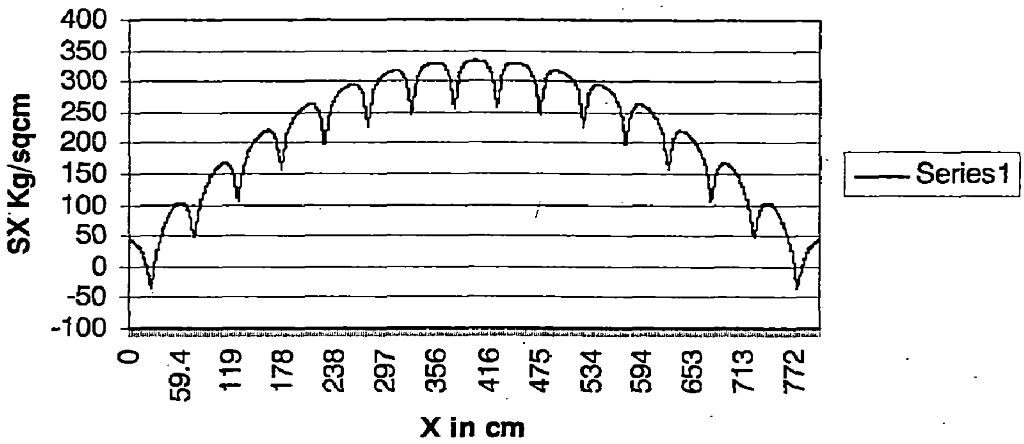


Figure 5.32 Bending Stress in skin plate in middle surface at bottom

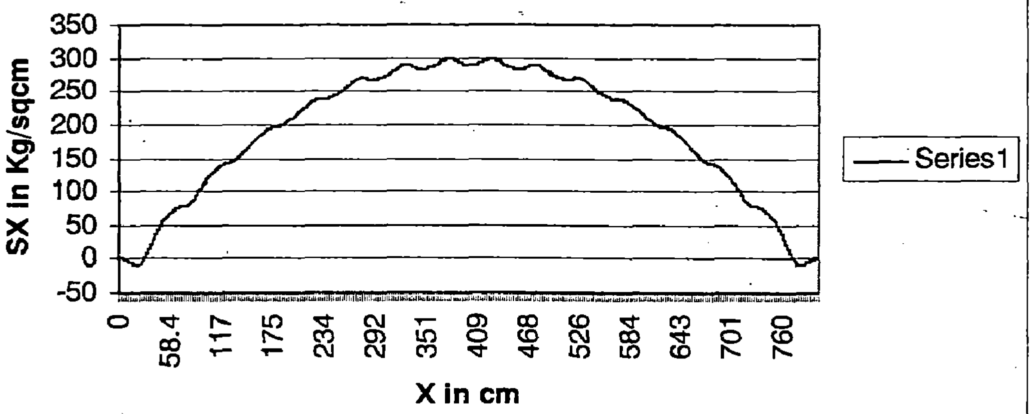
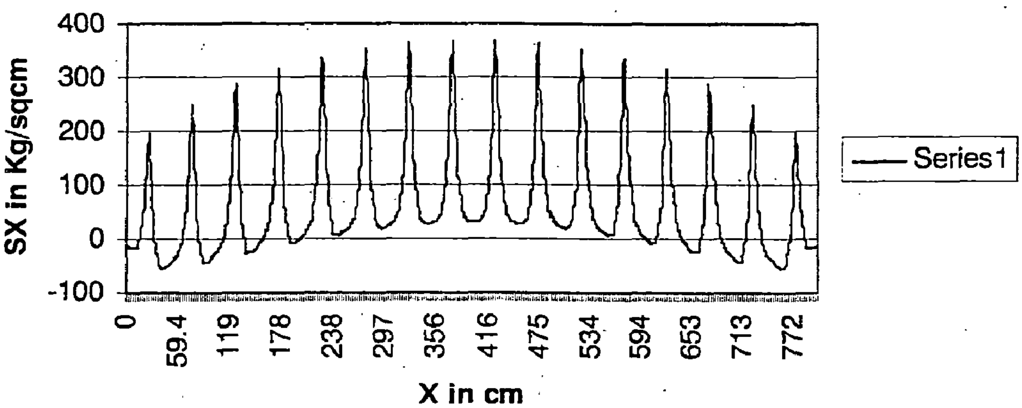


Figure 5.33 SX U/S of skin plate at bottom horizontal girder



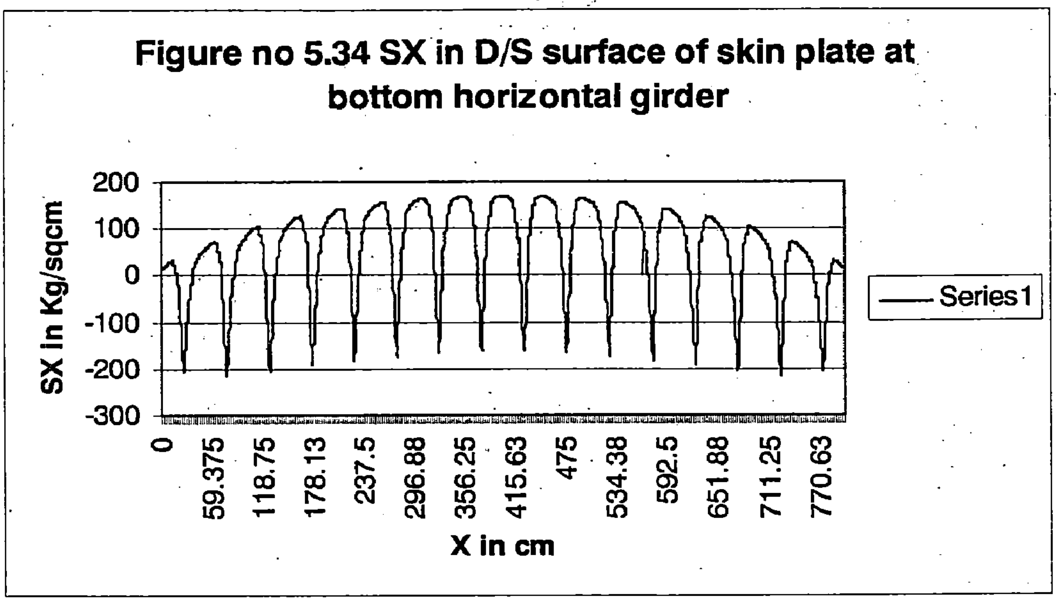


Figure no 5.34 SX in D/S surface of skin plate at bottom horizontal girder
SX in Kg/sqcm
200
100
0
-100
-200
-300
0
59.375
118.75
178.13
237.5
296.88
356.25
415.63
475
534.38
592.5
651.88
711.25
770.63
X in cm
Series1

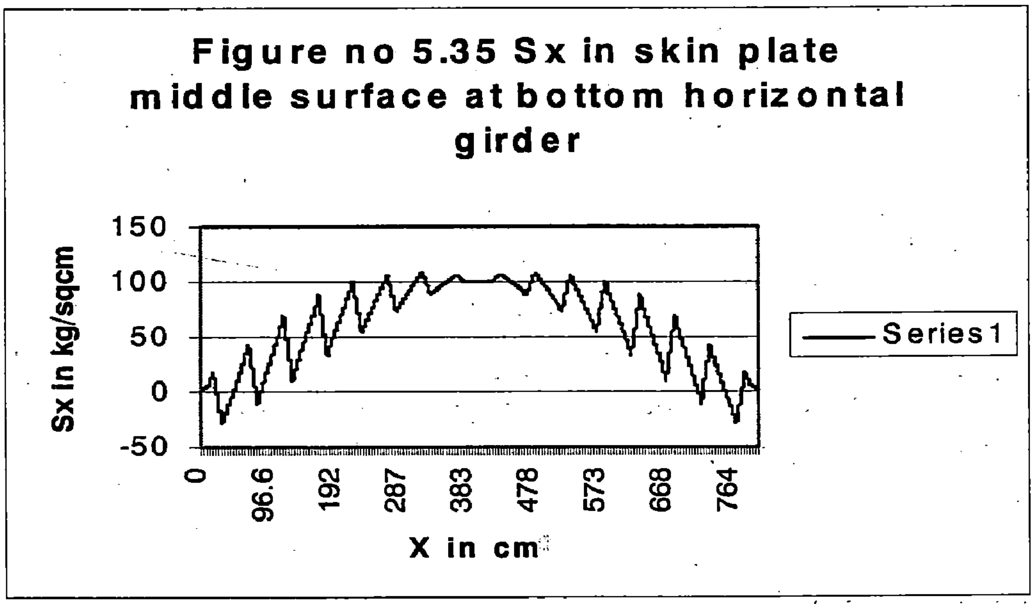


Figure no 5.35 Sx in skin plate middle surface at bottom horizontal girder
Sx in kg/sqcm
150
100
50
0
-50
0
96.6
192
287
383
478
573
668
764
X in cm
Series1

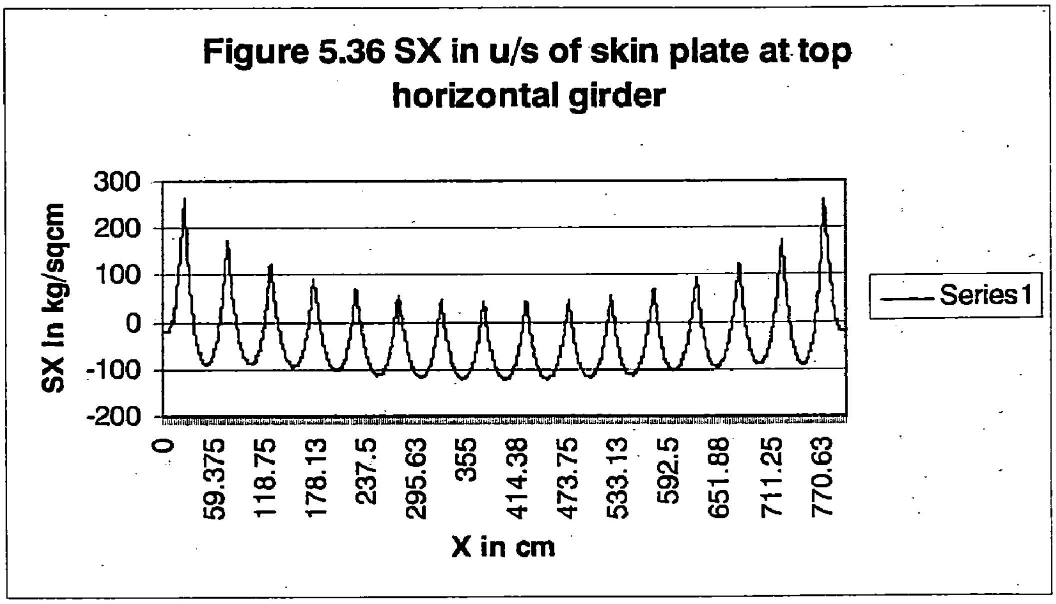


Figure 5.36 SX in u/s of skin plate at top horizontal girder
SX in kg/sqcm
300
200
100
0
-100
-200
0
59.375
118.75
178.13
237.5
295.63
355
414.38
473.75
533.13
592.5
651.88
711.25
770.63
X in cm
Series1

Figure 5.37 SX in d/s of skin plate at top horizontal girde

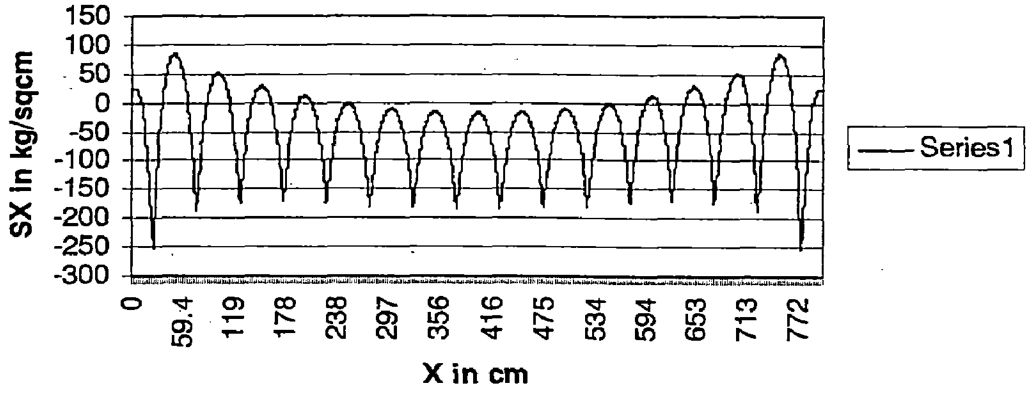


Figure 5.38 SX in skin plate middle surface at top horizontal girder

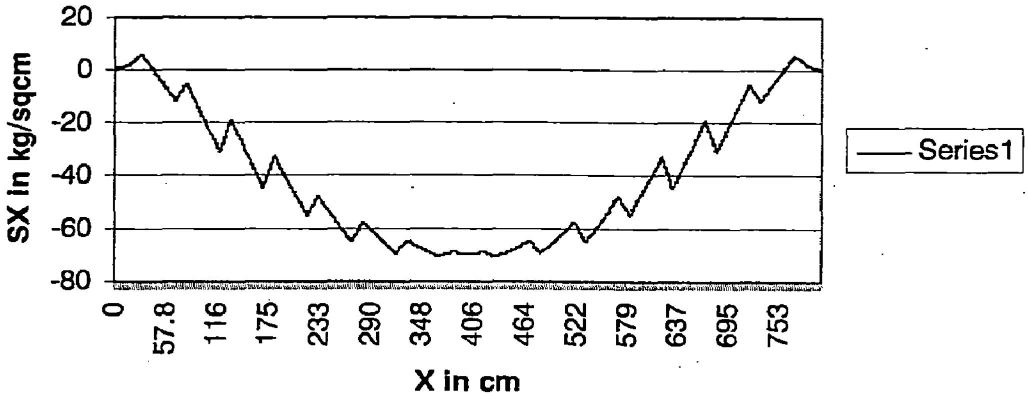


Figure 5.39 SX in u/s of skin plate at top

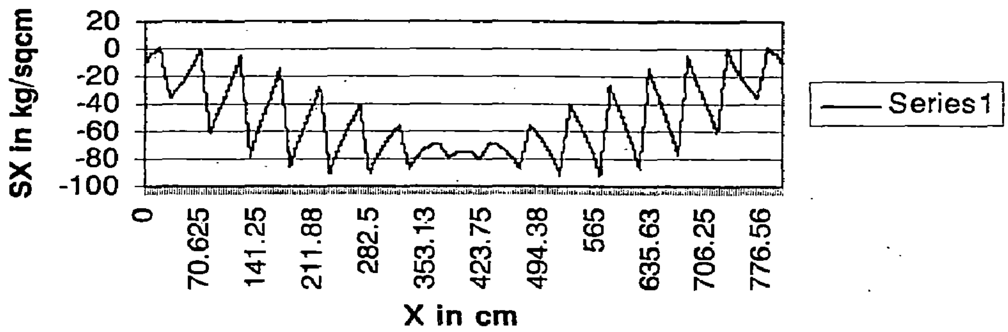


Figure 5.40 SX d/s of skin plate at top

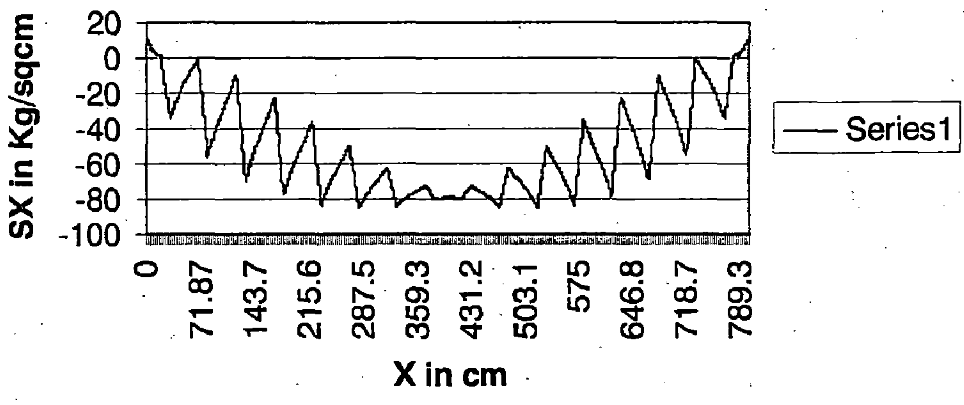


Figure 5.41 SX middle surface of skin plate at top

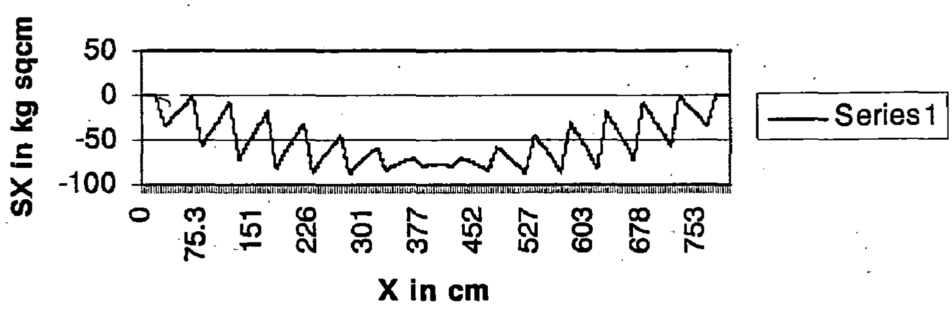
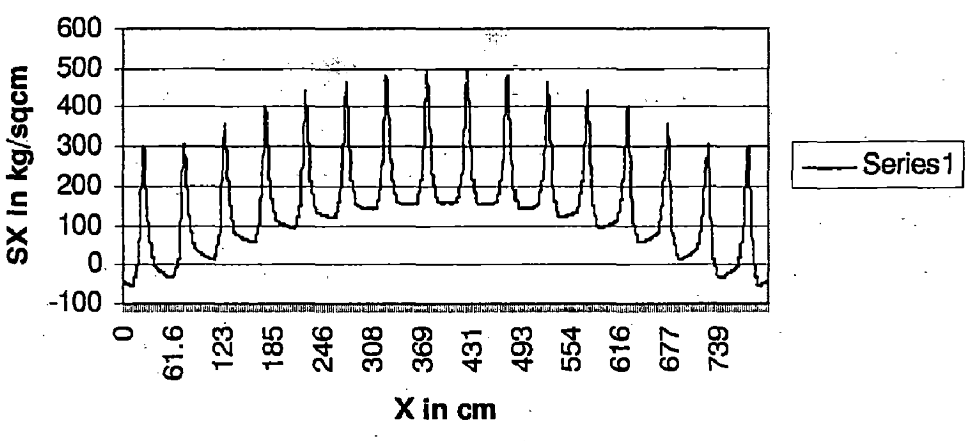


Figure 5.42 SX u/s of skin plate (y=-435.19cm)



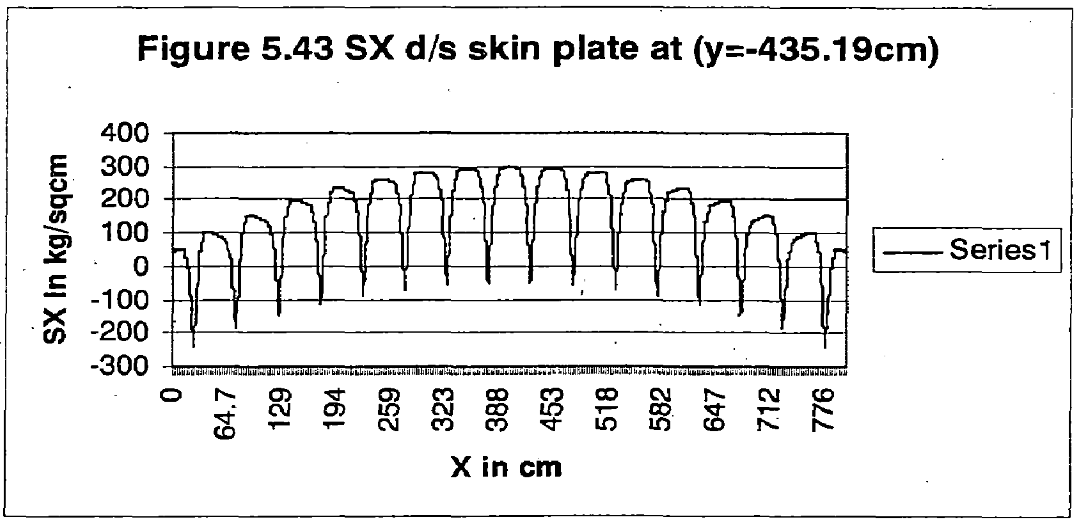


Figure 5.43 SX d/s skin plate at (y=-435.19cm)
SX in kg/sqcm
400
300
200
100
0
-100
-200
-300
0
64.7
129
194
259
323
388
453
518
582
647
712
776
X in cm
Series1

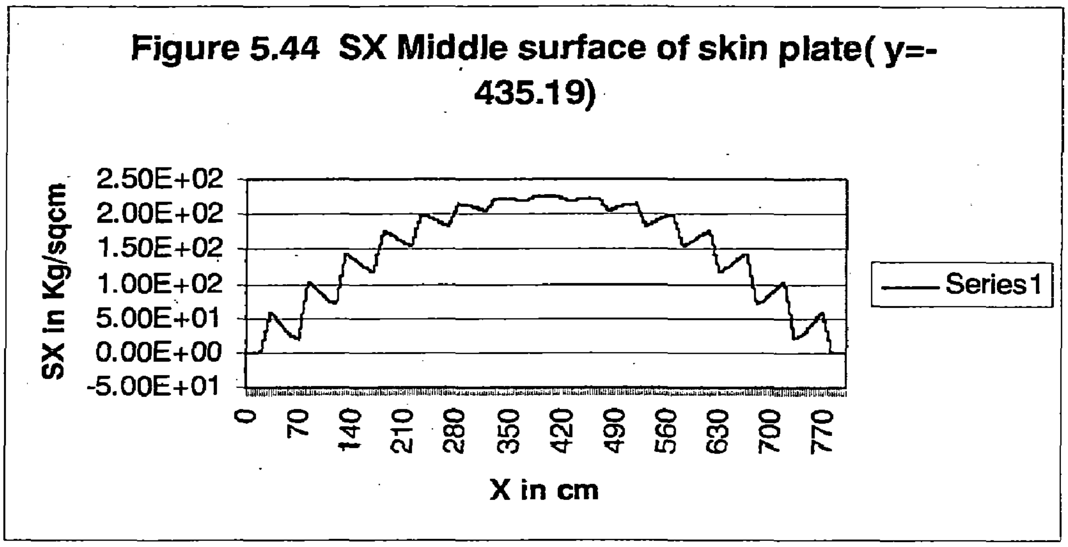


Figure 5.44 SX Middle surface of skin plate(y=-435.19)
SX in Kg/sqcm
2.50E+02
2.00E+02
1.50E+02
1.00E+02
5.00E+01
0.00E+00
-5.00E+01
0
70
140
210
280
350
420
490
560
630
700
770
X in cm
Series1

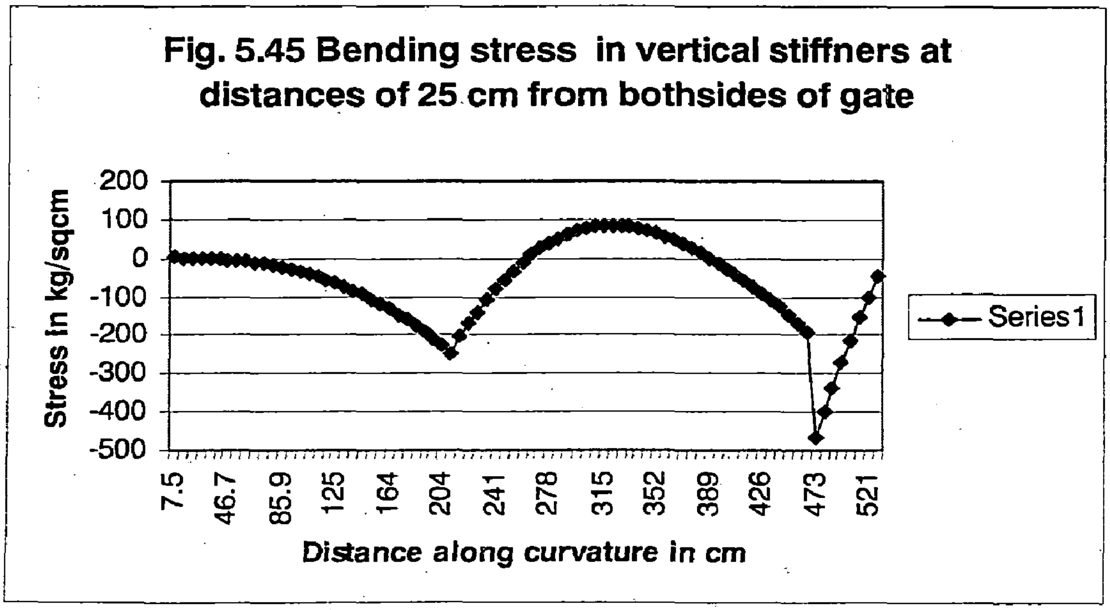


Fig. 5.45 Bending stress in vertical stiffners at distances of 25 cm from bothsides of gate
Stress in kg/sqcm
200
100
0
-100
-200
-300
-400
-500
7.5
46.7
85.9
125
164
204
241
278
315
352
389
426
473
521
Distance along curvature in cm
Series1

Figure 5.46 ,Bending stress in vertical stiffners at distance of 75 cm from bothsides of gate

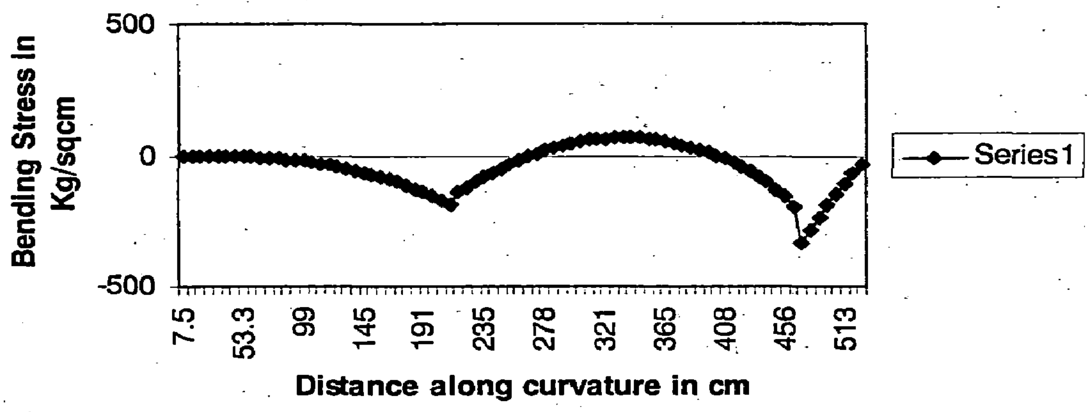


Fig 5.47 Bending stress in vertical stiffners at distance of 125 cm from bothsides of gate

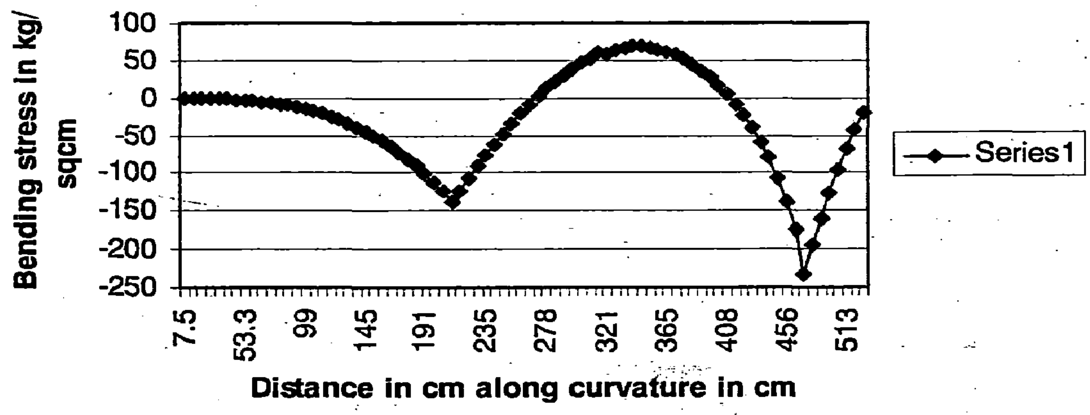


Fig 5.48 Bending stress in vertical stiffner at distance of 175 cm from both sides of gate

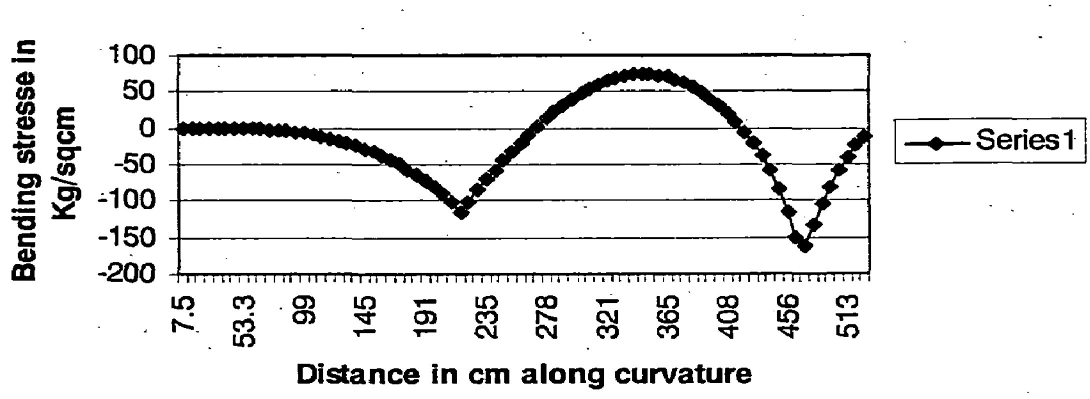


Figure 5.49 Bending stress in vertical stiffners at distance of 225 cm from both sides of gate

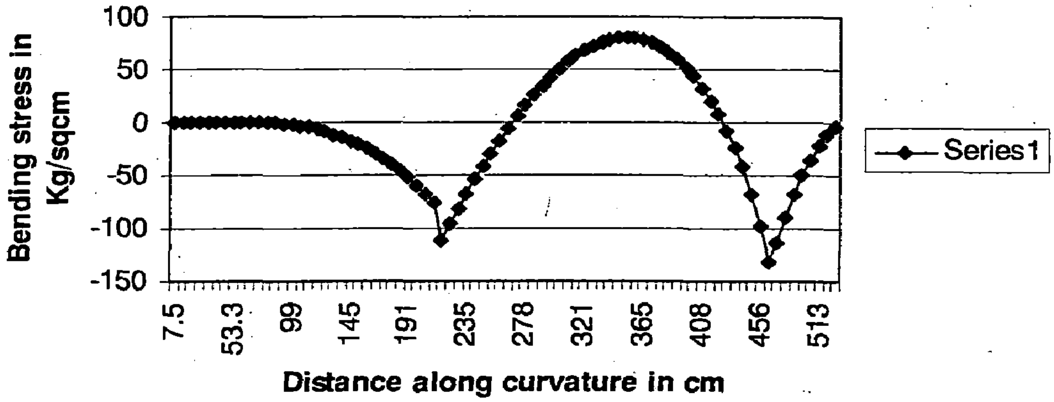


Fig 5.50 Bending stress in vertical stiffners at distance of 275cm from both sides of gate

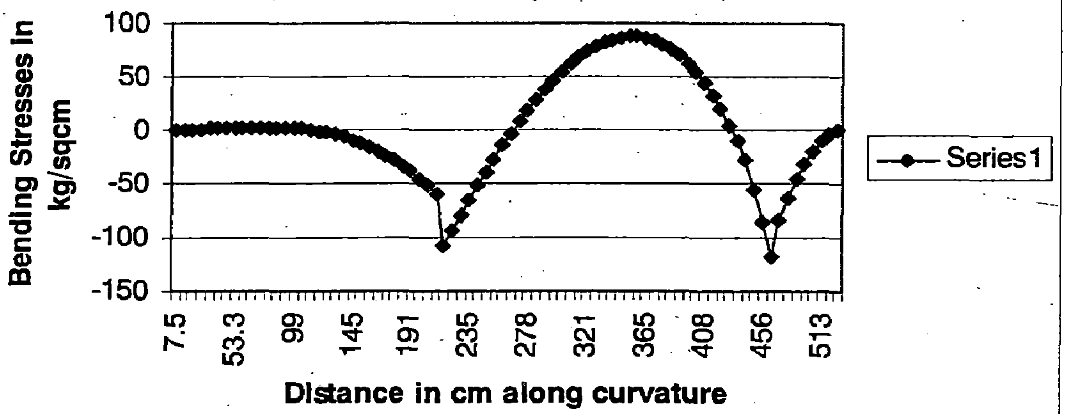


Figure 5.51 bending stress in vertical stiffners at distance of 325 cm from both sides

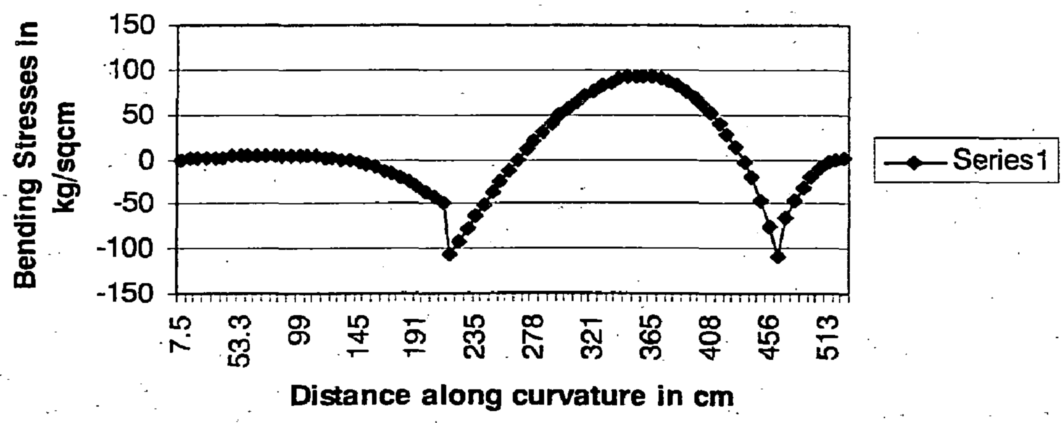


Fig 5.52 Bending stresse in vertical stiffners at distance of 375 cm from both sides of gate

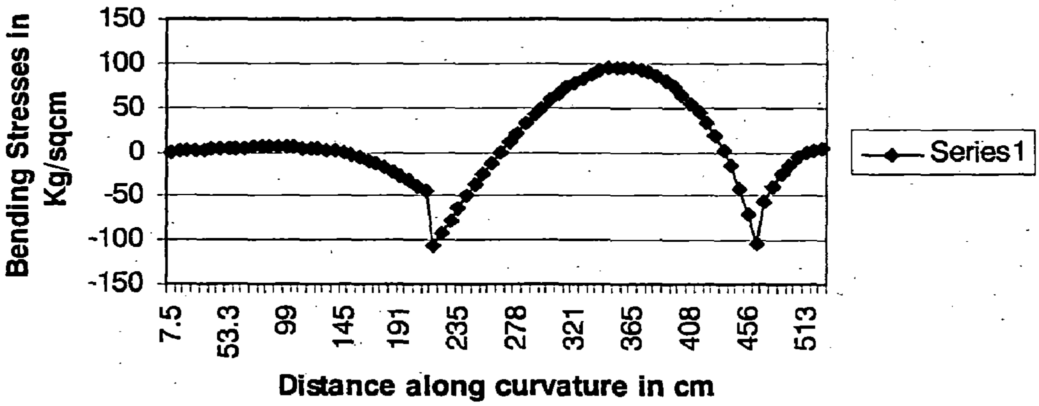


Fig 5.53 BENDING STRES AT HALF OF THE STIFFNER 8 stiffners

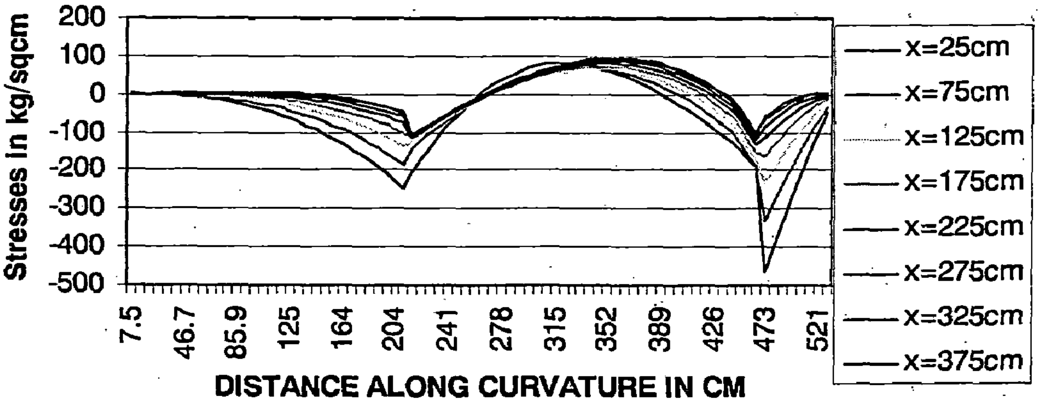


Figure 5.54 Bending stress in vertical stiffner at node of joint with bottom horizontal girder

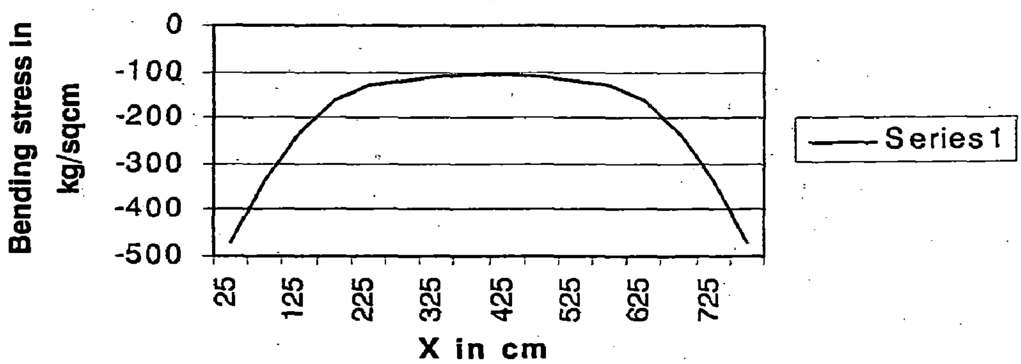


Figure 5.55 Bending Stress in Bottom Horizontal girder at I node

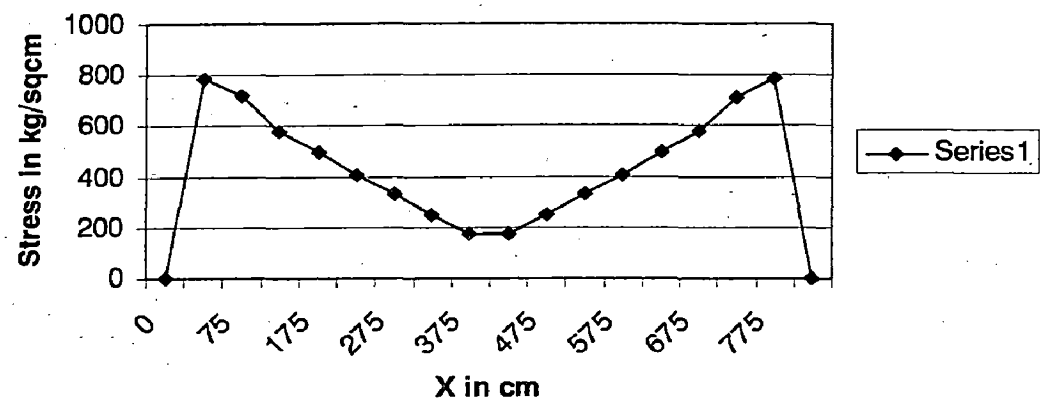


Figure 5.56 Bending stress in J nodes of bottom Horizontal Girder

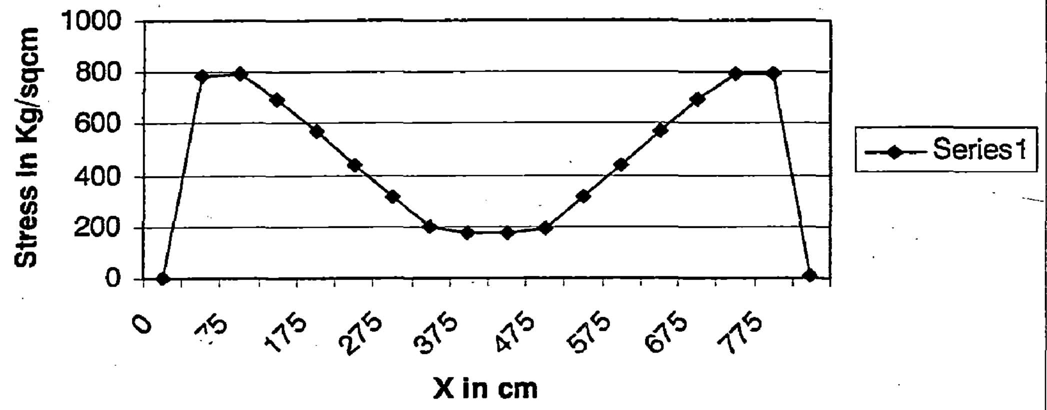


Figure 5.57 Bending stresses in Top horizontal girder at I node

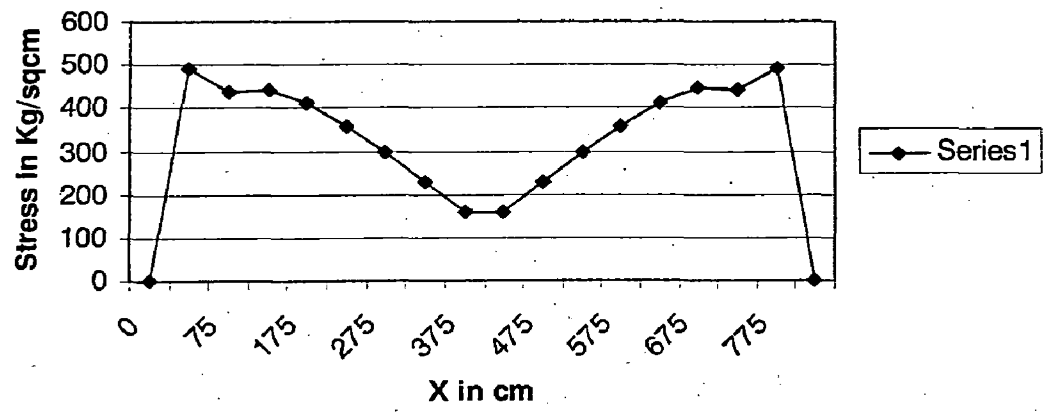


Figure 5.58 Bending stress in Top Horizontal girder at J node

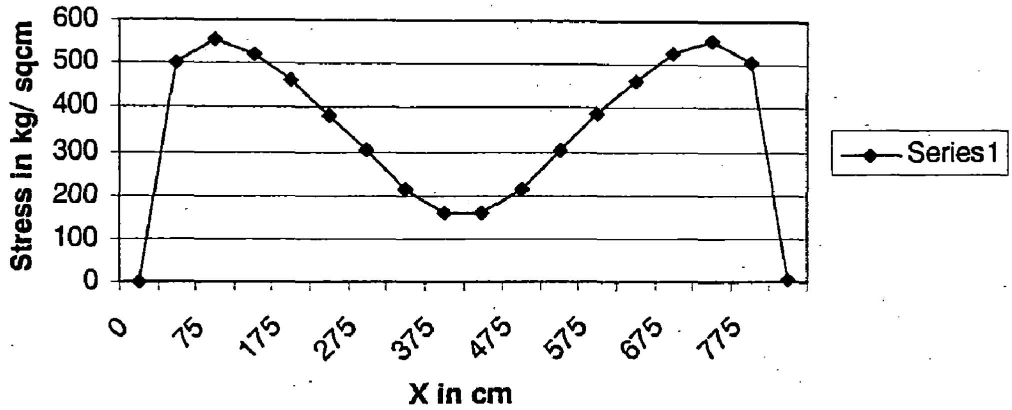
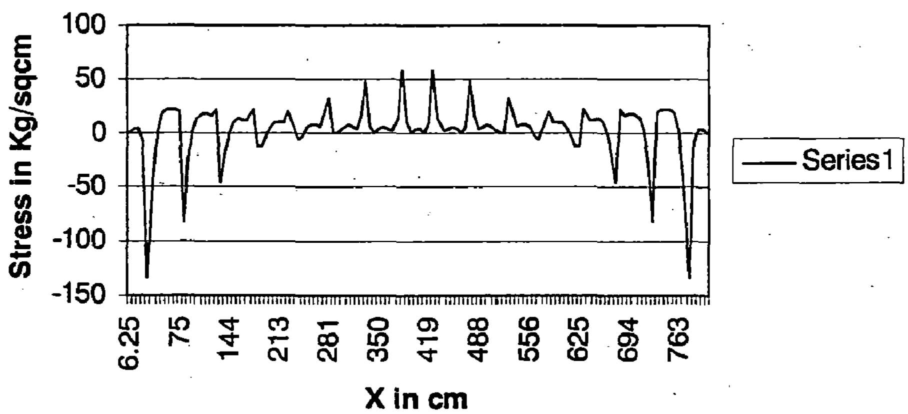
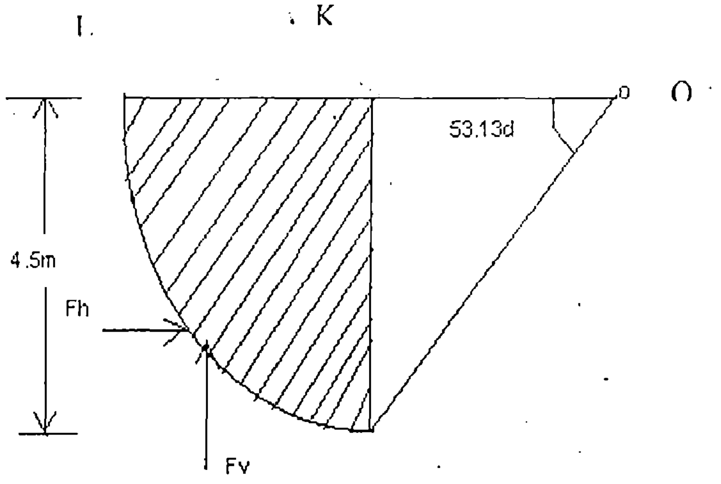


Figure 5.59 Bending stress in bottom horizontal stiffner



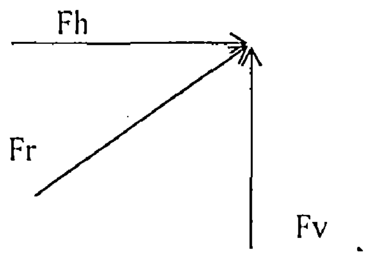
$\theta_3 = 0.455$ radius

$\theta_3 = 26.07^0$



A.1.4 Water Thrust

Fig. FA.2



GIVEN DATA

W = span in m. = 8.0 m.

H = Head in m. = 4.5 m.

ρ = Density of water (in t/m^3) = 1.0 t/m^3

i. Area LKJ = area 'OJL' – area 'OJK'

$$= \frac{\alpha}{2} \times R^2 - \frac{1}{2} R^2 / \sin\alpha \sin\alpha.\ \alpha$$

$$= \frac{0.927}{2} \times (5.625)^2 - \frac{1}{2}(5.625)^2 \times \sin 53.13 \times \cos 53.13$$

area LKJ = 7.07168 cm^2

ii. F_V= vertical component of Resultant water thrust (Buoyancy force)

= area LKJ × span × density of water

= 7.07168 × 8.0 × 1.0

F_V = 56.57 tonnes

iii. F_H = Horizontal water load

$$= \frac{\rho \times W \times H^2}{2}$$

$$= \frac{1.0 \times 8.0 \times (4.5)^2}{2}$$

F_H= 81.0 tonnes

iv. Resultant thoust $'F_x' = \sqrt{F_H^2 + F_v^2}$

$$F_r = \sqrt{(81.0)^2 + (56.57)^2}$$

CHAPTER 6

CONCLUSION AND SUGGESTIONS

6.1 CONCLUSION

3D FEM analysis through ANSYS of a radial gate and its comparison with conventional design results are presented in this study. The study revels that 3D stress and deformation analysis is most suitable to predict the nature of stress in a composite indeterminate structure which is otherwise not possible. The following points emerged from this analysis.

- The Maximum bending stress in X direction of the model is only 68% of the maximum bending stress of conventional maximum bending stress. The maximum bending stress occurs at the bottom in conventional design. But in 3D analysis, the maximum bending stress is 15cm above the bottom at two middle vertical stiffeners. The middle plane of skin plate is not neutral plane. Hence bending stress exist in middle plane. 3D analysis has shown bending in Y and Z direction also. However these stresses are not significant. Maximum bending stress in Y direction is 161kg/sqcm in conventional method and it is 160.34 kg/sqcm in 3D model.
- Shear Stress in XY, YZ, ZX plane does occur. However the values are very small.
- Deflection in skin plate is more at top than in the bottom as per conventional approach. However in 3D analysis deflection is maximum at bottom most middle point of skin plate. The reason behind this is that in conventional approach, horizontal girder having maximum deflection is connected with vertical stiffeners and vertical stiffeners connected with skin plate. Hence integrated deflection in horizontal girder is also reflected in skin plate.

- The vertical stiffener is found critically more stressed at the joint of horizontal girder and radial arm in 3D analysis as compared to conventional approach. Bending stress in vertical stiffener is highest at joint where horizontal girder and radial arm join together. This stress decreases gradually along horizontal girder towards centre. It is found 46% less than conventional stress at middle joints.
- The bending stress in horizontal girder in 3 D analysis is found as less than conventional approach stress. The deflection in bottom horizontal girder is also found to be less.
- The axial stress in radial arm is found approximately equal to that by conventional approach.
- In the conventional design the maximum value of hinged and fixed cases are considered as design deflections and stresses, but in 3D analysis it is neither fixed nor simply supported at any point. Hence the maximum values calculated through conventional approach do not tally with 3D values

6.2 SUGGESTATIONS FOR FURTHER STUDY

- The size of structural members of this gate may be suitably reduced and again tested in 3D model to develop an economical design.

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A.1 MATERIALS SPECIFICATION AND LOADINGS

A.1.1 Materials Specification

The following specifications for various components of the gate and embedded parts material have been recommended for the design of radial gate.

Table- TA.1

S.N.	Component Part	Material specified	Code reference
1.	Skin plate	Structural steel	IS : 226 up to 20mm thickness and IS : 2062 above 20mm thickness
2	Stiffeners, horizontal girders	Structural steel	IS : 226 up to 20mm thickness and IS : 2062 above 20mm thickness
3	Arms, Bracings, trunnion, brackets, anchors etc	Structural steel	IS : 226 up to 20mm thickness and IS : 2062 above 20mm thickness
4	(a) Guide Roller (b) Guide Roller Pin	Cast steel stainless steel	IS: 1030, Gr – 26-52 IS: 1570 (V) 1985 or AISI 304 Gr – 04 Co. 18 Ni 10.
5	Trunnion HUB	Structural steel	IS : 2062-1984
6	Trunnion pin	Stainless steel	IS: 1570(V)- 1985-AISI-304 Ge → 04 Cr18 Ni 10.
7	Bushings	Self Lubricating Manganese (UTS= Bronze (770mm/m^2)	ASTM – B22- UNS- C 86300
8	Seal seats (Side & Bottom)	Stainless steel	IS : 6603-1972 Gr → 5507 Cr 18 Ni 19
9	Sill beam wall plates (girders)	Structural steel	IS: 226 or IS : 2062

10	Rubber seals	Rubber	IS: 4623, appendix B
11	Seal fasteners	Galvanized bolts & Nuts	IS : 1367

A.1.2 Permissible Stresses

The permissible stresses for structural steel used in skin plate and vertical stiffeners have been taken as per Appendix 'A' of IS : 4623-1979 considering the condition "WET & ACCESSIBLE" but for the structural steel used in horizontal girders, arms, bracings and other components have been taken by considering the condition 'DRY & ACCESSIBLE"

Table- TA.2

Case I: Dry Inaccessible or Wet Accessible

S.No.	Type of stress	Up to 20mm as per IS : 226 kg/cm^2	20 to 40mm IS : 2062 kg/cm^2	Above 40mm IS : 2062 kg/cm^2
1	Direct compression & compression in bending (0.45 Y.P.)	1170	1080	1035
2	Direct tension & tension in bending. (0.45 Y.P.)	1170	1080	1035
3	Shear stress (0.35 Y.P.)	910	840	805
4	Combined stress (0.60 Y.P.)	1560	1440	1380
5	Bearing stress (0.35 UTS)	1470	1470	1470
6	Yield H. strength Y.P.	2600	2400	2300
7	Ultimate tensile strength UTS	4200	4200	4200

Table -TA .3

Case II: Dry Accessible

S.No.	Type of stress	Up to 20mm as per IS : 226 kg/cm^2	20 to 40mm IS : 2062 kg/cm^2	Above 40mm IS : 2062 kg/cm^2
1	Yield pt. Strength (Y.P.)	2600	2400	2300
2	Ultimate tensile strength (UTS)	4200	4200	4200
3	Direct compression and compression in bending (0.55 Y.P.)	1430	1320	1265
4	Direct tension and tension in bending (0.55 Y.P.)	1430	1320	1265
5	Shear stress (0.40 Y.P.)	1040	960	920
6	Combined stress (0.75 Y.P.)	1950	1800	1725
7	Bearing stress (0.40 UTS)	1680	1680	1680

A.1.3 Layout Of Gate

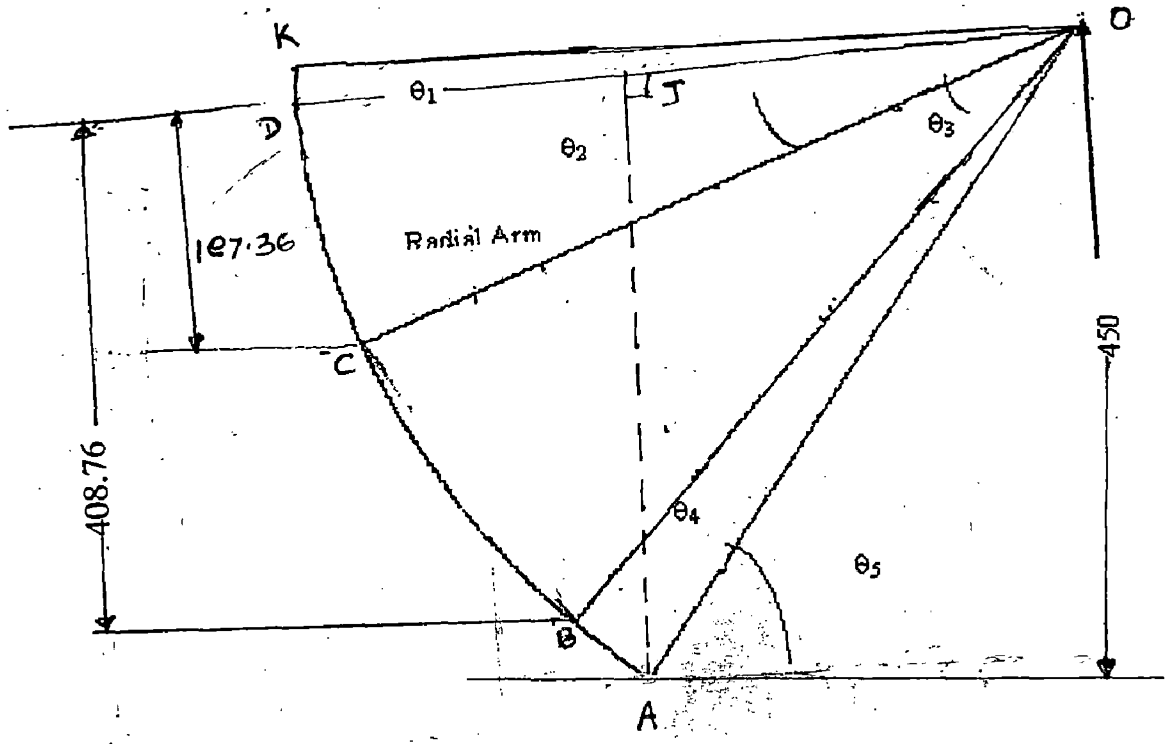


Fig.FA.1 All dimensions are in cm

i. $\sin\theta_5 = \left(\dfrac{4.50}{5.625}\right)$ and 'θ_5'

$$\theta_5 = \sin^{-1}\left(\frac{4.50}{5.625}\right)$$

$$\theta_5 = 0.927 \text{ radians}$$

$$\theta_5 = 53.1301^0$$

ii. $\sin\theta_1 = \dfrac{0.075}{5.625}$ (In Δ ODK) angle 'θ_1'

$$\theta_1 = 0.01333 \text{ radians}$$

$$\theta_1 = 0.76397^0$$

iii. Curved length (AD) 'l':

$$l = R \times \theta_5$$

$$= 5.625 \times 0.927$$

$l = 5.214m$

iv. Curved length (AK) ; 'L'

$L = R(\theta_5 + \theta_1)$

$L = 5.625(0.927 + 0.013333)$

$L = 5.28938mt.$

v. Curved length (AB), 'l_1':

$l_1 = 0.123l$

$l_1 = 0.123 \times 5.214$

$l_1 = 0.6413mt.$

adopt $l_1 = 640mm.$

vi. Curved length 'BC', l_2:

$l_2 = 0.491l$

$l_2 - 0.491 \times 5.214$

$l_2 = 2.56007m$

adopt $l_2 = 2560mm.$

vii. angle 'θ_4' :

$$\theta_4 = \left(\frac{l_1}{R}\right)$$

$$= \frac{640}{5625}$$

$= 0.11377$ Radians

$\theta_4 = 6.52^0$

viii. Angle 'θ_3':

$$\theta_3 = \left(\frac{l_2}{R}\right)$$

$$\theta_3 = \left(\frac{2560}{5625}\right)$$

$\theta_3 = 0.455$ radius

$\theta_3 = 26.07^0$

A.1.4 Water Thrust

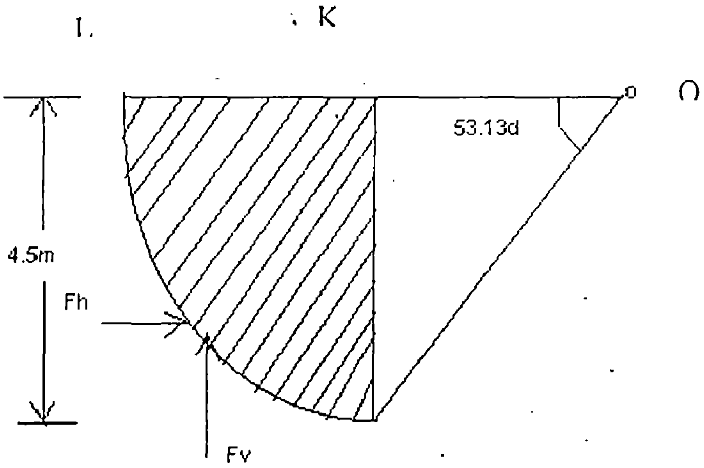
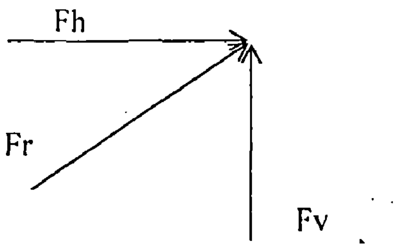


Fig. FA.2



GIVEN DATA

W = span in m. = 8.0 m.

H = Head in m. = 4.5 m.

ρ = Density of water (in t/m^3) = 1.0 t/m^3

i. Area LKJ = area 'OJL' – area 'OJK'

$$= \frac{\alpha}{2} \times R^2 - \frac{1}{2} R^2 / \sin\alpha \sin\alpha.\ \alpha$$

$$= \frac{0.927}{2} \times (5.625)^2 - \frac{1}{2}(5.625)^2 \times \sin 53.13 \times \cos 53.13$$

area LKJ = 7.07168 cm^2

ii. F_V= vertical component of Resultant water thrust (Buoyancy force)

= area LKJ × span × density of water

= 7.07168 × 8.0 × 1.0

F_V = 56.57 tonnes

iii. F_H = Horizontal water load

$$= \frac{\rho \times W \times H^2}{2}$$

$$= \frac{1.0 \times 8.0 \times (4.5)^2}{2}$$

F_H= 81.0 tonnes

iv. Resultant thoust $'F_x' = \sqrt{F_H^2 + F_V^2}$

$$F_r = \sqrt{(81.0)^2 + (56.57)^2}$$

say $F_r = 99$ tones

v. Angle of inclination of 'F_H' with 'F_r'

$$\tan v = \left(\frac{F_V}{F_H}\right) = \frac{56.57}{81.0} = 0.698395$$

$$v = 34.9303^0$$

A.1.5 Silt Pressure

silt load = 'F_s'

Maximum silt at the bottom of the gate

$$P_s' = W_s' \times h \times \left(\frac{1-\sin\phi_1}{1+\sin\phi}\right)$$

where P_s' = maximum silt pressure (t/m^2)

W_s' = Submerged weight of silt (t/m^3)

$$W_s' = W_s\left(\frac{\lambda - 1}{\lambda}\right)$$

W_s= Dry weight of silt $\simeq$ 1.6 t/m^3

λ = specific gravity of silt

λ = 2.65

$$W_s' = W_s\left(\frac{\lambda - 1}{\lambda}\right) = 1.6 \times \left(\frac{2.65-1}{2.65}\right)$$

$$= \frac{1.6 \times 1.65}{2.65}$$

$W_s' = 0.9962$ t/m^3

W_s'= 1.0 t/m^3

ϕ = Angle of interval friction for silt

$\phi = 30^0$ angle of repose

h = depth of silt

h = 1.0 m. (maximum)

Assuming that the gates shall be operated to remove excess deposition of silt and maximum height of silt deposition will not be more than 1.0 m

$$\therefore \quad P_s' = 1.0 \times 1.0 \times \left(\frac{1 - \sin 30^0}{1 + \sin 30^0} \right)$$

$$= 1.0 \times 1.0 \times \frac{0.5}{1.5}$$

$P_s' = 0.3333 t/m^2$ maximum silt pressure

$$\therefore \text{ average silt pressure} = \frac{P'_s}{2}$$

$$P_s = \frac{0.3333}{2}$$

$P_s = 0.1667 t/m^2$

'A' area of the part of the gate subjected to silt

A = width × height of silt

= 7.940 × 1.0

A = 7.940 m^2

∴ Total silt load on the Gate F_s'

= area 'A' × av. Silt pressure 'P_s'

= 7.940 × 0.1667

F_s= 1.323334 t

F_s= 1.35 t

A.1.6 Sill Reaction

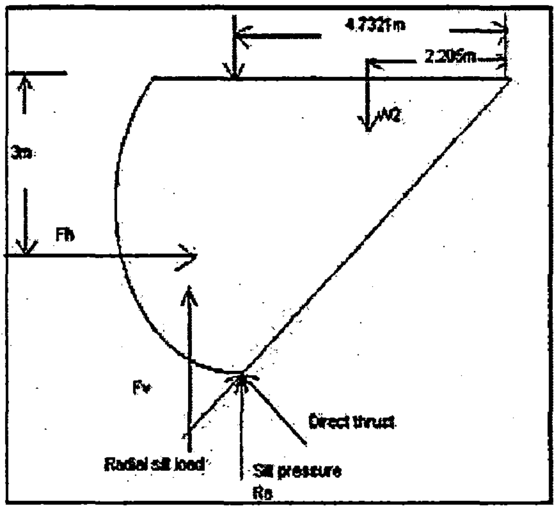


Fig. FA.3

Sill pressure is the Reaction of sill to the gate weight. etc. while the Gate is resting on it.

Where

W_1= wt. of gate excluding arms and arm bracings =11.354t

W_2 = wt. of End Arms and Arm Bracings = 0.3435 t.

F_V= Buoyant up thrust = 81t

F_H= Horizontal water road = 56.57t

Sill Reaction R_s = 12.384 t

Direct thrust on stiffeners

$$R_s \cos\theta = 12.384\cos(53.13^0)$$

$$= 7.43 \text{ t}$$

Radial load $R_s \sin\theta = 12384.\sin(53.13)$

$$= 9.9072t$$

Radial load /meter width of gate = 9.9072/8.0 = 1.2384 = 1.24 t/meter.

A.2 Various Forces Acting Upon the Radial Gate

The components of gate would be designed for the worst loading conditions

a. Gate Fully Closed Position

Here the following three forces would be acting together at one time upon the gate and its components

i. Water pressure

ii. Silt pressure

iii. Sill pressure

b. Loading analysis is being done assuming the support points (load transfer points) as **Hinged:** the support points are the points where the girders are connected to the end arms on both sides – At precisely these points or areas, the water load etc. are being transferred to end arms and thus to the piers.

Therefore in first case, we shall assume these joints/supports as hinged while analyzing the loads and thus stresses.

c. Loading analysis is being done assuming the support points (Load transfer points as fixed

Here in second case we shall assume the joints/ supports as FIXED POINTS while analyzing the loads and thus stresses for the worst loading case.

In the beginning, let us consider the condition '**a**' (first i.e. Gate fully closed. (Resting on the sill)

For this condition, two cases have been taken up '**b**' & '**c**' i.e. Hinged at supports and 'Fixed' at supports.

Ist case is '**a**' + '**b**', Gate fully closed + Hinged at supports.

IInd case is '**a**'+ '**c**', Gate fully claosed + fixed at supports.

A.2.1 First Case ⇒ Hinged At Supports

i. Water pressure

ii. Silt pressure

iii Sill pressure.

A.2.1.1 Water Pressure

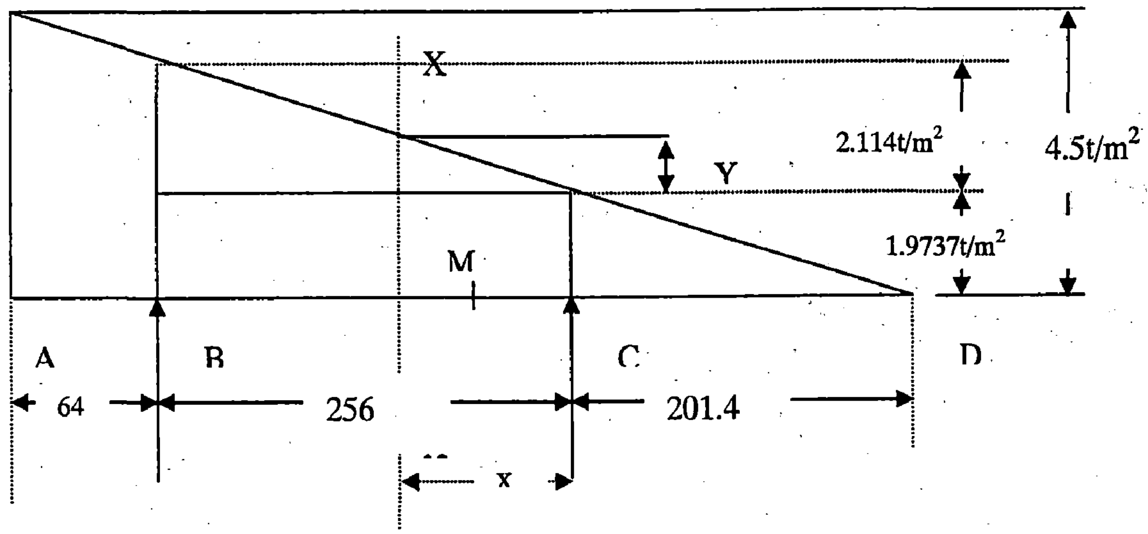


Fig FA.4

At any section X-X between B and C $\frac{2.114}{2.560} = \frac{y}{x}$

$$\therefore \quad y = \frac{2.114}{2.560} x \ \ t/m^2.$$

Total water load: in kg/m run of skin plate

$$\text{Total W.L.} = \left(\left(\frac{4500 + 4087.7}{2}\right) \times 0.64\right) + \left(\left(\frac{4087.7 + 1973.7}{2}\right) \times 2.56\right) + \left(\frac{1973.7}{2} \times 2.014\right)$$

Total W.L.= 2748.064 + 7758.592 + 1987.5159

Total Water load ⇒ 12474.171 kg/m run of skin plate

Now taking moment about 'B'

$$R_c \times 2.56 = \left\{\left(\frac{1973.7 \times 2.014}{2}\right) \times \left(2.56 + \frac{2.014}{3}\right)\right\} + \left\{1973.7 \times \frac{2.56}{2} \times 2.56\right\}$$
$$+ \left\{\frac{1}{2} \times 2114 \times \frac{2.56^2}{3}\right\} - \left\{\frac{4087.7 \times (0.64)^2}{2}\right\}$$
$$- \left\{\frac{1}{2} \times 0.64 \times 412.3 \times \frac{2}{3} \times 0.64\right\}$$

$$R_c \times 2.56 = 6421.668 + 6467.4106 + 2309.045 - 837.1625 - 56.292$$

$$R_c \times 2.56 = 15198.123 - 893.4545$$

$$R_c = \frac{14304.668}{2.56}$$

$R_c = 5587.76$ Kg/m. run of skin plate = Reaction at top horizontal girder

$\because \mathrm{R_c + R_c} = \text{Total water load}$

$\therefore\ R_B = 12494.171 - 5587.76$

$R_B = 6906.411$ Kg/m run of skin plate = Reaction at bottom horizontal girder

SHEAR FORCES

(1) Shear force at right of 'C'

$$R_{CD} = \frac{1}{2} \times 1973.7 \times 2.014$$

$R_{CD} = 1987.52$ Kg/m run of skin plate

(2) Shear force at left of 'C'

$$R_{CB} = 5587.76 - 1987.52$$

$R_{CB} = 3600.24$ Kg/m run of skin palate

(3) Shear force at left of 'B'

$$R_{BA} = \frac{4500 + 4087.7}{2} \times 0.64$$

$R_{BA} = 2748.064$ Kg/m run of skin plate

(4) Shear force at right of 'B'

$$R_{BC} = 6906.411 - 2748.064$$

$R_{BC} = 4158.347$ Kg/m run of skin plate

point of zero shear is say 'X' meters from 'C' where Bending moment shall be maximum.

$$\because R_C - \frac{1973.7 \times 2.014}{2} - 1973.7x - \frac{1}{2}\left(\left(\frac{x}{3.2}\right) \times 2526.3 \times x\right)$$

$\Rightarrow 5587.76\text{-}1973.7x - 394.7344\ x^2\text{-}1987.516 = 0$

$394.7344x^2 + 1973.7x - 3600.244 = 0$

$$x^2 + 5.00x - 9.1207 = 0$$

$$x = \frac{-5 \pm \sqrt{25 + 4 \times 9.1207}}{2}$$

$$x = \frac{-5 \pm 7.8411}{2}$$

x = +1.42055m

$x = 1.42\,\text{m}$ point of zero shear is 1.42 m. left of 'C'.

Skin Plate

Bending Moments

(1) -ve B.M. at 'B' = $\dfrac{4087.7\times(0.64)^2}{2}+\dfrac{1}{2}\times 412.3\times 0.64\times\dfrac{1}{3}$

$= 837.163 + 56.292$

= 893.455 Kg-m. /m runs of skin plate

(2) -ive B.M. at 'C' = $\dfrac{1973.7\times 2.014}{2}\times\dfrac{2.014}{3}$

-ive B.M. at 'C' = 1334.28 kg-m/m run of skin plate

(3) +ive B.M. at 'X' = $(5587.76\times 1.42)-\left\{\left(\dfrac{1}{2}\times 1973.7\times 2.014\right)\times\left(1.42+\dfrac{2.014}{3}\right)\right\}-\left\{\dfrac{1973.7\times 1.42}{2}\right\}$

$-\left\{\dfrac{1.42}{2}\times\dfrac{1}{3}\times 1.42\left[\dfrac{1.42}{3.2}\times 2526.3\right]\right\}$

= 7934.62-4156.558-1989.884-376.7

= 7934.62-6523.1881

+ive B.M. at 'X' $\Rightarrow$ 1411.432 kg-m/m. run of skin plate

(4) +ive B.M. at 'M' middle point

$\because\Rightarrow\{R_C\times 0.593\}-\left\{\dfrac{1973.7\times 2.014}{2}\left(\dfrac{2.014}{3}+0.593\right)\right\}$

$-\left\{\dfrac{1973.7\times 0.593^2}{2}\right\}-\left\{\dfrac{490\times 0.593}{2}\times\dfrac{0.593}{3}\right\}$

$= 5587.76\times 0.593 - 2512.883 - 347.025 - 287.72$

$= 3313.542 - 3147.63$

+ive B.M. at 'M' $\Rightarrow$ 165.912 kg-.m/ m run of skin plate.

Actual shear force in kg in vertical stiffener which carries the load of .50m of skin plate

(1) S.F. at right of 'C' = 1987.52 ×0.50

∵ R_{CD}= 993.76 kg.

(2) S.F. at left of 'C' = 3600.240 × 0.50

R_{CB}= 1800.12 kg

(3) S.F. at left of 'B' = 2748.064 × 0.50

R_{BA}= 1374.032 kg

(4) S.F. at right of 'B' = 4158.347 × 0.50

R_{BC}= 2079.174 kg.

Bending moment in vertical stiffeners in kg m/m run of skin plate.

-ive B.M. at 'B' = 893.455 kg-m/m. run.

-ive B.M. at 'C' = 1334.28 kg-m/m. run.

+ive B.M. at 'B' = 893.455 kg-m/m. run.

+ive B.M. at 'B' = 893.455 kg-m/m. run.

Actual B.M. in vertical stiffeners in kg-m.

-ive B.M. at 'B' = 893.455×0.50 = 446.7275 kg -m.

-ive B.M. at 'C' = 1334.28×0.5 = 667.14 kg- m.

+ive B.M. at 'X' = 1411.432×0.5 = 705.716 kg-m.

+ive B.M. at 'M' = 165.912×0.50 = 82.956 kg- m.

A.2.1.2 Silt Pressure:

For 1.0 M silt height

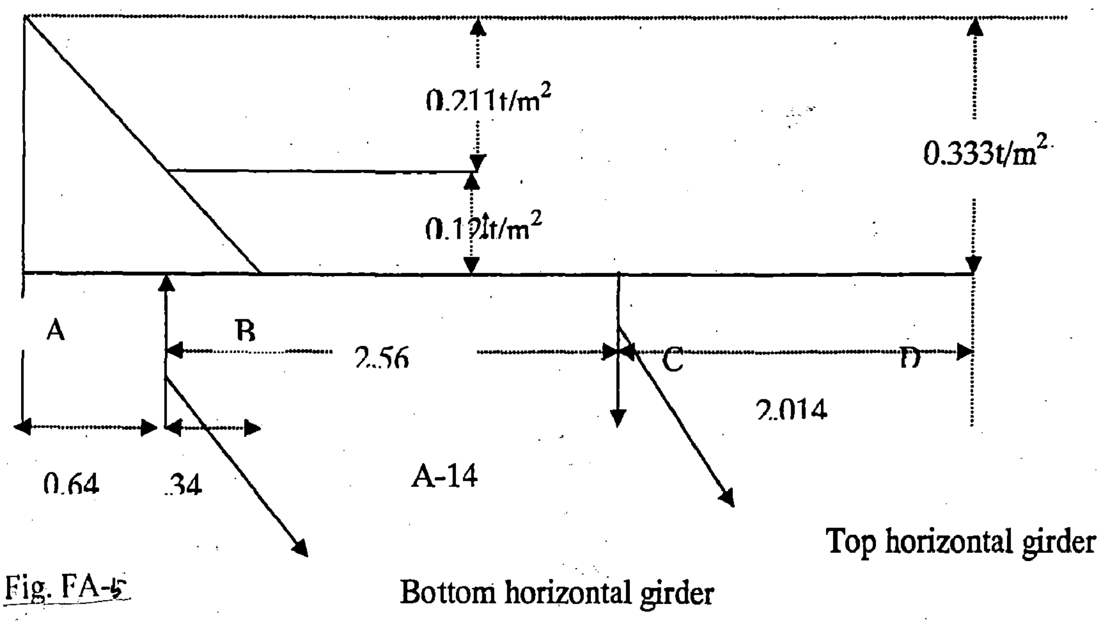


Fig. FA-5

In this case, directions of 'R_B' & 'R_C' reactions at Girder support points will be opposite to each other.

$$\frac{360}{1000} = \frac{x}{0.3333}$$

$$x = 0.11999 \text{ t/m}^2$$

say $x = 0.12 \text{t/m}^2$

(1) Total Silt load $= \left\{\left(\frac{333.3+120}{2}\right)\times 0.64\right\} + \left(\frac{120}{2}\times 0.36\right)$

$\because \qquad = 145.066 + 21.6$

Total silt load = 166.666 kg/m run of skin plate.

(2) Now taking moment about 'B'

$$R_C \times 2.56 = \frac{120\times(0.64)^2}{2} + \left\{\frac{1}{2}\times 213.3\times 0.64\times\frac{2}{3}\times 0.64\right\}$$

$$-\left\{\frac{1}{2}\times 120\times 0.36\times\frac{1}{3}\times 0.36\right\}$$

$$R_C \times 2.56 = 24.576 + 29.123 - 2.592$$

$$R_C = \frac{51.107}{2.56}$$

$R_C = 19.964$ kg/m run of skin plate.

If taken in the direction of 'R_B'

Then R_C= -19.964 kg/m

Now 'R_B'

$$\because R_B + R_C = \text{Total silt load}$$

$$\therefore R_B = \text{Total S.L.} - R_C$$

$R_B = 166.666 - (-19.964)$

$R_B = 186.63$ kg/m run of skin plate

Shear forces → in kg/m run of skin plate

(1) S.F. at left of 'B' = $\dfrac{333.3+120}{2} \times 0.64 = 145.066\,\text{kg/m}$

(2) S.F. at right of 'B' = 186.63-145.066

$$R_{BC} = 41.564 \text{ kg/m run}$$

(3) S.F.at right of 'C' = R_{CD} = zero = O kg/m run

(4) S.F. at left of 'C' = R_C= -19.964 kg/m run

Bending moments R_{CB} → In kg- m/m run of skin plate

(1) B.M. at 'B' $\left\{\dfrac{120\times(0.64)^2}{2}\right\} + \left\{\dfrac{1}{2}\times 213.3\times(0.64)^2 \times \dfrac{2}{3}\right\}$

$$= 24.576 + 29.123$$

B.M. at 'B' = 53.699

Say B.M. at 'B' = 53.7 kg-m/ m run of skin plate

(2) B.M. at 'C' $= \left\{\dfrac{1}{2}\times 333.33\times 1.0\left[1.0\times\dfrac{2}{3}+2.2\right]\right\} - \{186.63\times 2.56\}$

$$= 478.33 - 477.773$$

B.M. at 'C' = 0.557 kg-m/m run of skin plate.

(3) B.M. at 'M' $= \left\{\dfrac{1}{2}\times 333.33\times 1.0\times\left[\dfrac{1.0\times 2}{3}+1.607\right]\right\}$

$$- \{186.63\times 1.967\}$$

$$= 166.665\times 2.277 - 367.10$$

$$= 379.496 - 367.10$$

B.M. at 'M' = 12.396 kg-m/m run of skin plate

(4) B.M. at 'X' = $\left\{\frac{1}{2}\times 333.33\times 1.0\times\left[\frac{1.0\times 2}{3}+0.780\right]\right\}$

$$-\{186.63\times 1.14\}$$

$$= 241.6643 - 212.76$$

B.M. at 'X' = 28.904 kg-m/m run of skin plate

A.2.1.3 Radial Sill Pressure

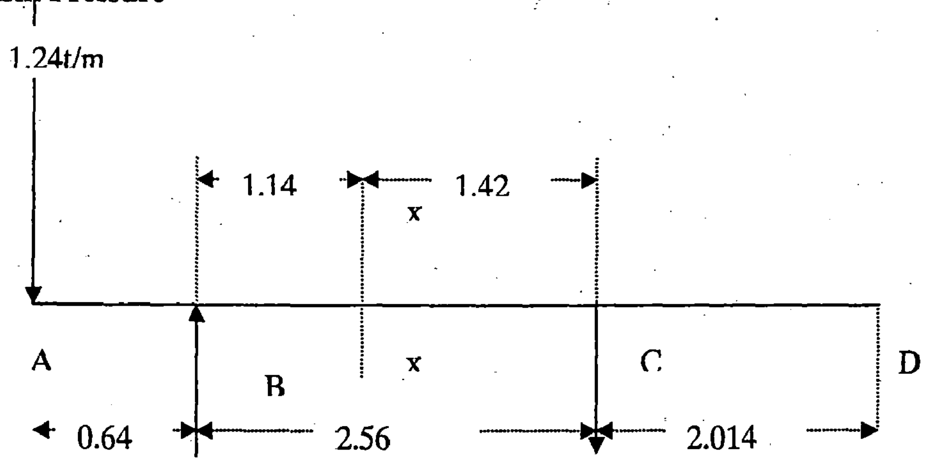


Fig FA.6

Radial sill pressure

Taking moments about 'B' →

$$R_C \times 2.56 = 1.24\times 0.64$$

$$R_C = \frac{0.792576}{2.56}$$

R_C = 0.3096t/mt run of skin plate

Direction of R_C is opposite to 'R_B'

$$\therefore R_C = -309.6 \text{ kg/m run of skin plate}$$

Say R_C= -309.6 kg/m run

R_B = Radial sill pressure – R_C

$\therefore R_B = 1240 - (-309.6)$

$\therefore R_B = 1549.6$ kg/m run of skin plate

Say R_B = 1550 kg/m run

Shear Forces → in uplift run of skin plate

(1) S.F. at left of 'B' = 1240 kg/m run = R_{BA}

(2) S.F. at right of 'B' = 1550-1240

R_{BC} = 310 kg/m run of skin plate

(3) S.F. at right of 'C' R_{CD}= zero = 0 kg/m run

(4) S.F. at left of 'C' = -310 kg /m run = R_{CB}

Bending Moments → in kg-m /m run of skin plate

(1) B.M. at 'B' = 1240 × 0.64

= 793.6 kg –m /m run

Say B.M. at 'B' = 800 kg-t/m run of skin plate

(2) B.M. at 'C' = zero = 0 kg m/ m run of skin plate

(3) B.M. at 'X' = 310 ×1.42

= 4402. kg-m /m run of skin plate

(4) B.M. at 'M' = 310 × 0.593

= 183.83 kg-m/m run

Say B.M. at 'M' = 184 kg-m/m run of skin plate

A.2.2 Second Case – Fixed At Supports

A.2.2.1 Water Pressure

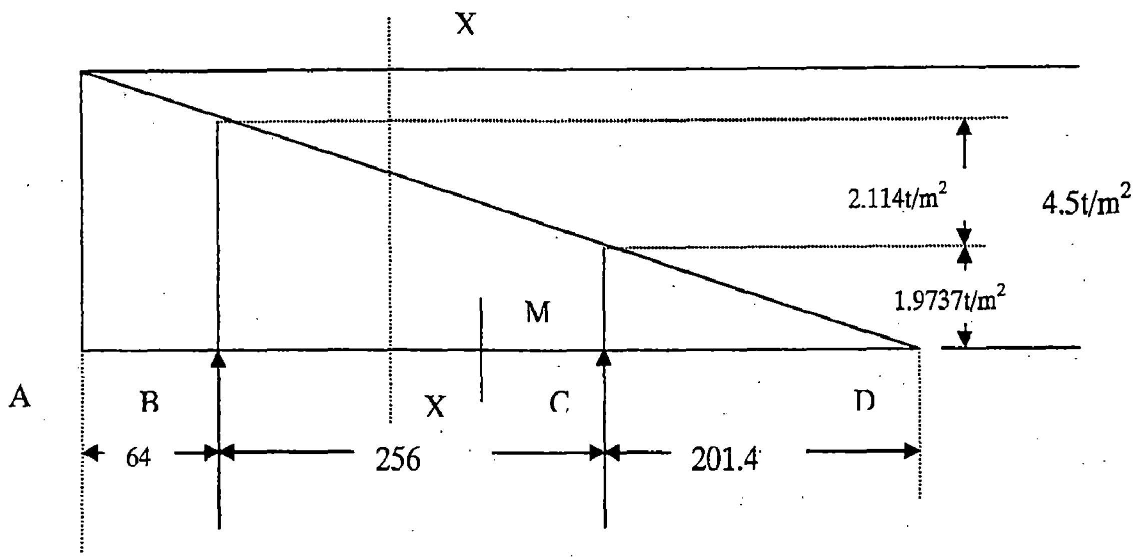


Fig. FA-7

At 'M' middle of skin plate water pressure $= \dfrac{2.114}{2.56} \times 0.593$

$= 0.489688$

At 'M' water pressure = 0.49 t/m^2

FIXED END MOMENTS → for general loading cases

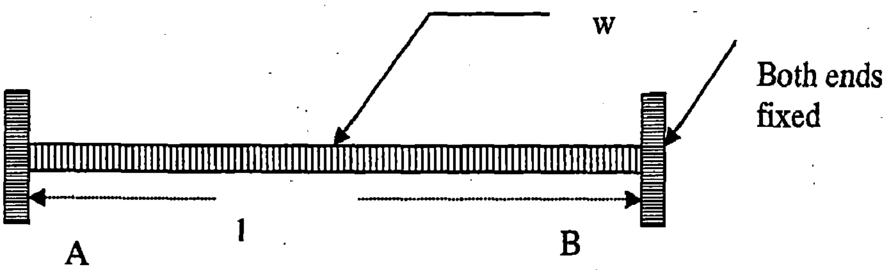


Fig FA.8

(i) $MF_{AB} = -\dfrac{wl^2}{12}$

W kg/m. is the uniformly distributed load over length 'l'

$MF_{BA} = +\dfrac{wl^2}{12}$

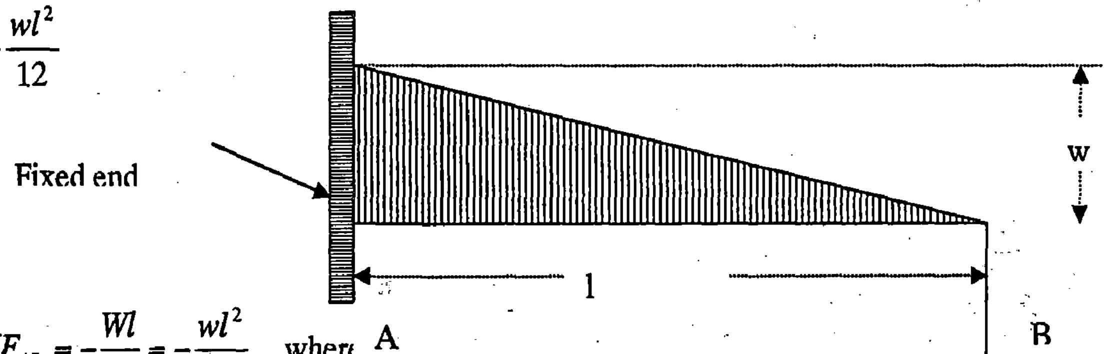


fig. FA.9

(ii) $MF_{AB} = -\dfrac{Wl}{15} = -\dfrac{wl^2}{30}$, wher

$MF_{BA} = +\dfrac{Wl}{10} = +\dfrac{wl^2}{20}$, where W= $\dfrac{wl}{2}$

NOW FIXED END MOMENTS for water loading

(1) $MF_{BA} = \dfrac{4500 \times 0.64^2}{2} - \dfrac{412.3 \times 0.64^2}{6}$

$= 921.6 - 28.146$

$MF_{BA} = 893.454$ kg-m/m run of skin plate

(2) $MF_{BC} = \dfrac{1973.7 \times 2.56^2}{12} + \dfrac{2114 \times 2.56^2}{20}$

$= 1077.9033 + 692.716$

$= 1770.6193$

$MF_{BC} = 1770.62$ kg-m/m run of skin plate

(3) $MF_{CB} = \frac{2114 \times 2.56^2}{30} + \frac{1973.7 \times 2.56^2}{12}$

$= 461.81 + 1077.9033$

$MF_{CB} = 1593.7133$ kg-m/m run of skin plate.

(4) $MF_{CD} = \frac{1973.7 \times 2.014^2}{6}$

$\because MF_{CD} = 1334.286$ kg-m/m run of skin plate.

REACTIONS

Span AB:

(1) $R_{BA} = \left(\frac{4500 + 4087.7}{2}\right) \times 0.64$

$R_{BA} = 2748.064$ kg/m run of skin plate

Span BC :→

(2) $R_{BC} = \frac{1973.7 \times 2.56}{2} + \frac{2114 \times 2.56}{3} - \left[\frac{MF_{IB} - MF_{BC}}{2.56}\right]$

$= 2526.336 + 1803.9466 - \left[\frac{1593.7133 - 1770.62}{2.56}\right]$

$= 4330.2826 - (-69.1042)$

$= 4399.3868$ kg/m run

say $R_{BC} = 4400$ kg/m run of skin plate

(3) $R_{CB} = \frac{1973.7 \times 2.56}{2} + \frac{2114 \times 2.56}{6} - \left[\frac{MF_{BC} - MF_{CB}}{l}\right]$

$\because = 2526.336 + 901.9733 - \left(\frac{1770.62 - 1593.713}{2.56}\right)$

$= 3428.3093 - 69.1042$

$R_{CB} = 3359.2051$ kg/m run of skin plate

Say $R_{CB} = 3360$ kg/m run of skin plate

Span C.D →

(4) $$R_{CD} = \frac{1973.7 \times 2.014}{2}$$

$R_{CD} = 1987.52$ kg/m run of skin plate

∴ Now $R_B = R_{BA} + R_{BC}$

$= 2748.064 + 4400$

$R_B = 7148.064$ kg/m run of skin plate

and $R_C = R_{CB} + R_{CD}$

$= 3360 + 1987.52$

$R_C = 5347.52$ kg/m run of skin plate.

Maximum bending moment at point 'X'

$$\because \text{ Maximum B.M.} = R_{CB} \times 1.42 - \frac{1973.7 \times 1.42^2}{2}$$

$$-1172.61 \times \frac{1.42}{2} \times \frac{1.42}{3} - MF_{CB}$$

$= 3360 \times 1.42 - 1989.884 - 394.075 - 1593.7133$

$= 4771.2 - 3977.6723$

Maximum B.M. at 'X'⇒ 793.53 kg-m/m run of skin plate

A.2.2.2 SILT PRESSURE ⇒ For 1.0 m silt Weight

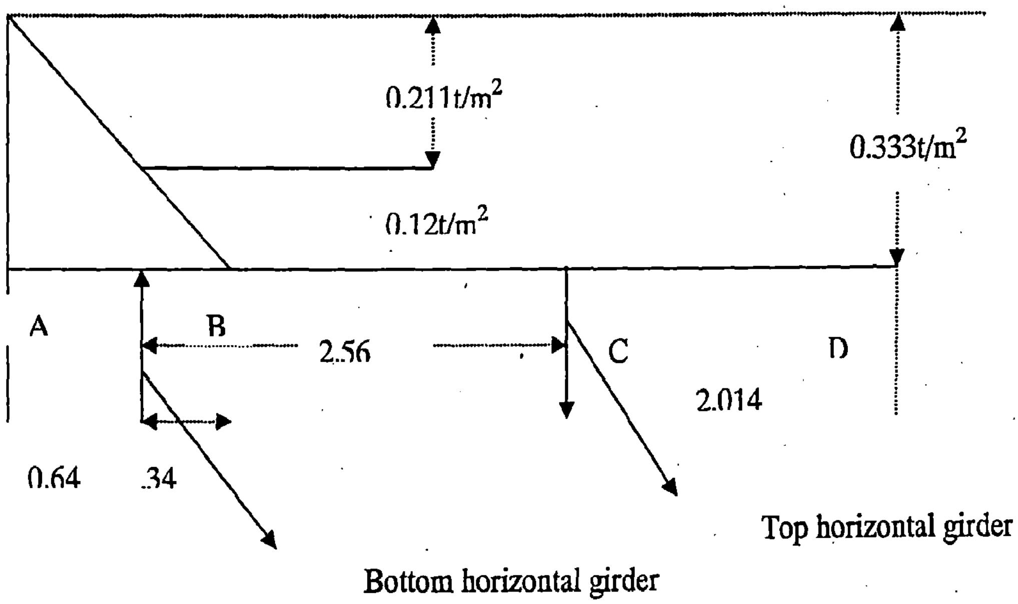


Fig. FA-10

Span Ab → Fixed End Moments

$$MF_{BA} = \frac{333.3 \times 0.64^2}{2} - \frac{213.3 \times 0.64^2}{6}$$

$$\Rightarrow 68.26 - 14.5613$$

$$MF_{BA} = 53.6987 \text{ kg-m/m run of skin plate}$$

say $MF_{BA} = 53.7$ kg-m/m run of skin plate

Span BC:

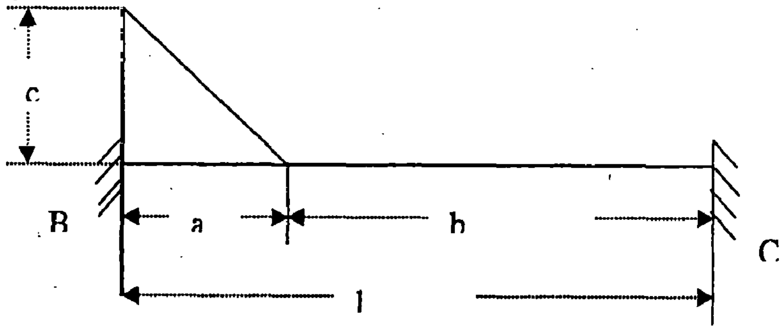


Fig FA.11

$$MF_{BC} = \frac{Wa}{30lz}\left(3a^2 + 10bl\right)$$

where $W = \frac{1}{2}ac$

a=0.36m, b=2.20m

$$MF_{CB} = \frac{Wa^2}{30l^2}\left(5l - 3a\right)$$

$\therefore W = \frac{1}{2} \times 120 \times 0.36$ = 21.6 kg/m run of skin plate

(2) $$MF_{BC} = \frac{21.6 \times 0.36}{30 \times (2.56)^2}\left(3 \times (0.36)^2 + 10 \times 2.2 \times 2.56\right)$$

$$= 0.0395507 \times 56.7088$$

$= 2.2429$ kg-m/ m run of skin plate

Say $MF_{BC} = 2.243$ kg-m/ m run of skin plate

(3) $$MF_{CB} = \frac{21.6 \times (0.36)^2}{30 \times (2.56)^2}\left(5 \times 2.56 - 3 \times 0.36\right)$$

$= 0.16687$ kg-m /m run of skin plate

Say $MF_{CB} = 0.17$ kg-m/m run of skin plate.

Span CD→

$\because MF_{CD} = 0 =$ Zero kg-m run of skin plate

REACTIONS →

Span A-B

(1) $R_{BA} = \dfrac{333.3+120.0}{2} \times 0.64$

$R_{BA} = 145.06$ kg/m run of skin plate

Span B-C

(2) $R_{BC} = \dfrac{120\times 36}{2}\left(\dfrac{2.56-0.12}{2.56}\right)+\left(\dfrac{MF_{BC}}{l}\right)$

$= \dfrac{(120\times 0.36)}{2}\times\dfrac{(2.56-0.12)}{2.56}+\dfrac{2.243}{2.56}$

$= 20.59 + 0.8762$

$R_{BC} = 21.47$ kg/m run of skin plate.

Total load on BC

$\Rightarrow W = 21.6$ kg/m run

$\Rightarrow R_{BC} + R_{CB}$

(3) $R_{CB} = 21.6 - 21.47$

$R_{CB} = 0.13$ kg/m run of skin plate.

(4) R_{CD} = zero = 0 kg/m run of skin plate.

$\therefore R_B = R_{BA} + R_{BC}$

$= 145.06 + 21.47$

$R_B = 166.53$ kg/m run of skin plate.

and $R_C = R_{CB} + R_{CD}$

$= 0.13 + 0$

$R_C = 0.13$ kg/m run of skin plate.

A.2.2.3 RADIAL SILL REACTION

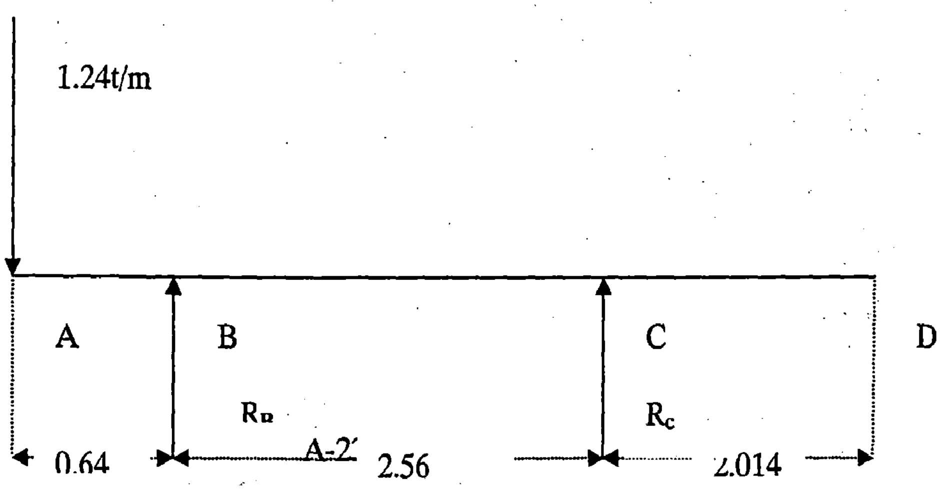


Fig FA-12 (All dimensions are in cm)

Fixed End Moments

(1) $MF_{BA} = 1240 \times 0.64 = 793.6$ kg-m/m run of skin plate.

(2) $MF_{BC} = 0$ kg-m/m run of skin plate.

(3) $MF_{CB} = 0$ kg-m/m run of skin plate.

(4) $MF_{CD} = 0$ kg-m/m run of skin plate.

Reactions

(1) $R_{BA} = 1240$ kg /m run of skin plate.

R_{BC} =0 kg/m run skin plate.

R_{CB} = 0 kg/m run skin plate.

$R_{CD} = 0 = 0$ kg /m run skin plate.

$R_B = R_{BC} + R_{BA} = 1240 kg/m$ run & R_C=0

Compiling Hinged Case And Fixed Case

Bending moments → in kg-m /m run of skin plate

Table TA.4

Case II: fixed at support

S.No.	Type of loading	At support pt. 'B'	At ht. X	At mid point 'M'	At support ht. 'C'
1.	For water pressure	893.454/1770.62	793.53	-	1593.7133/1334.286
2.	For silt	53.6987/2.243	-	-	0.17/zero

	pressure				
3	For radial sill pressure	793.0	-	-	
	Total Σ	2566.463	793.33		

Table TA.5

Case II: Hinged at support

S.No.	Type of loading	At support pt. 'B'	At ht. X	At mid point 'M'	At support ht. 'C'
1.	For water pressure only	893.455	1411.432	-165.912	1334.28
2.	For silt pressure	053.7	-028.904	-012.396	000.557
3	For radial sill pressure	800.00	-440.20	-184.0	000.000
4	Total Σ	1747.155	942.328	362.308	1334.837

Table -TA.6 **Case II: Fixed at support**

B Reactions → in kg/m run of skin plate

S.No.	Type of loading	At 'B' 'R_B'	At 'C' 'R_c'
1	For water pressure	7148.064	5347.52
2	For silt pressure	166.53	0.13
3	For radial sill pressure	1240.0	-
	Total Σ	8554.584	5347.65

Table TA.7 **Case I: Hinged At Supports**

Sl No.	Type of loading	At 'B' 'R_B'	At 'C' 'R_c'
1	Water pressure only	6906.411	5587.76
2	Silt pressure only	186.63	-19.964
3	Radial sill pressure only	1550.0	-310.0
	Total Σ	8643.041	5257.796

(c) Shear forces → in kg/mt run of skin plate

Table TA.8 **Case II: Fixed at supports**

S.No.	Type of loading	R_{BA}	R_{BC}	R_{CB}	R_{CD}
1	Water pressure only	2748.064	4400.0	3360.0	1987.52
2	Silt pressure only	145.06	21.47	0.13	00.000
3	Radial sill pressure only	1240.00	00.00	00.00	00.00
	Total Σ	4133.124	4421.47	3360.13	1987.52

Table A.9 **Case 1: Hinged at supports**

S.No.	Type of loading	R_{BA}	R_{BC}	R_{CB}	R_{CD}
1	For water pressure	2748.064	4158.347	3600.24	1987.52
2	For silt pressure	145.066	41.564	-19.964	00.00
3	For radial sill pressure	1240.00	340.00	-310.00	00.00
	Total Σ	4133.130	4509.911	3270.276	1987.52

For design, we add the reactions, bending moments at both support points 'B' and 'C' or the maximum loading condition whether hinged/fix and that will give us "the worst loading condition", Which shall be used to design the different components of gate.

A.3 DESIGN AND STRESS ANALYSIS SKIN PLATE

The skin plate is taken continuous over a number of vertical stiffeners whose spacing is 500mm. The end span is 500 mm. With cantilever span of 250mm including 30mm clearance of skin plate from wall plate face on either side.

Table TA.10

Loadings	At pt. 'A'	At pt 'B'	At pt 'C'	At ht. 'D'
(i) water pressure	4500 kg/m^2 or 0.45 kg/cm^2	4087.7kg/m^2 or 0.41 kg/m^2	1973.7 kg/m^2 or 0.19737 kg/cm^2	00
(ii) Silt pressure	333.3 kg/m^2 or 0.0333 kg/cm^2	120 kg/m^2 or 0.012 kg/cm^2	00	00
(ii) Radial sill	1240 kg/mt or	00	00	00

pressure	12.4 kg/cm			

Radial sill pressure would be acting just at point 'A' and above point 'A; it will have no effect. Thus, in the design of skin plate we neglect the effect of sill (radial) reaction at point 'A', while we shall be strengthening the lower edge of skin plate with a stiffeners plate all along the span of the gate.

Design of skin plate without radial sill pressure only water pressure and silt pressure are attainted

$\therefore$ Maximum bending moment at pt. 'A'

(1) $\Rightarrow \dfrac{(0.45+0.033)}{10}\times 50^2$

Maximum B.M. at 'A' = 120.75 kg-cm/cm run of skin plate

(2) Maximum B.M. at pate 'B' = $\dfrac{(0.41+0.012)}{10}\times 50^2$

B.M. at 'B' = 105.5 kgcm/cm run of skin plate

(3) Maximum S.f. at pt. 'A' = $\dfrac{(0.45+0.033)}{2}\times 50$

S.F. at 'A' = 12.07 kg/cm run of skin plate

(4) Maximum B.M. at 'C' = $\dfrac{0.20\times 50^2}{10}$

B.M. at 'C' = 50 kg-cm/cm run of skin plate

(5) Maximum B.M. at 'X' $\left(\dfrac{2.114}{2.56}\times 1.42+1.9737\right)=3.14631t/m^2$

Water pressure at 'X' $\dfrac{0.315\times 50^2}{10}$

B.M. at 'X' = 78.75 kg-cm /cm run of skin plate

Provide plate thickness = 10 mm = 1.0 cm

$\because$ Section modulus of skin plate Z = $\dfrac{bt^2}{6}$

$$Z=\frac{1.0^2\times 1.0}{6}\ 6=1.0$$

$$Z=\frac{1}{6}cm^2/cm \text{ Run of skin plate}$$

$\therefore$ Maximum bending stress i.e. at 'A'

(1) $\Rightarrow \dfrac{120.75 \times 6}{1}$

Bending stress $\Rightarrow$ 724.5 kg/cm^2 /cm run of skin plate

$\cdot_b < 1170 kg/mc^2$

Hence safe; O.K.

(2) Bending stress at 'B' = $\dfrac{105.5 \times 6}{1}$ = 633 kg/cm^2

(3) Bending stress at 'C' = $\dfrac{50 \times 6}{1}$ = 300 kg/cm^2

(4) Bending stress at 'X' = $\dfrac{78.75 \div 6}{1}$ = 472.5 kg/cm^2

all less then 1170 kg/mt.

Hence O.K.

(1) $\because$ Maximum S.F. at pt. 'A'

$$= \frac{(0.45 + 0.033)}{2} \times 50 = 12.07 \text{ kg/cm run of skin plate}$$

$\therefore$ Maximum shear stress, at 'A'

$$\tau = \frac{S.F.}{\left[b \times d \times \frac{2}{3}\right]} \text{ for section}$$

$$\tau_A = \frac{12.07 \times 3}{10 \times 1.0 \times 2}$$

τ Shearing = 18.105 kg/cm^2

τ_A < 910 kg/cm^2

Hence safe; O.K.

(2) Maximum S.F. at 'B' $\Rightarrow \frac{0.41+0.012}{2} \times 50 = 10.55$ kg/cm runs of skin plate

$$\therefore \tau_B = \frac{10.55 \times 3}{1 \times 2} = 15.825 \text{ Kg/cm2}$$

(3) Maximum S.F. at 'C' $\Rightarrow \frac{0.20}{2} \times 50 \approx 5.0$ kg/cm runs of skin plate

$$\therefore \tau_c = \frac{5.0 \times 3}{1 \times 2} = 7.5 \text{ Kg/cm2}$$

Thus, shear stress is also safe; will less than 910 kg/cm^2

Hence O.K.

A.4 Design OF Horizontal Stiffener at (Lower most edge of skin plate)

Considering radial sill pressure, sill pressure and water pressure combined at just above pt 'A'.

Assuming a plate of size 100 x 10 mm^2 welded to the edge of skin plat

For Effective Width Of The L-Section:

Taking the least of the following as per IS 4623 2000

(i). Centre to centre of span = 50.0 cm.

$L_1 = 0.577 \times 50 = 28.85 \simeq 29.0$cm

L_2 =50-29 = 21 cm

$$B = \frac{64}{2} = 32cm$$

$$L_1 / B = \frac{29}{32} = 0.9063$$

$$L_2 / B = \frac{21}{32} = 0.66$$

Here in this case effective width would be 'VB' instead of '2VB' as it is a cantilever portion and only on one side of it.

$\therefore$ Effective width = VB

From IS: 4623-1979

Value of V for $\frac{L_1}{B} = 0.9063$

$V_1 = 0.12$

Value of V for $\frac{'L_2'}{B} = 0.66$

$V_2 = 0.18$

(ii) (1) $\therefore$ Effective width in $V_1 = 0.12$

$$\Rightarrow 0.12 \times 32 = 3.84 cm$$

(iii) (2) $\therefore$ Effective width for $V_2 = 0.18$

$$\Rightarrow 0.18 \times 32 = 5.76 \text{ cm}$$

The least of $i, ii, \& \, iii$ (of these) is 3.84 cm = 38.40 mm.

Co-acting width of the skin plate with $100 \times 100 \text{ mm}^2$ plate would be 38.40 mm

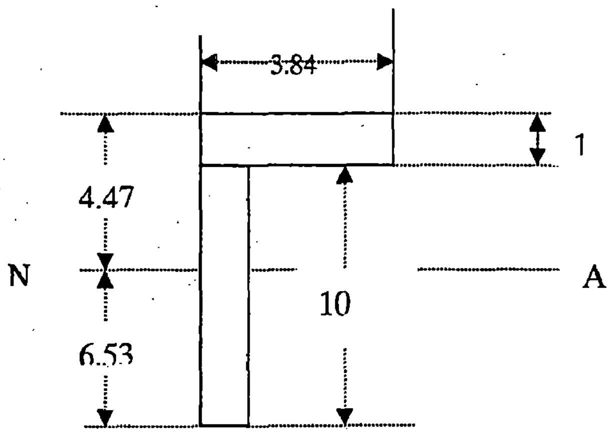
Table TA.11

S.N.	Section (cm x cm)	Area A (cm^2)	Y cm	Ay cm^3	Ay^2 cm^4	Iself cm^4
1	Skin plate 3.84 x 1.0 cm^2	3.84	0.5	1.92	0.96	0.32
2	Web 10.0 x 1.0 cm^2	10.0	6.0	60.0	360.0	83.333
	Σ	13.84	-	61.92	360.96	83.653

$$\bar{y} = \frac{\Sigma Ay}{\Sigma A} = \frac{61.92}{13.84} = 4.47 cm$$

$I_{NA} = . \, Ay^2 + EI_{self} - (\Sigma A)(\bar{y})^2$ **Fig FA.13**

$$= 360.96 + 83.653 - (13.84)(4.47)^2$$



$= 444.613 - 276.536 = 168.08\text{cm}^4$

Total loadings in kg/cm /cm run of skin plate

$$\Rightarrow (0.45 + 0.0333) \times \frac{64}{2} + 12.4$$

$\Rightarrow 27.856$ kg/cm /cm run of skin plate

(1) Maximum bending moment $\Rightarrow \dfrac{27.856 \times 50^2}{10} = 6964\text{kg} - \text{cm}$ run of skin plate.

Maximum B.M. = 6964 kg-cm/cm run of skin plate

(2) Maximum shearing force

$$\Rightarrow \frac{27.856 \times 50}{2} \Rightarrow 696.4 \text{ kg cm run of skin plate}$$

(3) Maximum Bending stress (skin plate side) = $\dfrac{M \times \bar{y}}{I_{NA}}$

$$= \frac{6964 \times 4.47}{168.08}$$

$= 185.2$ kg/cm^2 < 1170 kg/cm^2

Safe O.K.

(4) Maximum Bending stress (web side) $= \dfrac{6964 \times 6.53}{168.08}$

$\Rightarrow 270.56$ kg/cm^2 < 1170 kg.

Hence safe O.K.

(5) Maximum shear stress

$$\Rightarrow \frac{F.\Sigma AY^2}{b.I_{NA}}$$

$$= \frac{696.4 \times 1 \times 6.53^2}{1 \times 168.08 \times 2}$$

(6) Shear stress = 88.34 kg/cm^2

< 910 kg/cm^2

Hence safe; O.K.

A.5 Design Of Vertical Stiffeners

Co-acting width of the skin plate with the vertical stiffeners shall be the least of the following as per IS 4623 2000

(1) 40 t + B t = thickness of skin plate

(2) 0.11 x span B = width of the stiffener flange

(3) C/c of stiffeners in contact with the skin plate.

(4) 2 VB

(1) $40\,t + B \Rightarrow 40 \times 1.0 + 0 = 40$ cm

(2) 0.11 of span $\Rightarrow 0.11 \times 256.0 = 28.16$

(3) C/c of stiffeners $\Rightarrow$ 50 cm

(4) 2 VB : $\rightarrow$

(a) for span BC $\rightarrow$ L = 256 cm

$L_1 = 0.577 \times 256 = 147.7$ cm

$L_2 = 256 - 147.7 = 108.3$ cm

2B = 50 cm

$$\frac{L_1}{B} = \frac{147.7}{25.0} = 5.9 \Rightarrow V_I = 0.85$$

$$\frac{L_2}{B} = \frac{108.3}{25.0} = 4.33 \Rightarrow V_{II} = 0.55$$

V_I & V_{II} seen from the IS : 4623-1979

This co-acting width $= 2 \times 0.55 \times 25 \Leftarrow (2V_{II}B)$

$= 27.5$ cm

(b) for span AB $\rightarrow$

L = 2 × 64 = 128 cm

B = 25 cm

$$\frac{L_2}{B} = \frac{128}{25} = 5.1$$

$V_2 = 0.6$

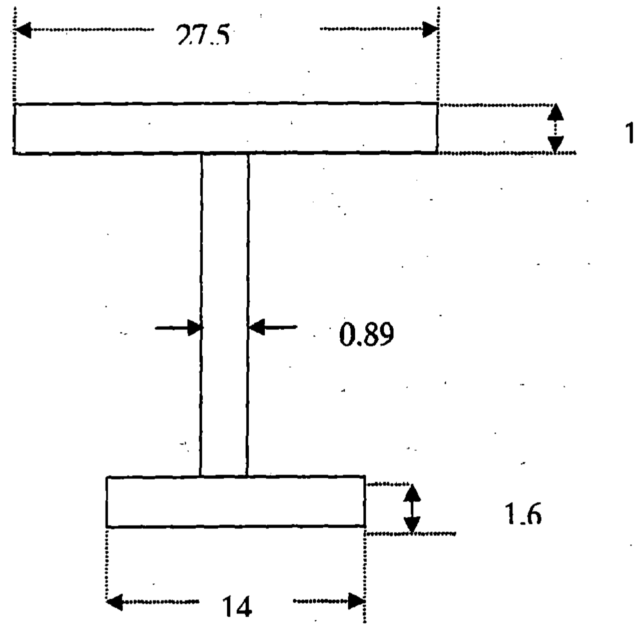
Effective co-acting width = 0.6 × 50

= 30 cm

Least of all the above cases in co-acting width = 27.5 cm

Thus adapting 275 × 10-mm2-skin plate's co-acting (plate size) with the vertical stiffener, which is taken as half section of ISMB – 400.

Fig FA.14



All values are in cm

Table : A.12

S.No.	Sections cm x cm	Area cm^2	$\bar{y} cm$	$A\bar{y} cm^3$	$A\bar{y}^2 cm^4$	Iself cm^4
1	Skin plate 27.5 $\times$1.0	27.5	0.5	13.75	6.875	2.292
2	Web 18.4 $\times$ 0.89	16.376	10.2	167.035	1703.759	462.022
3	Flange 14.0 $\times$ 1.6	22.4	20.2	452.48	9140.096	4.78
	Total Σ	66.276	-	633.265	10850.73	469.094

$$\therefore \bar{y}_1 = \frac{\Sigma Ay}{\Sigma A} = \frac{633.265}{66.276} = 9.555 cm$$

$$\bar{y}_1 = 9.56 cm$$

$$\bar{y}_2 = 11.44 cm$$

$$I_{NA} = \Sigma(Ay^2 + I_{self}) - (\Sigma A)(\bar{y})^2$$

$$\because \quad = 10850.73 + 469.094 - (66.276)(9.56)^2$$

$$= 11319.824 - 6057.20$$

I_{NA}= 5262.624 cm^4

Bending stresses due to stiffener bending

Maximum Bending moment = it is maximum in the fixed case at support points while the gate is fully resting on the sill.

Maximum B.M. $\Rightarrow$ (1770.62+2.243) = 1772.863 kg-cm/cm run of skin plate.

Actual Maximum B.M. = 1772.863 $\times$50

B.M. = 8864315 kg-cm

(1) $\therefore \sigma$ bending = $\frac{M\bar{y}}{I} = \frac{88643.15 \times 9.56}{5262.624}$

skin plate σ bending = 161.08 kg/cm^2< 1170 kg/cm^2

(2) Stiffener flange σbending = $\frac{88643.15 \times 11.44}{5262.624}$

$\because$ stiffener; σ bending = 192.695 kg/cm^2

< 1170 kg/cm^2 hence safe , O.K.

(3) Combined stress

at 'B' $\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_x\sigma_y + 3\sigma_{xy}^2}$

But for σ_v, first we need

τ_{xy}= shear stress

Shear Force

Maximum shear force = 4509.911 kg/mt run of skin plate

= 45.09911 kg/cm run of skin plate

= 45.1 kg/cm runoff skin plate

Total shear force = 45.1 $\times$50

Maximum S.F. = 2255 kg

(1) Maximum shear stress = $\dfrac{2255}{18.4\times 0.89}$

= 137.702 kg/cm^2

< 910 kg/cm^2

Hence safe, O.K.

Combined stress $\rightarrow \sigma_v$

$$\sigma_v\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_x\sigma_y + 3\tau_{xy}^2}$$

where σ_x = sum of stresses along X-axis

σ_y = sum of stresses along Y-axis

τ_{xy} = sum of shear stress in X-Y plane.

σ_x = maximum bending stress in skin plate in X-direction.

$\sigma_x = 724.5$ kg/cm^2

σ_y = maximum bending stress in skin plate in Y-direction.

$\sigma_y = 161.08$ kg/cm^2

τ_{xy} = maximum shear stress in skin plate in X-Y plane

$\tau_{xy} = 18.105$ kg/cm^2

$$\sigma_v = \sqrt{(724.5)^2 + (161.08)^2 + (161.08 \times 724.5) + 3(18.105)^2}$$

$$\sigma_v = \sqrt{524900.25 + 2594.766 + 168946.19 + 983.3731}$$

$$\sigma_v = \sqrt{668532.84}$$

$$\sigma_v = 817.639$$

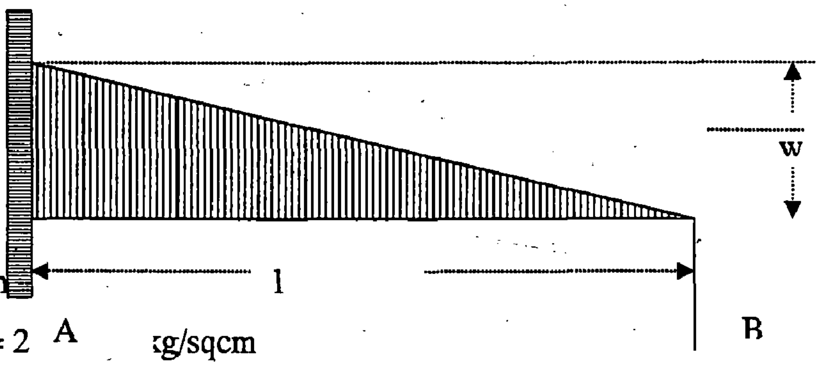
$$\sigma_v = 817.64 \text{kg/cm}^2$$

A.6 Deflection In Skin Plate And Vertical Stiffener

A.6.1Deflection at top of skin plate co-acting with vertical stiffener (assuming skin plate fixed at horizontal girder)

Top Deflection at point D i,e at top of skin plate co-acting with vertical stiffener $\delta = \frac{wl^4}{30EI}$

Fig FA.15



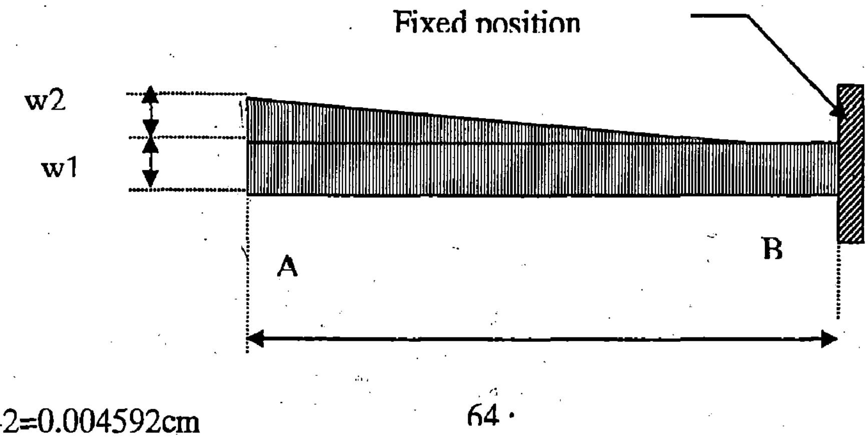
Where w= 0.1973 x50=9.865 kg/cm

l =201.4 cm, I= 5262.624 cm^4 , E= 2 kg/sqcm

δ= .05116cm

A.6.2 Bottom Deflection at point A (assuming Skin plate and vertical stiffener are fixed at bottom horizontal girder)

$$\delta = \frac{w_1 l^4}{8EI} + \frac{w_2 l^4}{120EI} x11$$



w_1 =20.435 Kg/cm

w_2=3.73 Kg/cm

l= 64cm, I= 5262.624 cm^4

Hence δ=0.00405+0.000542=0.004592cm

Fig FA.16

A.6.3 Maximum deflection at top (at D) of skin plate co-acting with vertical stiffener (Hinged at support)

Deflection at a distance of x cm toward right of C is as per followings

Bending moment M= EI $\frac{d^2y}{dx^2}$=69.06x (256+X)+ 55.87xX - 1.32(42.66+256+X) – 28.8 (32+ 256 +X) -52.3136x (128+X) – 27.3 x (170.66 + X) – 19.8948x (X – 67.13)

Or, EI $\frac{d^2y}{dx^2}$=4.694X +3699.44

Integrating above equation we got

EI $\frac{dy}{dx}$ =2.347X^{2}+3699.44X + C_1

At X = 201.4, $\frac{dy}{dx}$=0

$\therefore C_1$= -8.4x 10^5

Integrating again tom above equation

EI y = 0.78233X^3 + 1849.5 X^2 + C_1X + C_2

At X= 0, Y= 0

Putting this value in above equation it was found that C_2 =0

Y =0.414cm

A.6.4 Maximum deflection at bottom (at A) of skin plate co-acting with vertical stiffener (simple supported case)

Deflection at a distance of x cm toward left of D is as per followings

Bending moment M= EI $\frac{d^2y}{dx^2}$=69.06 x X + 55.87(256 + X) – 52.3136 (128 + X) - 27.30 (85.33 + x) – 28.8 (X – 32) – 1.32 (X – 21.33)

Or, EI $\frac{d^2y}{dx^2}$= - (4.6984 X+ 201.744)

Integrating above equation we got

EI $\frac{dy}{dx}$ =2.349X^{2}+ 201.774 X + C_1

A.6.5 Deflection at point of zero shears at point x (simple supported case)

Bending Moment at X M= 55.87x X - 0.5x0.1973(X+67.133) x201.4 - 0.098685X^2- .000138X^3

Hence EI $\frac{d^2y}{dx^2}$=36.00229 - 0.098685X^2- 0.00138X^3 - 1334.285

Integrating above equation and taking boundary condition dy/dx=0 at X = 142 cm

C_1= -54934.774

After double integration we got the following equation

Ely =-(6.000381667X^3 -.00822375X^4 -0.0000069X^5-667.1425X^2+

C_1X +C_2) ------------------ (2)

Putting boundary condition that X=0, Deflection Y= 0 in equation 2 we got

C_2 =0

Putting the values of E, I, X= 142cm

Here E=2.01x 10^6kg/sqcm

Hence multiplying 50 and putting I=5262. 624 cm^4

We got the maximum deflection in vertical stiffener between two supports y=0 .04275cm

At X = 64, $\frac{dy}{dx}$=0

$\therefore C_1$= -22535.04

Integrating again above equation

EI y = 0.783 X^3 + 100.887 X^2 + C_1X + C_2

At X= 0, Y= 0

Putting this value in above equation it was found that C_2 =0

Y =0.00389 cm

A.7 Design and Stress Analysis of Horizontal girder

Connection of Horizontal Girders with Parallel Arm.

The following two cases have been considered

Case – I : When horizontal girder is hinged at support with parallel arm.

Case – II : Horizontal girder is fixed with parallel arm.

. Total load coming on horizontal girders comprises of following components.

(i) Water pressure

(ii) Silt pressure

(iii) Radial sill pressure.

The values of above components have been tabulated below for the case I and case II.

Table TA- 13

Item	R_B (kg/m)	R_C (kg/m)
Case I : Horizontal girder is hinged at support with parallel arm		
a. Water pressure	6906.411	5587.76
b. Silt pressure	186.63	- 19.964
c. Radial sill pressure	1550.0	- 310.00
Total	8643.041	5257.796
Case – II Horizontal girder is fixed at support with parallel arm		
a. Water pressure	7148.064	5347.52
b. Silt pressure	166.53	0.13
c. Radial sill pressure	1240.0	-

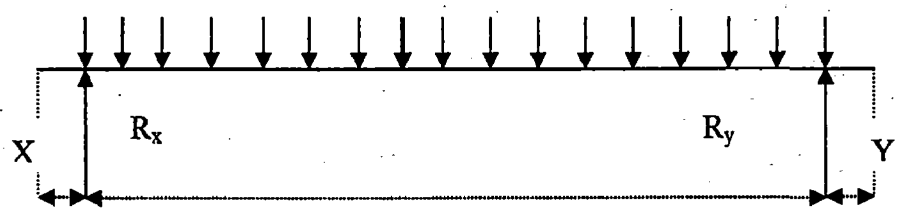


Fig FA.17

Case – I : Assuming horizontal girder as a hinged one at support point

(1) Maximum load at bottom horizontal girder

= 8643.041 kg/m run of skin plate

⇒ 8 6.43 kg/ cm run of skin plate

say = 86.5 kg / cm run of skin plate

(2) Load from each stiffener to horizontal girder

$= 86.5 \times 50$

$= 4325$ kg.

(3) Reactions : R_X and R_Y

$R_X = R_Y$ ($\because$ symmetrical loading)

$$R_X = \frac{4325 \times 16}{2}$$

$R_X = 34600$ kg $= R_Y$

(4) Shear forces at left of 'X' = 4325 kg

at right of 'X' = 34,600 – 4325 = 30,275 kg.

(5) +ive Bending Moment at Center

$\Rightarrow \{34{,}600 \times 3.75\} - \{4325\,[3.75 + 3.25 + 2.75 + 2.25 + 1.75 + 1.25 + 0.75 + 0.25]\}$

= 129,750 – 69,200

+ve B.M. at Girder $\Rightarrow$ 60,550 kg – m.

(6) -ve Bending Moment at "support" -

$\Rightarrow$ 'zero kg-m'

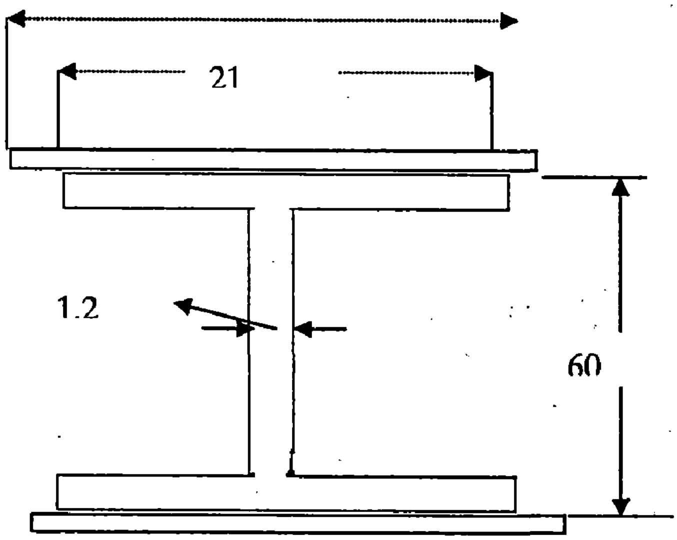
Provide "ISMB-600 x 210

With '2' flange plates' of 230 x 10 mm^2 one on

each girder flange as section of Horizontal Girder

From Steel Tables : for ISMB 600

$t_{web} = 12$ cm ; $t_{flange} = 2.08$ cm



All values in cm

$I_{section} = 91813\ cm^4$

$a_{section} = 156.21\ cm^2$

Fig FA.18

Area of each flange plate 230 x 10 mm^2

$A = 23 \times 1.0 = 23\ cm^2$

'I' of the plates co-acting with 'I' of ISMB – 600

(Moment of Inertia)

$= 2.Ar^2$ (from parrallel axis theorem of moment of inertia)

r = distance of the plate's C.G. to ISMB's C.G.

$= 30.0 + 0.5$

$r = 30.5$ cm.

$\therefore\ I_{plates} = 2 \times 23 \times (30.5)^2$

$= 42791.5\ cm^4$

$\therefore$ Total moment of inertia of the section

$\Rightarrow I_{plates} + I_{(ISMB\text{-}6\ cm)}$

$I_{total} \Rightarrow 42791.5 + 91813.0$

(1) $I_{total} \Rightarrow 134{,}604.5\ cm^4$

(2) Bending stress at center $\sigma = \dfrac{M\bar{y}}{I}$

σ = bending stress

M = B.M. at center

31 cm $\Leftarrow$ (30 +1) $\Leftarrow$ $\bar{y}$ = C.G's distance from the external of one flange

$$I = I_{total}$$

$$\therefore \sigma = \frac{60{,}550 \times 31.0 \times 100}{1{,}34{,}604.5} \qquad (\because \text{B.M. is in (kg} - \text{m))}$$

$$\therefore \sigma_{bending} = 1394.493 \text{ kg/cm}^2$$

Actual Bending Stress $\Rightarrow$ 1394.493 kg/cm^2 in H.G.'s flange.

Allowable Stress in Horizontal Girder's Flange

(a) H.G.'s Sectional Area

$A_s = 2 \times 23 + 156.21$

$A_s = 202.21 \text{ cm}^2$

(b) I_{yy} (of H.G.) $= 2651.0 + 2 \times \left(\dfrac{1 \times 23^3}{13}\right) \text{cm}^4$

$$= 2651.0 + 2027.83$$

$I_y = 4678.83 \text{ cm}^4$

(c) $\therefore r_{yy} = \sqrt{\dfrac{4678.83}{202.91}} = \sqrt{23.1385}$

$r_y = 4.8102$ cm

Say = $r_{yy} = 4.81$ cm

(d) Assuming that Cross – Bracings between the two horizontal girders on outer flange be spaced at 240 cm (center to center).

$\therefore$ Effective length 'l' = 240 cm

$$\therefore l/r_{yy} = \frac{240}{4.81} = 49.9 \qquad \text{Say} = 50$$

(e) Depth of Girder's section

$\therefore$ 'D' = 60 + 2

D = 62 cm

(f) Thickness of flange of the section

T = 2.08 + 1.0

T = 3.08 cm

(g) $\therefore D/T = \dfrac{62}{3.08} = 20.13$

Now refer to Table 6.1A (IS : 800 – 1984).

For $\dfrac{D}{T} = 20.13$ say 20 and

$$\frac{l}{r_{yy}} = 50$$

Allowable Bending Stress = 1530 kg/cm^2

But as per "permissible Stresses" (IS: 4623 – 1979).

For "DRY & ACCESSIBLE" condition

Allowable Bending Stress = 1430 kg/cm^2

$\therefore$ We shall be comparing the actual bending

Stress $\Rightarrow$ 1394.493 kg/ m to allowable bending

Stress $\Rightarrow$ 1430 kg/cm^2

Hence safe : O.K.

Shear Stress : S.F. at right of 'x' = 39275 kg

$$\therefore\ \tau = \frac{\text{S.F.}}{\text{Shear area}}$$

$$= \frac{30{,}275}{(1.2)(60-4.16)} = \frac{30{,}275}{67.008},$$

$$\tau = 451.81\ \text{kg/cm}^2 \quad < 1040\ \text{kg/cm}^2$$

Hence, 'safe' O.K.

Allowable shear stress as per IS : 4623 – 1975) for DRY & accessible condition.

Case – II: Assuming Horizontal Girder as a fixed one at support points.

Now, we shall calculating B.M. & S.F.'s for Horizontal Girder and Arms with Moment Distribution method.

Proposed Section Of End Arm

"moment of inertia "I_{xx} of ARM".

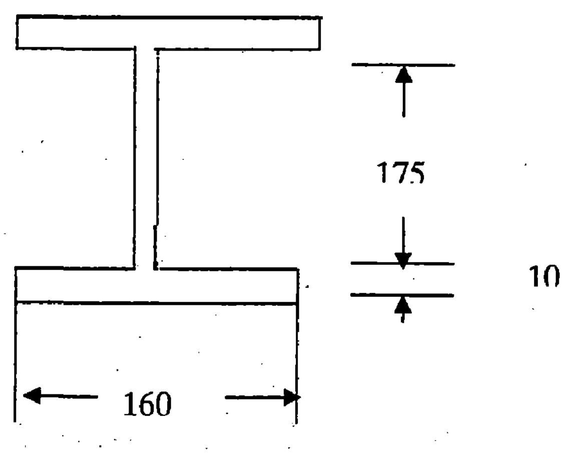


Fig FA.19

(All values are in mm)

$$I_{xx} = \frac{1.0 \times (7.5)^3}{12} + \left\{ 2\left(\frac{16.0 \times 1.0^3}{12} + 16 \times 1 \times 9.25^2 \right) \right\}$$

$I_{xx} = (446.615 + 2740.667)$

$I_{xx} = 3187.282 \text{ cm}^4$

$I_{xx} = 3187.3 \text{ cm}^4$

Say $\quad I_{xx} = 0.32 \times 10^4 \text{ cm}^4 \quad = I_{arm}$

Maximum Load on Horizontal Girder = 8.643 t/mt rm

Say $\quad$ = 8.65 t/mt rm

Also I_{xx} of horizontal girder = 134604.5 cm^4

$I_G = 13.46 \times 10^4 \text{ cm}^4$

Length of Arm in Elevation from central line of PIN = RADIUS – (200 + 600 + 20)

$L_{arm} = 5625 - 820 = 4805$ mm.

FIXED END MOMENTS

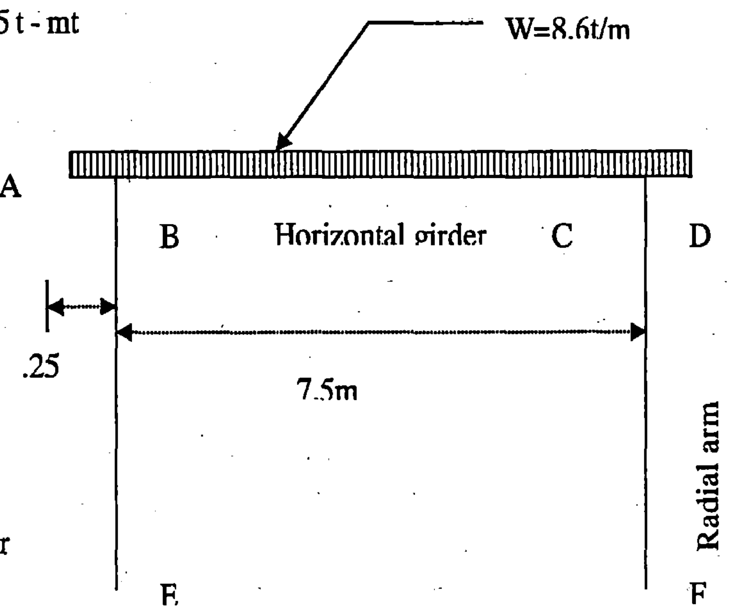
(1) $\quad M_{F_{BA}} = +\dfrac{8.65 \text{ X } 0.25^2}{2} = 0.2703125 \text{ t - mt}$

$M_{F_{BA}} \Rightarrow +0.27 \text{t - m}$

(2) $\quad M_{F_{cd}} \Rightarrow -0.27 \text{ t - m}$

(3) $\quad M_{F_{BC}} \Rightarrow -\dfrac{8.65 \times 7.5^2}{12} = 40.55 \text{ t - m}$

$M_{F_{CB}} = 40.55$ t-m



Effective length of horizontal girder

$L_{HG} \Rightarrow 7.5$ m.

Effective length of End Arm $l_{arm} \Rightarrow 4.805$ m. **Fig FA.20**

Effective = 4.805 + 0.3 m

"Half depth of horizontal girder".

Arm's effective = 5.105 m

Say = 5.1 m.

(1) Stiffness of Horizontal Girder

Considering the frame to be symmetrical about

$$S_{H.G.} \Rightarrow \frac{2EI}{l_{H.G.}}$$

$$\Rightarrow \frac{2 X 13.46 X 10^4 \times E}{7.5}$$

$$S_{H.G.} \Rightarrow 3.59 \times 10^4 \times E$$

(2) Stiffness of Arm – Other end being – hinged

$$S_{ARM} \Rightarrow \frac{3 \times 0.32 \times 10^4 \times E}{5.1}$$

$$S_{ARM} \Rightarrow 0.19 X 10^4 \times E$$

Therefore distribution factor for H.G. = $\frac{S_{H.G.}}{S_{ARM} + S_{H.G.}}$

$$k_{H.G.} = \frac{3.59 \times 10^4 E}{3.59 \times 10^4 E + 0.19 \times 10^4 E}$$

$$K_{H.G.} = \frac{3.59}{3.78} = 0.94974$$

$$K_{H.G.} = 0.95$$

$\therefore$ D.F. for End Arm = $1 - K_{H.G.}$

$= 1 - 0.95$

$K_{arm} = 0.05$

Analysis for fixed end moments

Horizontal Girder and arm both taken "together"

$M_{F_{BC}} = -40.55 \quad t-m$

$M_{F_{BA}} + +0.27 \quad m - m$

$\therefore \; M_{BC} = -2.28$ t-m

and $M_{BA} \Rightarrow +\, 0.27$ t-m

$\therefore \; M_{BE} = +\, 2.01$ t-m

Also now reaction at 'B' $\Rightarrow$ 8.643 x 4 = 34.572t

Reaction = 34.6 t

$$\text{Maximum S.F.} = \frac{8.643 \times 7.5}{2} = 32.411$$

Say = 32.4 t

Area of section = 2 x 23 x 1 + 156.21

$\Rightarrow$ 202.21 cm^2

$I_{xx} = 134604.5 \; cm^4$

$I_{yy} = 4678.83 \; cm^4$

$L_{xx} = 7.5$ mt

$L_{yy} = 2.4$ mt

(since it is proposed to provide bracings to outer flange at 240 cm c/c)

$$r_{xx} = \sqrt{\frac{134604.5}{202.21}} \Rightarrow 25.8 \; cm$$

$$r_{yy} = \sqrt{\frac{4678.83}{202.21}} \Rightarrow 4.82 \; cm$$

$$\lambda_{xx} = \frac{L_{xx}}{Y_{xx}} = \frac{7.5 \times 100}{25.8} = 29.07$$

$$\lambda_{yy} = \frac{L_{yy}}{Y_{yy}} = \frac{240}{4.82} = 49.8$$

$$\text{B.M. at mid} - \text{span} = \frac{8.643 \times 7.5^3}{8} - 2.28$$

$$= 60.771 - 2.28$$

Mid – span B.M. = 58.49 t-mt

$$\text{Maximum bending stress} = \frac{M.\bar{y}}{I}$$

Where,

M = Mid span B.M.

$\bar{y} = 31$ cm

I = 134604.5 cm^4

$$\sigma_{bending} = \frac{58.49 \times 10^5 \times 31.0}{134604.5}$$

$\sigma = 1347.05$ kg/cm^2

Permissible bending stress

$$\frac{D}{T} = \frac{60 + 2.0}{3.08 + 1.0} = \frac{62}{3.08} = 20.13$$

$$\frac{D}{T} \text{ say} \Rightarrow 20$$

$$\lambda_{yy} = 50$$

From T 6.1A, p.57 of IS ; 800 – 1984

$\sigma_{permissible} > \sigma_{actual}$, it is safe O.K.

Maximum shear stress $= \dfrac{\text{Maximum S.F.}}{area}$

$$= \frac{32.4 \times 10^3}{1.2 \times 62} = 435.5 \text{ kg / cm}^2 \quad < 1040 \text{ kg / cm}^2$$

Hence safe (O.K.)

Maximum shear force between two flange plates

$$= \frac{32.4 \times 10^3 \times 23 \times 30.5}{134604.5}$$

$$= 168.8 \text{ kg}$$

A.7.1 Deflection in bottom horizontal girder (hinged at support)

For calculating the deflection of horizontal girder above two cases have been considered. Total load coming on horizontal girders comprises of following components.

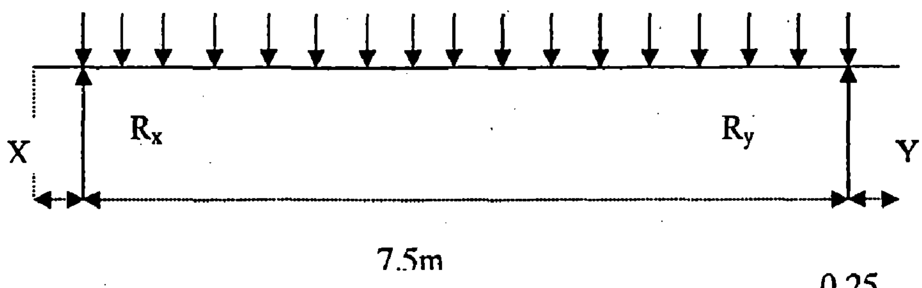
(iv) Water pressure

(v) Silt pressure

(vi) Radial sill pressure.

Considering the uniform distributed load (u.d.c.) on entire length of girder i.e. 8000 mm. Horizontal girder HG IS hinged as shown below on point X and Y. where X and Y shows the location of parallel arms [As load is coming maximum on bottom horizontal girder we will analyze the deflection for bottom girder only].

Fig FA.21



$$R_x = \frac{Wl}{2} = \frac{86.5x800}{2} = 34600\,kg$$

For finding the deflection take a section at distance x from X at mid point of span (as shown in the above fig.).

Taking moment of all the forces about mid point

$$M = -w\,x\,.\,\frac{x}{2} + Rx\,(x - 250)$$

$$\Rightarrow \frac{d^2y}{dx^2} = \frac{-1}{EI}\left[\frac{-wx^2}{2} + Rx\,(x - 250\right]$$

$$\frac{dy}{dn} = -\frac{1}{EI}\left[-\frac{wx^3}{6} + \frac{rx\,(x-250)^2}{2} + A\right] \tag{1}$$

Integrating once again

$$y_x = \frac{-1}{EI}\left[-\frac{wx^4}{24} + \frac{rx\,(x-250)^3}{6} + Ax + B\right] \tag{2}$$

where A and B are constants of integration. For finding– these following boundary condition are to be applied.

Boundary Condition

$\frac{dy}{dx} = 0$ at x = 4000 mm or 400 cm

y = 0 at x = 250 mm or 25 cm

Put these condition in equation (1) and (2)

$$0 = \frac{-1}{EI}\left[\frac{-w\,x\,400^3}{246} + \frac{Rx\,.0}{6} + Ax\,25 + B\right]$$

$$B = \frac{86.5 \times 25^4}{24} - A \times 25$$

$$= \frac{86.5 \times 25^4}{24} - A \times 25$$

$$= \frac{86.5 \times 25^4}{24} + 1.507 \times 10^9 \times 25$$

$$B = 3.77 \times 10^{10}.$$

Case I.

If section of ISMB-600 is provided for which the moment of inertia is given below.

From steel tables. For ISMB – 600

$T_{web} = 12.0$ mm.

$T_{flange} = 20.8$ mm.

Isection = 91813 cm^4.

A=Cross sectional area = 156.21 cm^2

Case II: If the horizontal girder is provided as ISMB- 600 with 10mm flange plate as shown.

Fig.3.18

Area of each

Flange plate = A = 23 × 1.0 = 23 cm^2 600

'I' of plates co-acting with I of ISMB – 600

$= 2\ Ar^2$. (From parallel axis theorem of moment inertia).

Where r = distance of CG of plates and CG of ISMB.

$= 30.0 + 0.5$

r $= 30.5$ cm.

I plate $= 2 \times 23 \times (30.5)^2$

$= 42791.5\ cm^4$.

Total moment of Inertia of combined section

$I_{total} = 42791.5 + 91813.0$

$I_{total} = 134604.5\ cm^4$.

Now check the deflection at mind of Horizontal Girder for both cases i.e. when combined section is provided and when only ISMB-600 is provided of horizontal girder.

$$y = -\frac{1}{EI}\left[-\frac{wx^4}{24} + \frac{Rx(x-25)^3}{6} + Ax + B\right]$$

$$= -\frac{1}{EI}\left[\frac{-86.5 \times 400^4}{24} + \frac{34600(400-25)^3}{6} - 1.507 \times 10^9 \times 400 + 3.77 \times 10^{10}\right]$$

$$= -\frac{1}{EI}\left[-9.23 \times 10^{10} + 3.04 \times 10^{11} - 6.03 \times 10^{11} + 3.77 \times 10^{10}\right]$$

$$= -\frac{1}{EI}\left[-6.95 \times 10^{11} + 3.42 \times 10^{11}\right]$$

$$y = \frac{3.533 \times 10^{11}}{EI}$$

Take. $E = 2.01 \times 10^5$ kgf/cm^2

$I = 91813\ cm^4$. (where only ISMB-600 is provided)

$$y_{x=400} = \frac{3.533 \times 10^{11}}{2.01 \times 10^6 \times 91813}$$

$$y = 1.91 cm$$

$y_{allowed} = \frac{L}{325}$ (As per IS 800) clause no 3.13.1.2

$$y_{allowed} = \frac{800}{325} = 2.46 cm.$$

$y_{actual} = 1.91cm.$ $\quad Y_{actual} < Y_{allowed}$ hence safe.

In actual combined section (ISMB 600 with 10 thk flange plate) is provided for which I–134604.5 cm^4

$$y_{x=400} = \frac{3.533\times10^{11}}{2.01\times10^{6}\times134604.5}$$

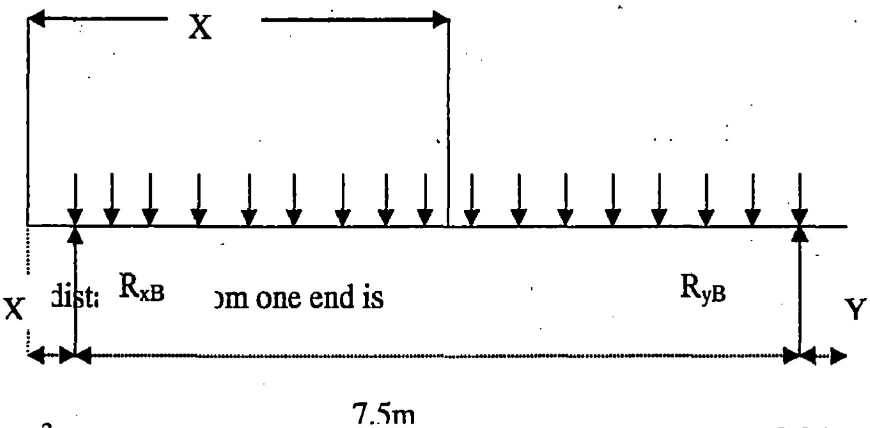
$= 1.30$ cm.

$y_{acual} = 1.30 < y_{allowed}$ hence safe.

A.7.2 Deflection in Top Horizontal Girder (considering simple supported case)

Each vertical stiffener transmit 2673.5 kg to horizontal girder. There are 16 stiffeners . Hence total load transfer to top horizontal girder = 2673.5x 16=42776 kg

Reaction at each support $R_{xB} = R_{yB} = 21338$ kg



Bending momen dist om one end is

$M = EI\frac{d^2y}{dx2} = -[\, wX^2/2 + R_{xB}(X\text{-}25)]$

Integrating above equation it was found

$EI\,\text{-}\frac{dy}{dx} = [wX^3/6 + R_{xB}(X\text{-}25)^2 + A]$

At X = 400cm, $\frac{dy}{dx} = 0$

$\therefore$ A=- 9.3x 10^8

Integrating above equation again

It was found EI y= -[$-wX^4/24 + R_{xB}(X-25)^3/6 + AX + B$

At X = 25 cm y= 0

Hence B = 2.25×10^{10}

Now putting the value of w= 52.57 kg/cm

R_{xB} = 21338 kg

E= 2.01×10^6 kg/cm^2

I= 134604.5 cm^4

It was found that maximum deflection at X= 400 cm is

y = 0.805cm

A.7.3 Deflection at middle of Bottom Horizontal girder considering it is fixed at support

In this case $y = \dfrac{wl^4}{384EI}$

Where w= 86.5 Kg/cm

L= 750cm

E= 2.01x 10^6 kg/cm^2

I=134604.5 cm^4

Putting above value in above it is found that y= 0.2634355 cm

A.7.4 Deflection at middle of top Horizontal girder Considering it is fixed at both ends by radial arm.

In this case $y = \dfrac{wl^4}{384EI}$

Where w= 52.57 Kg/cm

l= 750cm

E= 2.01x 10^6 kg/cm^2

I=134604.5 cm^4

Putting above value in above it is found that y= 0.1564cm cm

3.9 Design Stress Analysis of End Arms

Maximum axial load $\Rightarrow$ Reaction $Rx(= Ry)$

$\Rightarrow$ 34,600kg

Maximum B.M. (in x –direction)

$= 2.01$ t-m

$= 2.01 \times 10^5$ kg-cm

Maximum S.F. $= \dfrac{\text{B.M.}}{\text{length of arm}}$

$= \dfrac{2.01 \times 10^5}{5.1 \times 10^2}$

$= 394.1176 kg$

Say $\simeq 0.4$ t

Area of arm's section $= 2 \times 16 \times 1 + 17.5 \times 1$

$= 32 + 17.5$

$a = 49.5 \text{ cm}^2$

Moment of Inertia $I_{xx} = \dfrac{2 \times 16 \times 1^3}{12} + 2 \times 16 \times 9.25^2 + \dfrac{1 \times 17.5^3}{12}$

$I_{xx} \Rightarrow 3187.3 \text{cm}^4$

$I_{yy} = \dfrac{2 \times 16^3}{12} + \dfrac{1^3 \times 17.5}{12} = 684.13 cm^4$

Length of Arm between H.G. and Trunnion Hub

$L_{arm} = 5.1$ mt

Effective length $= 0.8 \times 5.1$

$\Rightarrow 4.08$ mt.

But clear length of Arm = Actual length – Hub radius

$= 4.08 - 0.125$ mt.

clear length of Arm $\Rightarrow 4.675$ mt.

$\therefore$ Effective clear length of arm $= L_{exx}$

$L_{exx} = 4.675$ mt (∴ it is greater than 4.08 mt.)

$$\therefore\ r_{xx} = \sqrt{\frac{I_{xx}}{a}} = \sqrt{\frac{3187.3}{49.5}} = \sqrt{64.39}$$

$$r_{xx} = 8.02cm$$

and $$r_{yy} = \sqrt{\frac{I_{yy}}{a}} = \sqrt{\frac{684.13}{49.5}} = \sqrt{13.821}$$

$$r_{yy} = 3.718cm$$

therefore $$\lambda_{xx} = \frac{4.675\times100}{8.02}$$

$$\lambda_{xx} = 58.3$$

and $$\lambda_{yy} = \frac{160}{3.718}$$ (assuming spacing of cross-bracing of arms at 160 cm)

$$\lambda_{yy} = 43.03$$

Now for $\lambda = 58.3$, . $_y$ = 2600mPa from Table 5.1. of IS : 800-1984.

Axial permissible stress $\sigma_{ac} = 1260 kg/cm^2$

(2) Also permissible bending stress from T 6.1A of IS –800-1984.

For $\frac{D}{T} = \frac{19.5}{1} = 19.5$ and $\lambda_{xx} = 58.3$

Permissible benting stress $\sigma_{bc} = 1480kg/cm^2$

(3) Now actual axial stress

actual $$\sigma_{ac} = \frac{34.6\times10^3}{49.5} = 698.99$$

actual $\sigma_{ac} = 699kg/cm^2$

(ii) Actual bending stress

(ii) Actual bending stress

$$\text{actual } \sigma_{bc} = \frac{M\bar{y}}{I} = \frac{2.01\times10^5\times9.75}{3187.5}$$

$$= 614.86 \text{ kg/cm}^2$$

$$\text{actual } \sigma_{bc} \simeq 614 \text{ kg/cm}^2$$

From section 7 of IS : 800-1984

(5) $fcc_x = \dfrac{\pi^2 E}{\lambda_x^2}$ where E = Young's modulus for maximum end Arm's

$$= \frac{\pi^2\times2.01\times10^6}{(58.3)^2} \qquad E = 2.01\times10^6 \text{ kg/cm}^2$$

$\lambda_x = 58.3$ (for structural steel)

(6) $Cm_x = 0.85$ ($\because$ side-sway is not being prevented)

$$\text{Now } \frac{\sigma_{ac}(\text{actual})}{\sigma_{ac}} + \frac{C_{mx}\sigma_{bc(\text{actual})}}{\left\{1-\left(\dfrac{\sigma_{ac}\text{actual}}{0.60\times fcc_x}\right)\right\}\times\sigma_{bc}} \le 1$$

Condition for checking the End Arm's design's safety

$$\frac{699}{1260} + \frac{0.85\times615}{\left\{1-\left(\dfrac{699}{0.6\times5840}\right)\right\}1480} \le 1$$

$\Rightarrow$ $0.5548 + 0.44123 \text{ U} \le 1$

$0.99603 \le 1$

condition is just satisfied

End Arm's design (with Bracings spacing (at 160cm) O.K.

Maximum shear stress $\Rightarrow \dfrac{\text{S.F.}}{\text{area}}$ maximum S.F. = 0.4 t

$$\Rightarrow \frac{0.4 \times 1000}{19.5 \times 1.0} = 20.513 kg/cm^2$$

$\tau_{max} \Rightarrow 20.5 kg/cm^2$ Maximum limit is 1040 kg/cm^2

Hence it is within permissible limit and safe.