OPTIMAL DESIGN OF UNDER SLUICE GATE USING FEM -A CASE STUDY OF BHIMGODA BARRAGE

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I do hereby declare that the dissertation entitled "**OPTIMAL DESIGN OF UNDER SLUICE GATE USING FEM-A CASE STUDY OF BHIMGODA BARRAGE**" is being submitted by me in partial fulfillment of requirement for the award of degree of **Master of Technology** in **Water Resource Development** and submitted in the Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from July 2009 to June 2010 under the guidance of **Prof. Gopal Chauhan**, Department of Water Resources Development and Management, and **Prof. B K Mishra,** Department of mechanical and Industrial Engineering, Indian Institute of Technology Roorkee.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Dated: June, 2010

Place: Roorkee.

(VIJAI DIWAKER)

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

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IIT Roorkee

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Gates are essential hydro mechanical control equipment required for under sluice in the water resources projects. Several types of gates are developed, out of which fixed wheel vertical lift gate and radial gate are used in general. Without sacrificing the operation requirements like failure free performance, water tightness, rapidity in operational and convenience in installation and maintenance, it is desired that the cost of the gate should be minimum with lesser weight of gate and hoisting capacity. To achieve these goals, the design of various components of the gates is to be optimized. The numbers of horizontal girders control the skin plate thickness as well as section of vertical stiffeners and the numbers of wheels control the section of end vertical girder. Hence the quantity of steel for the vertical lift gate depends on all these factors for given water head.

In this dissertation an attempt has made to analyze stress and displacements and carry out design optimization of vital parts using Finite Element Model through ANSYS software. A comparative study between conventional design results and FEM design results has been carried out to find out the effectiveness of conventional design procedure. A comparison between design results before optimization and after optimization has also been made. This study is limited to skin plate, Vertical stiffener, horizontal girder, vertical end girder and wheel of an existing Fixed Wheel Vertical Lift Gate Fitted in under Sluice of Bhimgoda Barrage.

From the FEM analysis, it is established that the conventional design results of under sluice gate of Bhimgoda barrage quite safe but we should take care of top horizontal girder and Skin plate Panel-C (upper portion of second unit of gate).

From optimization study of under sluice gate of Bhimgoda barrage, it is found that the optimal number of horizontal girders is 4 as against 3 girders actually presented. The total steel quantity decreases by 5.42% with 4 numbers of horizontal girders, as against 3 girders provided of the gate. Similarly the total steel quantity decreases by 4.52% with 8 numbers of wheels on each side, which is optimum number of wheels as against 6 wheels on each side of the gate.

LIST OF NOTATIONS

Sl No.	Notation	Details
1.	UH	Displacement in X-direction
2.	UY	Displacement in Y-direction
3	UZ	Displacement in Z-direction
4.	XROT	Rotation about X-direction
5.	YROT	Rotation about Y-direction
6.	ZROT	Rotation about Z-direction
7.	DOF	Degree of freedom
8.	$SX \dots or .. \sigma_x$	Bending stress in X-direction
9.	$SY \dots or .. \sigma_y$	Bending stress in Y-direction
10.	$SZ \dots or .. \sigma_z$	Bending stress in Z-direction
11.	$SXY \dots or .. \tau_{xy}$	Shear Stress in X-Y plane
12.	$SYZ \dots or .. \tau_{yz}$	Shear Stress in Y-Z plane
13.	$SXZ \dots or .. \tau_{xz}$	Shear Stress in X-Z plane
14.	SF	Shear Force
15.	BM, or M	Bending Moment
16.	I_{xx}	Moment of inertia about X-direction
17.	I_{yy}	Moment of inertia about Y-direction
18.	I_{zz}	Moment of inertia about Z-direction
19.	Z	Section modulus
20.	mm	Millimeter
21.	cm	Centimeter
22.	kg	Kilogram
23.	kg-cm	Kilogram-centimeter
24.	t	Tonne, thickness
25.	E	Young's Modulus of Elasticity
26.	ν	Poisson's Ratio
27.	ρ	Density
28.	P	Hydraulic Pressure
29.	f_t , f_b	Flexural or Bending Stress in Top or Bottom fibre
30.	S_c, f_c	Contact Stress or Combined Stress

INTRODUCTION

1.1 GENERAL

Under sluice portion of a barrage, having its sill at a level lower than the other bays, is provided adjacent to the head regulator .Gates are provided for regulating the flow in the poundage to the downstream without damaging the barrage structure or the downstream bed and help to store water in the reservoir for its use in the lean period. Under sluice gates normally closed during non-flood season and are partly or fully open during flood season. Fixed wheel Vertical lift gate is normally used for controlling the flow of water through the under sluice.

It is desired that the cost of the gate should be minimum with lesser weight of gate and hoisting capacity. To achieve these goals, the design of various components of the gates is to be optimized. The number of horizontal girders which control the skin plate thickness as well as section of vertical stiffeners and number of wheels control the section of end vertical girder. Hence the quantity of steel for the vertical lift gate depends on all these factors for a given water head. Design optimization includes structural analysis, stress and displacement analysis of structure nested in the process of optimization. For the structural analysis, the finite element software ANSYS, has been used.

1.2 FIXED WHEEL VERTICAL LIFT GATE

The fixed wheel vertical gates are rectangular in shape and are movable vertically up and down as per the requirement. The assembly of fixed wheel vertical lift gate consists of skin plate mounted on a frame work of horizontal girders, vertical stiffeners and end vertical girders. Transit of vertical gate along the vertical plane is achieved by the wheels fixed to the end girders which move on the vertical track fixed to the pier.

Figure 1.1: Bhimgoda Barrage

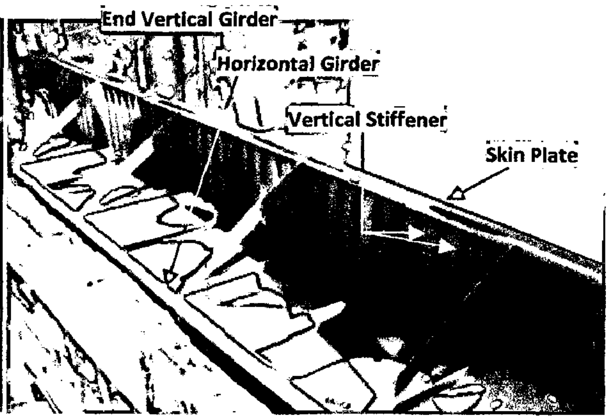


Figure 1.2: Under Sluice Gate

Components of this gate are shown in Fig.1.2 & 1.4

1. Skin plate
2. Horizontal stiffeners
3. Vertical stiffeners
4. Horizontal girders
5. Vertical end girders
6. Wheels
7. Guide rollers
8. Rubber seals

The water loads are transferred from skin plate to vertical stiffeners to horizontal girders to vertical end girders and finally to tracks and piers through wheels. Due to the loads, deflection take place and therefore, stresses are developed in various parts of the gate. Each side of the gate carries half of the total load acting on it. The joints of skin plate with vertical stiffeners and horizontal girders are expected high stress zone. Similarly the joints between horizontal girders and vertical stiffeners as well as with vertical end girders are also expected to be high stress zone. Generally the gates are designed as per guidelines given in various handbooks of hydroelectric engineering, gates and valves and IS: 4622:1992, Indian Standard Fixed Wheel Vertical-Lift Gates Structural Design Recommendations (2nd.revision) etc.

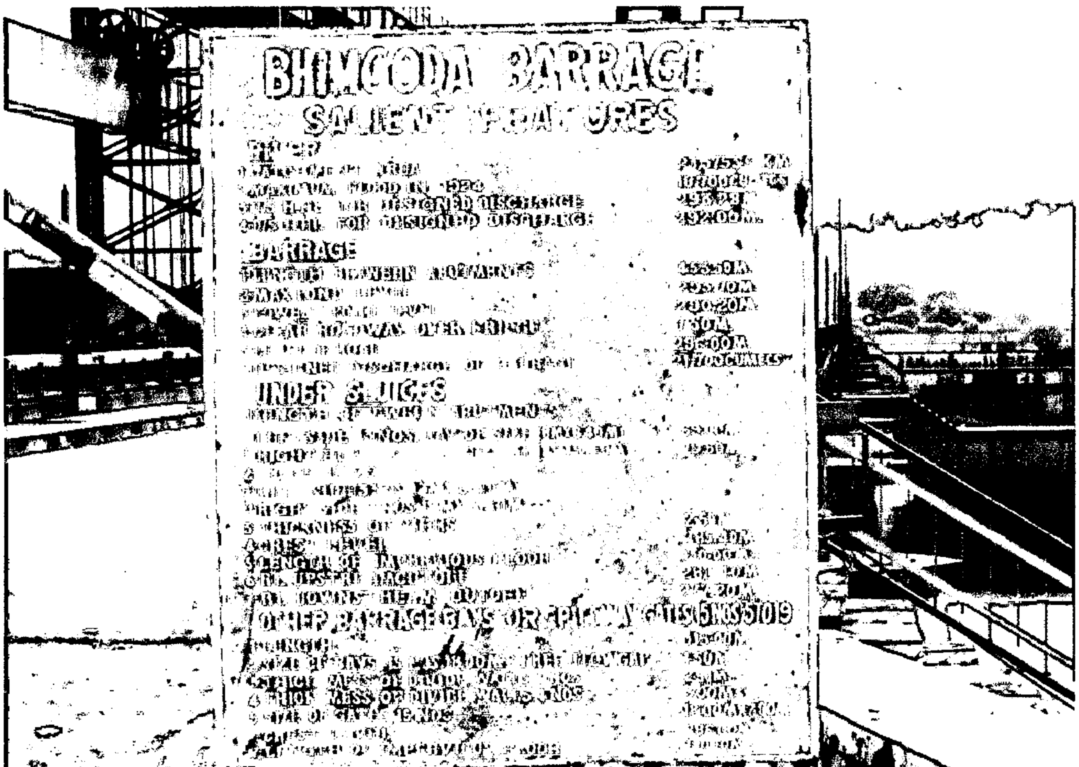


Figure 1.3: Salient features of Bhimgoda Barrage

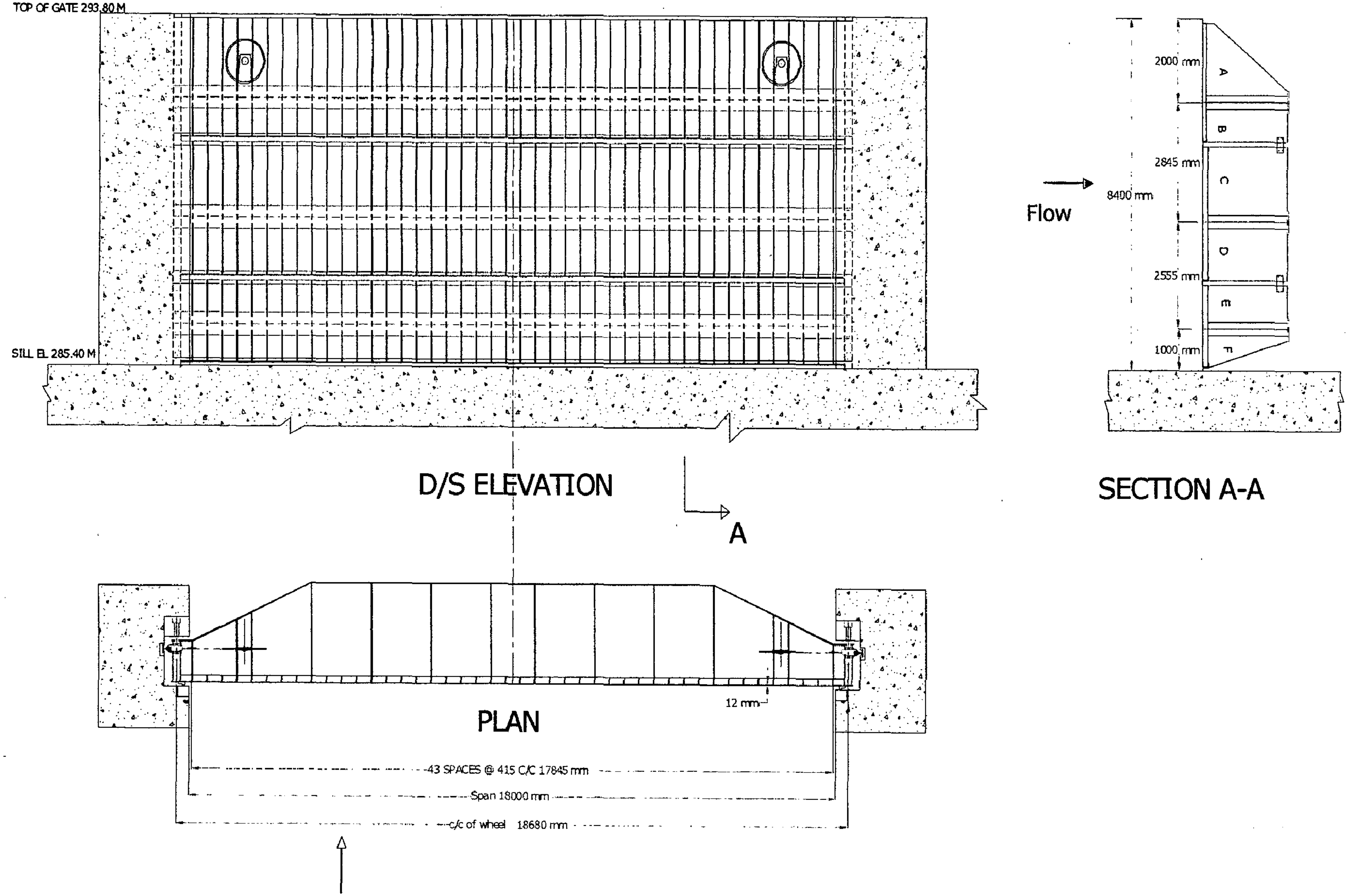


Figure 1.4: Fixed Wheel Vertical Lift Gate (Under Sluice Gate of Bhimgoda Barrage)

1.3 SCOPE OF STUDY

The present study has been performed with Under Sluice Gate of Bhimgoda Barrage in Haridwar, UK, India. In this barrage, there are two under sluice portion right side under sluice having 4 bays and left side having 3 bays, which are shown in Fig. 1.3. **Fixed Wheel Vertical Lift Gate** of size 18mx8.4m (clear opening) has been used with crest level at EI 285.40 m and top level of gate is EI 293.80 m are shown in Fig. 1.3.

In this dissertation an attempt has been made to study stresses, deflection and optimization in a Under Sluice Gate of Bhimgoda Barrage on different components like skin plate, vertical stiffeners, horizontal girders, end vertical girders and wheels using **FEM** (finite element method) when the gate rests on the sill at maximum pond level. The deflection of the gate also computed at high flood level and normal pond level condition to check the varying condition. This analysis is carried out by the ANSYS 11.0 software, which is based on FEM to compare the results with conventional design results for establishing the effectiveness of the structure and utility of these analyses.

1.4 ORGANIZATION OF DISSERTATION

This dissertation consists of seven chapters.

Chapter-1: covers introductory remarks.

Chapter-2: literature review.

Chapter-3: contains basic concept of finite element method.

Chapter-4: contains the design considerations of fixed wheel vertical lift gate, design criteria in general for skin plate, vertical stiffeners, horizontal girders, end vertical girders and wheels.

Chapter-5: contains the FEM model, analysis, results and discussion of under sluice gate of Bhimgoda barrage.

Chapter-6: contains the optimal design of under sluice gate of Bhimgoda barrage.

Chapter-7: contains conclusions and scope of further study

LITERATURE REVIEW

It is considered pertinent to add at the outset itself the literature review has been confined to use of conventional & computerized design of gates.

Darnief (1984) has computed conventional design practices for vertical lift gates & radial gates.

Sahu (1987) has covered specifically the design fabrication erection and maintenance of spillway gates in Tehri Dam project by using conventional approach.

Indrakusuma (1990) has developed a computer program in Fortran for computerized design of radial gates.

Kumar S M (1990) has developed a general computer program in C++ for design of vertical lift gates by using conventional design approach.

Boro J R (2000) studied optimization of spillway crest gates of vertical lift and redial types. A computer program has been developed in 'C++' and adopted for cost analysis of gates of both, fixed wheel vertical lift type and redial type for 2, 3 and 4 number of horizontal girders in each case. The analysis indicates that radial gate is cheaper than the fixed wheel vertical lift gate. Basically, heads of water govern the numbers of horizontal girders. The optimized number of horizontal girders is found to be 2 up to 8.5m of head, 4 above 13.5m and 3 in between this range for vertical lift gate, while slightly lower values of head have been established for radial gate.

Soerjantoro B (2000) carried detailed design of inclined emergency intake gate, Design as per Japanese standard for gates and penstocks when compared with design using Indian Standard Code (IS-4622-1992) reveal that similar principles are used and hence the values of several parameter are almost same except in some cases, like the thickness of wheel track, where Indian Standard give higher value and is considered to be safer.

Sharma M K (2004) studied the stresses and displacement of Radial Gate through ANSYS 5.4 software. Also a comparative study between conventional approaches i.e. 2D approach and 3D 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 existing parallel arm radial gate fitted in a cross regulator on parallel Upper Ganga Canal at Jawalapur Haridwar.

Wahab M A (2005) studied the stress and displacements from finite element model using ANSYS software. A comparative study between two-dimensional design and three-dimensional FEM results has been made to find out the effectiveness of two-dimensional design procedure. This study included skin plate, vertical stiffeners, horizontal girders, end vertical girder and wheel of an existing "fixed wheel vertical lift gate" fitted in tailrace channel of Dharasu Power House.

BASIC CONCEPT OF FINITE ELEMENT METHOD

3.1 Finite Element Method (FEM)

Finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems like analyzing structures, which permit the calculations of stresses and deflections. The most distinctive feature of the finite element method that separates it from others, is the division of a given domain into a set of simple sub domains called elements. The finite element procedure produces many simultaneous algebraic equations, which are generated and solved on a digital computer. Results are rarely exact. However, processing more equations minimizes errors and 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, is 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.

3.2 Description of Finite Element Method

3.2.1 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 is subdivided into an 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 gradients 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 indicated 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. It may be noted that the continuum is simply zoned into small regions

3.2.2 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. The degree of the polynomial chosen depends on the number of nodes assigned to the elements.

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 Ø 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 Ø in terms of the position (x, y) within an element. If mesh of element is not too coarse and if ϕ_1 happened to be exact, and then Ø would be a good approximation.

3.2.3 Convergence Requirements

In any acceptable numerical formulation, the numerical solution must coverage 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.

$$\left.\begin{aligned} u(x) &= a_1 + a_2x + a_3y \\ v(y) &= a_4 + a_5x + a_6y \end{aligned}\right\} \qquad (3.3)$$

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 3 D elasticity the three conditions mentioned above are easily satisfied by linear polynomials.

3.2.4 Nodal Degrees 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.

3.2.5 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 coefficient. 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 isotopic body, Modulus of Elasticity (E) and Poisson's ratio (v) define the local material properties. The stiffness matrix is essentially symmetric matrix, which follows from the principle of stationery 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 action through displacements caused by first set.

3.2.6 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

3.2.7 Assembly of Algebraic Equations for the Overall Discretised continuum

This process includes the assembly of overall or global stiffness matrix for the entire body form 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 n x n where, n = total number of nodal points in the entire body. The steps involved in generation of global stiffness 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 ' i' node of an element ' e' is directed to the address of $\{F_i\}$ total load vector i.e.

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

3.2.8 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.

3.2.9 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 of elimination procedure. Once the nodal displacements are found, then element stains or stresses can be easily found from generalized Hooke's law for a linear isotropic material.

The assumption in displacements 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 strains obtained are for the centers of gravity of the elements and linear variation is assumed to calculate them at other points in the body.

3.3.10 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 coordinates, 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 equation numbers.

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

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] {δ} = {F} for {δ}

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

3.4 MATHEMATICAL MODEL

3.4.1 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 undermined 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.

3.4.2 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 present U^e must be complete (ie 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.

3.4.3 Displacement function

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

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

Where, $[N] = [N_i, N_j, N_m \ldots\ldots\ldots\ldots\ldots]$

and

$$\{\delta\}^e = \{\delta_i, \delta_j, \delta_m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\} \quad (3.5)$$

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

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

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

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

are the corresponding displacements of node i.

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

3.4.4 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:

$$\{\epsilon\} = \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_z \\ \epsilon_{xy} \\ \epsilon_{yz} \\ \epsilon_{zx} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial w}{\partial z} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \\ \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \end{Bmatrix} \qquad (3.8)$$

Which can be further written as

$\{\varepsilon\} = [B] \{\delta\}^e = [B_i, B_j, B_k] \{\delta\}^e$ (3.9)

In which $[B_i]$ is the strain displacement matrix

$[B_i]$ is given by

$$[B_i] = \begin{bmatrix} \frac{\partial N_i}{\partial x} & 0 & 0 \\ 0 & \frac{\partial N_i}{\partial y} & 0 \\ 0 & 0 & \frac{\partial N_i}{\partial z} \\ \frac{\partial N_i}{\partial y} & \frac{\partial N_i}{\partial x} & 0 \\ 0 & \frac{\partial N_i}{\partial z} & \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial z} & 0 & \frac{\partial N_i}{\partial x} \end{bmatrix} \qquad (3.10)$$

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

$$
\left.
\begin{aligned}
x &= \sum_{i=1}^{n} N_i\, x_i \;, y = \sum_{i=1}^{n} N_i\, y_i \,, z = \sum_{i=1}^{n} N_i\, z_i \,, x \\
u &= \sum_{i=1}^{n} N_i\, u_i \;, v = \sum_{i=1}^{n} N_i\, v_i \,, w = \sum_{i=1}^{n} N_i\, w_i \,, u
\end{aligned}
\right\} \qquad (3.11)
$$

The summation is 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 hence it is necessary to relate derivatives in Eq. (3.10) to the derivates 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 the partial differentiation, we can write:

$$
\frac{\partial N}{\partial \xi} = \frac{\partial N_i}{\partial x} \cdot \frac{\partial x}{\partial \xi} + \frac{\partial N_i}{\partial y} \cdot \frac{\partial y}{\partial \xi} + \frac{\partial N_i}{\partial z} \cdot \frac{\partial z}{\partial \xi} \qquad (3.12)
$$

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

$$
\begin{Bmatrix} \dfrac{\partial N_i}{\partial \xi} \\ \dfrac{\partial N_i}{\partial \eta} \\ \dfrac{\partial N_i}{\partial \varsigma} \end{Bmatrix}
=
\begin{bmatrix}
\dfrac{\partial x}{\partial \xi} & \dfrac{\partial y}{\partial \xi} & \dfrac{\partial z}{\partial \xi} \\
\dfrac{\partial x}{\partial \eta} & \dfrac{\partial y}{\partial \eta} & \dfrac{\partial z}{\partial \eta} \\
\dfrac{\partial x}{\partial \varsigma} & \dfrac{\partial y}{\partial \varsigma} & \dfrac{\partial z}{\partial \varsigma}
\end{bmatrix}
\begin{Bmatrix} \dfrac{\partial N_i}{\partial x} \\ \dfrac{\partial N_i}{\partial y} \\ \dfrac{\partial N_i}{\partial z} \end{Bmatrix}
= [J]
\begin{Bmatrix} \dfrac{\partial N_i}{\partial x} \\ \dfrac{\partial N_i}{\partial y} \\ \dfrac{\partial N_i}{\partial z} \end{Bmatrix} \qquad (3.13)
$$

where [J] is given by:

$$[J] = \begin{Bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} & \frac{\partial z}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} & \frac{\partial z}{\partial \eta} \\ \frac{\partial x}{\partial \varsigma} & \frac{\partial y}{\partial \varsigma} & \frac{\partial z}{\partial \varsigma} \end{Bmatrix} \tag{3.14}$$

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

$$\begin{Bmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial z} \end{Bmatrix} = [J]^{-1} \begin{Bmatrix} \frac{\partial N_i}{\partial \xi} \\ \frac{\partial N_i}{\partial \eta} \\ \frac{\partial N_i}{\partial \varsigma} \end{Bmatrix} \tag{3.15}$$

Substituting Eq. (3.11) in to Eq. (3.14) the Jacobian matrix ix given by

$$[J] = \begin{bmatrix} \Sigma \frac{\partial N_i}{\partial \xi} x_i & \Sigma \frac{\partial N_i}{\partial \xi} y_i & \Sigma \frac{\partial N_i}{\partial \xi} z_i \\ \Sigma \frac{\partial N_i}{\partial \eta} x_i & \Sigma \frac{\partial N_i}{\partial \eta} y_i & \Sigma \frac{\partial N_i}{\partial \eta} z_i \\ \Sigma \frac{\partial N_i}{\partial \varsigma} x_i & \Sigma \frac{\partial N_i}{\partial \varsigma} y_i & \Sigma \frac{\partial N_i}{\partial \varsigma} z_i \end{bmatrix} \tag{3.16 a}$$

$$[J] = \begin{bmatrix} \frac{\partial N_1}{\partial \xi} & \frac{\partial N_2}{\partial \xi} & \dots\dots\dots\dots \\ \frac{\partial N_1}{\partial \eta} & \frac{\partial N_2}{\partial \eta} & \dots\dots\dots\dots \\ \frac{\partial N_1}{\partial \varsigma} & \frac{\partial N_2}{\partial \varsigma} & \dots\dots\dots\dots \end{bmatrix} \begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \\ . & . & . \\ . & . & . \\ . & . & . \end{bmatrix} \tag{3.16 b}$$

3.4.5 Stresses

The stresses are related to the strains

$$\{\sigma\} = [D](\{\epsilon\} - \{\epsilon_0\}) + [\sigma_0] \qquad (3.17)$$

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

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

For linear elastic, isotropic material the elasticity is given by

$$D = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & 2(1+\nu) & 0 & 0 \\ 0 & 0 & 0 & 0 & 2(1+\nu) & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(1+\nu) \end{bmatrix} \qquad (3.18)$$

Where, E = Young's modulus of elasticity and ν = Poisson's ratio of the material of the element.

3.4.6 Stiffness Matrix

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

$$\{F\}^e = [K]^e \{\delta\}^e \qquad (3.19)$$

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

$$[K]^e = \iint [B]^T [D][B]\, dA \qquad (3.20)$$

Where A refers to the area of the element.

The equivalent nodal forces are obtained as i). Forces due to pressure distribution $\{p_x, p_y, p_z\}$ per unit area given by :

$$\{F^e\}_p = \int_v [N]^T \{p\} dA \qquad (3.21\ a)$$

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

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

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 :

$$\left.\begin{aligned} [K] &= \Sigma_{0=1}^{E} [K]^e \\ \{F\} &= \Sigma_{0=1}^{E} \{F\}^0 \end{aligned}\right\} \qquad (3.22)$$

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.

$$dA = dx.dy = \det[J] d\xi\, d\eta \qquad (3.23)$$

is used

Writing explicitly

$$\int_A dx\, dy = \int_{-1}^{+1}\int_{-1}^{+1} \det[J] d\xi\, d\eta \qquad (3.24)$$

And the characteristic element stiffness matrix can be expressed as

$$[K] = [B]T[D][B] \int_{-1}^{+1}\int_{-1}^{+1} \det[J] d\xi\, d\eta \qquad (3.25)$$

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

CONVENTIONAL DESIGN OF VL GATE

4.1 INTRODUCTION

Conventionally, the fixed wheel vertical-lift gates are designed on the basis of guidelines given in various handbooks of hydro-electric engineering, gates & valves and IS:4622: Indian Standard Fixed Wheel Vertical-lift Gates Structural Design Recommendations. Normally the skin plate is fitted on the upstream side of the frameworks and it can be fitted on the downstream side also when advantageous as the case of under study. 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 stiffeners, which are connected to horizontal girders transferring the load to the two vertical end girders. The wheels are fitted to the vertical end girders and ultimately loads are transferred to the wheel tracks and piers.

4.2 DESIGN CRITERIA

4.2.1 Main Components of the Gates

i. Skin Plate;
ii. Vertical Stiffener;
iii. Horizontal Girder
iv. Vertical end girder
v. Wheel;
vi. Wheel axle;
vii. Track and
viii. Seal.

4.2.2 Design of Skin Plate

The skin plate and stiffeners are 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 4622.

The maximum bending moments can be found only after knowing the number of horizontal girder and their location.

Number of horizontal girders is decided on economics. If the number of horizontal girders increases the thickness of skin plate decreases as such cost of horizontal girder increases and skin plate decreases, and vice-versa a shown in graph.4.1.

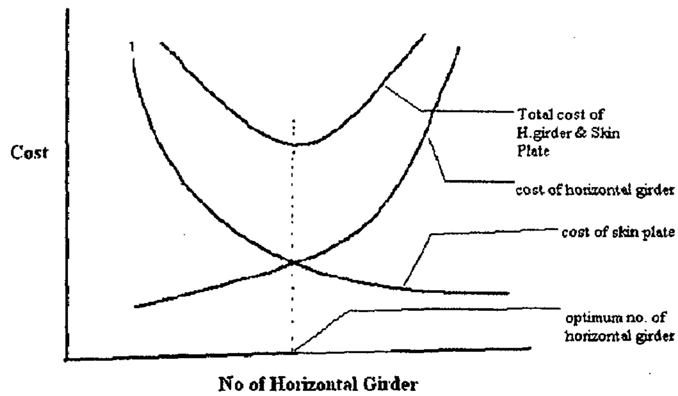


Figure 4.1: Optimal number of horizontal girders

The number of girders depends on the total height of the gate but to be kept as minimum as possible to simplify fabrication and erection and to facilitate maintenance.

The spacing of horizontal girders is based on the criteria that, load on all girders is equal for economic reasons. If all girders carry equal load then cross section of each girder throughout the gate height will be same. The spacing of girders for equal loading can be found by:

i. Analytical Method;

ii. Graphical Method;

iii. By trial and error.

Analytically for surface gate, on the basis of equal loading, spacing of the horizontal girders is given by the following formula as shown in Fig.4.1.

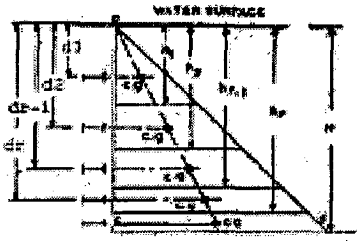


Figure 4.2: Spacing of horizontal girders

$$- \; = \qquad (4.1)$$

Where,

d_r = distance of C/L of horizontal girders from the top of the gate in m or cm;

H = total head of water in m or cm;

n = number of horizontal girders;

r = sequence no. of the horizontal girders (1,2,--------n)

The analytical method can also be used for intake (submerged) gates with slight modification on the basis of equal loading. The final formulation is given as below.

$$- \quad \rule{1cm}{0.4pt}$$

$$- \quad \rule{8cm}{0.4pt}$$

Where,

d_r = distance of C/L of horizontal girders from the top of the gate in m or cm;

H = total head of water in m or cm;

H_1= depth of water at the top of the gate in m or cm;

n = number of horizontal girders;

r = sequence no. of the horizontal girders (1,2,--------n)

Graphically, for barrage gates the problem of girder spacing can also be solved as follows given by Leliavsky. Let a b c in Fig.4.2 be the triangle representing the water pressure applied to the gate. Draw a semicircle with a b as diameter. Then divide a b in to equal intervals a a_1, a_1 a_2 ... ... of the number of girders to be used. Through the points a1, a2,. ... ...draw a set of parallel lines at right angles to a b and mark the intersections of these lines with semicircle as b_1, b_2, ...Draw arcs with centre at points a through the points b_1, b_2, ... which cut a b at points c_1, c_2, ...yield the positions of the horizontal lines c_1 d_1, c_2 d_2, ... dividing the area of the basic triangle in equal parts. Find the centroid of the areas of the areas a c_1 d_1, d_1 c_1 c_2 d_2, ...and space the girders accordingly.

The graphical method is also applicable to two-tier and intake gates as shown in Fig. 4.3 where opening requirements are such that:

a) top girder of top tier is subjected to repeated impact.

b) same is true for:

i. top girder of lower tier,

ii. bottom girder of top tier.

In this case the top tier girders spacing is done as follows:

Divide the hypotenuse of water pressure triangle in to $2n_{ti}+1$ equal parts.

Where , n_{ti} = number of intermediate girder in top tier = $n_t - 2$,

n_t = number of girder in top tier.

Similarly, for the bottom tier, number of division = $2n_{bi}+2$;

Where, n_{bi} = number of intermediate girders in bottom tier = $n_b - 2$,

n_b = number of girder in bottom tier.

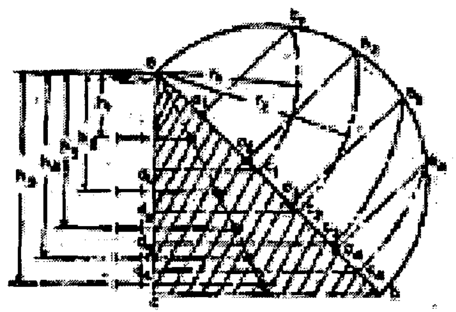


Figure 4.3: Spacing of girders on barrage gate

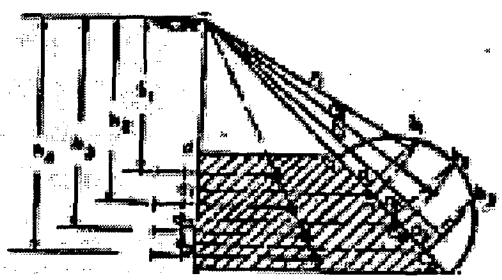


Figure 4.4: Spacing of girders on intake gate

A trial and error method can also be applied for spacing of girders. All the girders are of same section but the top and bottom girder each are supposed to carry half the load. While the top girder is flushed with the gate, the bottom girder is placed a little above the bottom in order that the bottom sealing is properly fixed.

Once horizontal girder are located to carry almost equal load, the skin plate can be designed on bending either across the horizontal girder or vertical stiffeners.

Now, with reference to IS 4622: 1992, page 12. Fig.5 Annex-C, Clause 5.2.3(a), we have the following equation for stresses in skin plate. (Note: symbols of stress & thickness have been changed).

$$S = \frac{K}{100} x \frac{Pxa^2}{t^2} \qquad \text{.. (4.3)}$$

Where,

S = bending stress in flat plate in N/mm^2 or kg/cm^2;

K = non dimensional factor depend on the value of a & b;

P = water pressure in N/mm^2 or kg/cm^2 (relative to the plate centre);

a, b = bay width in mm or cm as shown in ref. and

t = plate thickness in mm or cm.

The value of 'K' are given with due consideration to biaxial bending in contrast to simple bending of plates. Once stresses are found, they are converted into equivalent stress as follows:

$$S_c = \sqrt{S_x^2 + S_y^2 - S_x \times S_y + 3S_x^2} \quad \ldots\ldots\ldots\ldots (4.4)$$

where,

S_c = combined or equivalent stress in N/mm² or kg/cm²;

S_x = Stress in 'X' direction N/mm² or kg/cm²;

S_y = Stress in 'Y' direction N/mm² or kg/cm²;

S_s = Shear stress in N/mm² or kg/cm²;

In the above equation due consideration is to be given to proper sign of stresses i.e. compression or tension. Finally $S_c < S_{permissible}$. the values of permissible stresses are given in the IS in terms of S_{yp}. In case of skin plate design S_s is neglected. In considering the thickness of skin plate, due consideration is also given to corrosion allowance. Minimum corrosion allowance is 1.5 mm. The minimum thickness of the skin plate shall not be less than 8 mm, exclusive of corrosion allowance.

4.2.3 Design of (Vertical) Stiffeners

The vertical stiffeners are designed as simply supported beam on horizontal girders as shown in Fig. 4.4.

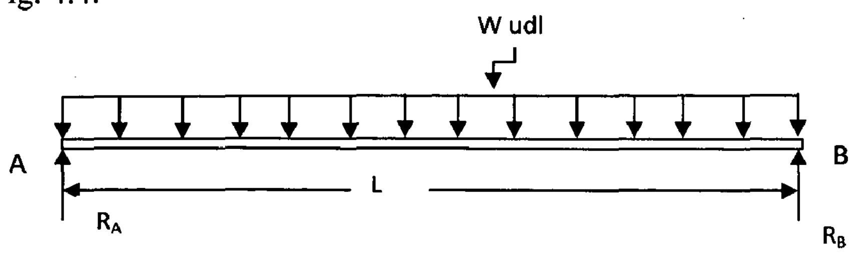


Figure 4.5: Loading diagram of vertical stiffener

Maximum Bending Moment, M= WxL²/8 in kg-cm;

Where,

udl W = P.b in kg/cm;

P = Water pressure in kg/cm²;

B = spacing of vertical stiffeners in cm.

L = spacing of horizontal girders in cm.

Flexural or fibre stress is given by the following formula.

$$f = \frac{M.y}{I} = \frac{M}{Z} \qquad \text{.......................................} \quad (4.5)$$

Where,

Y = distance of the fibre from the neutral axis in cm;

I = Moment of inertia about neutral axis in cm^4;

Z = I/y, section modulus of the section in cm^3.

For taking in to account the section, due consideration is to be given on coacting width of skin plate.

Coacting width can be found; as per ANNEX-'D' page 15 of IS 4622: 1992.and also page 4, art. 5.2.4, coacting width are given by:

i) 40 t + B;

Where, t = thickness of skin plate, and

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

ii) 0.11 span;

iii) Centre to centre of stiffeners of girders;

The least of the above values shall be considered as coacting width.

4.2.4 Design of Horizontal Girder

Number of horizontal girders, spacing or location is already mentioned in the section of design of skin plate. The horizontal girders are designed as simply supported beam on bending as shown in Fig. 4.5.

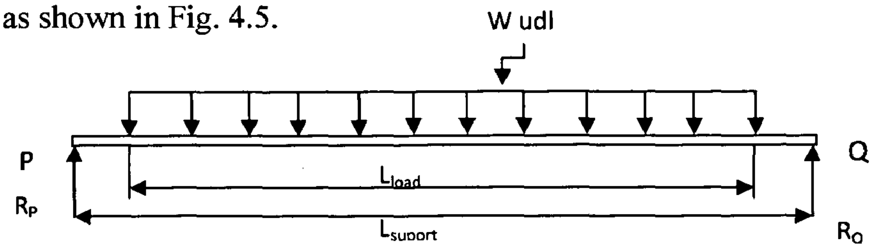


Figure 4.6: Loading diagram of horizontal girder

where,

P = Water pressure in kg/cm^2;

B = width of water pressure on beam in cm;

Then Water load per unit length (udl), $W=PxB$ in kg/cm;

L_{load} = C/C of verticaql seals, load span on beam in cm;

$L_{support}$ = C/C of wheels, support span of the bean in cm;

Reaction force on each support in kg, $R_P = R_Q = WxL_{load}/2$;

l = Offset of load from point P in cm;

x = distance of any point P in cm;

So, B.M at a distance x in kg-cm, $M = R_{P}.x - \{W.(x - l)^2/2\}$;

And max. BM in kg-cm, $M_{max} = R_p.L_{support}/2 - \{W(L_{support}/2 - l)^2/2\}$;

Flexural or fibre stress is given by the following formula.

$$f = \frac{M.y}{I} = \frac{M}{Z} \qquad \text{.. (4.5)}$$

Where,

Y = distance of the fibre from the neutral axis in cm;

I = Moment of inertia about neutral axis in cm^4;

$Z = I/y$, section modulus of the section in cm^3.

For taking in to account the section, due consideration is to be given on coacting width of skin plate as described in the above section.

Maximum deflection of the gate under normal conditions of loading is limited to 1/800 of the span. However, in case of gates with upstream top seals, the maximum deflection of the gate leaf at the top seal should not be more than 80% of the initial interference of the seal.

The actual deflection can be found from the following formula:

$$d_{actual} = \frac{5}{384} \times \frac{WL^4}{E.I} \qquad \text{........................... (4.6)}$$

where, W = load per unit length in kg/cm;

L = supporting span of the girder;

E = modulus of elasticity of the materials in kg/cm^2 and

I = Moment of inertia of the section in cm^4.

4.2.5 Design of Vertical End Girder

Load comes on vertical end girders from the horizontal girders. These girders are supported on wheels. Design is carried out as continuous beam by using any of the methods used for analysis of statistically indeterminate structures viz. theorem of 3 moments or, moment distribution methods in bending, such that maximum bending stress,

$$S_{bending} = \frac{M_{max}}{I} \times \bar{Y} < S_{permissible}$$

Then it is checked for shear as well as bearing stresses.

Also design is to be checked for:

i. Normal operating conditions (when all the wheel touches the track) and

ii. Emergency operating conditions (when one of the wheels is off the track).

For 2nd conditions, permissible stresses are increased by 33% (as per IS clause 6.2). However, before designing of vertical end girders, location of the wheels and tread width of the wheels and pin diameter has to be known.

The location of the wheels is decided by the following design criteria:

a) All wheels should carry equal loads and their physical similarity in wheel diameter etc. can be assumed;

b) Wheel pin should not interfere with the horizontal girder.

In most cases wheels are conventionally located symmetrically on both sides of the horizontal girders. In some cases, the vertical end girders comprise of a flexible arrangement where the girder is discontinuous between adjoining wheel pairs such that the structure is statically determinate.

4.2.6 Design of Wheel

The wheel capacity can be calculated on the basis of the stress in the tread. The product of wheel diameter and net tread width, which can be determined by the following formula, gives the required projected area:

Critical stress (kg/cm^2) on the projected area, $S_c = 1.72$ BHN – 154.93;

Allowable critical stress, $S_{ac} = S_c/sf$, (sf = safety factor, 2 - 3)

Projected area of the wheel = wheel load/allowable critical stress

i.e $A_{pa} = D_w x l_w = P/S_{ac}$;

For an assumed suitable wheel diameter, net tread width can be found or vice versa. Then, wheel to be checked for contact stress. For line contact, contact stress between wheel and track shall be calculated in accordance with the following formula:

$$f_c = 0.418\sqrt{\frac{PE}{r.l}} \qquad \text{.. (4.7)}$$

Where,

f_c = contact stress in N/mm^2 or kg/cm^2;

P = wheel load in N or kg;

E = modulus of elasticity of material in N/mm^2 or kg/cm^2;

r = radius of wheel in mm or cm and

I = tread width of wheel in mm or cm.

The permissible contact stress (as per IS: 4622, 1992, page-18) at the surface of the wheel is given by-

f_{pc} = 1.4 UTS;

4.2.7 Design of Wheel Axle (Shaft)

Usually wheel axle is designed as simply supported beam in bending as follow:

$$S_{bending} = \frac{M_{max}}{I} \times \bar{Y} < S_{permissible}$$

Where,

$S_{bending}$ = bending stress in kg/cm^2.

M_{max} = maximum bending moment in kg-cm;

for shaft, moment of inertia, $I = \pi D^4/_{64}$ in cm^4;

D = diameter of shaft in cm;

$\bar{Y} = D/2$; *and*

$S_{permissible}$ = permissible bending stress in kg/cm^2;

Permissible bending stress, S_{pb} = UTS/3; and

Permissible shear stress, $S_{ps} = 0.6\ S_{pb}$;

Then, it is checked for shear.

4.3 DESIGN COSIDERATION OF THE FIXED WHEEL VERTICAL LIFT GATE FOR UNDER SLUICE OF BHIMGODA BARRAGE

4.3.1 The conventional design calculations of fixed wheel vertical lift gate for under sluice of Bhimgoda barrage is given in Appendix-A.

4.3.2 Design optimization of fixed wheel vertical lift gate for under sluice of Bhimgoda barrage is presented in Appendix-B.

FEM MODEL ANALYSIS, RESULTS & DISCUSSION OF UNDER SLUICE GATE OF BHIMGODA BARRAGE

5.1 INTRODUCTION

There are various finite element software's and ANSYS is one of them. It is a powerful tool in FEM analysis. Any complicated structure can be analyzed suitably by ANSYS. It is reasonably flexible and has multi-physics capabilities i.e. option to analysis in various fields like mechanical, structural, thermal, fluid, electromagnetic etc.

The ultimate purpose of a finite element analysis is to realize the behavior of an actual engineering system. So, the prototype object must be modeled accurately in physical and mathematical sense for accurate results. A physical model consists of geometrical shapes like key points, lines, area and volumes and a mathematical model consists of nodes, elements, real constants and material properties. Therefore, selection of proper element type and feeding of real constant is important. Then, appropriate boundary conditions and loads are applied to represent the physical situation of the system. Convergence of the results is checked with coarse to fine meshes.

In the beginning of analysis, physical modeling technique should be planned out and the elements types should be decided.

A general guideline for deciding the element size is that, where stress/strain gradients are expected to be flat, coarse mesh and where stress/strain gradients are likely to be steeper, fine mesh should be used to get more accurate results.

5.2 SELECTION OF ELEMENTS

Selection of proper element is most important in ANSYS to have desired results.

Table: 5.1: Selections of elements

S.NO.	COMPONENT NAME	ELEMENT TYPE
1	Skin Plate	SHELL 63
2	Vertical Stiffener	BEAM 44
3	Horizontal Girder	BEAM 44
4	End Vertical Girder	BEAM 44
5	Wheel	SOLID 95

5.3 PARTICULARS OF THE SELECTED ELEMENTS

5.3.1 3D Elastic SHELL63 element

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.

5.3.1.1 Input Data SHELL63

The geometry, node locations, and the coordinate system for this element are shown in Figure 5.1 the element is defined by four nodes, four thicknesses, an elastic foundation stiffness, and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate 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 x and z axes.

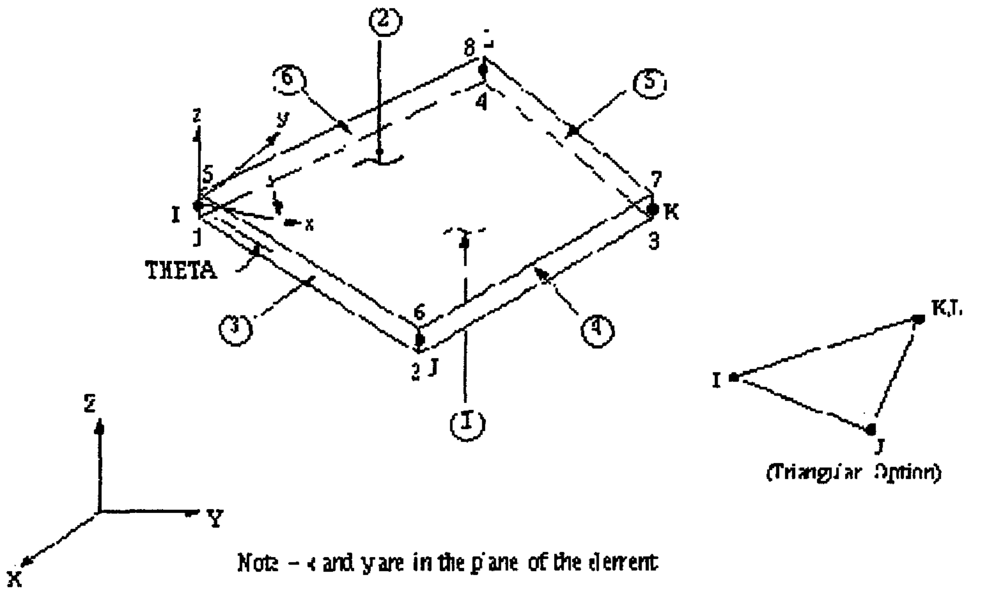


Figure 5.1 3D Elastic shell 63 Elements

5.3.1.2 Output Data SHELL63

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 5.2

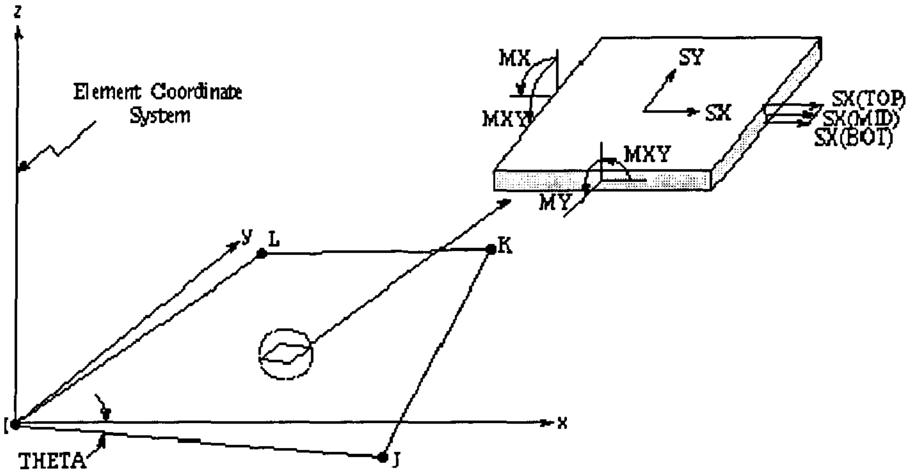


Figure 5.2 Shell 63 stress output

5.3.1.3 Assumptions and Retractions for SHELL63

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.

5.3.1.4 Shape function for 3D4- Node quadrilateral shells

These shape functions are for 3-D 4-node quadrilateral shell elements with RDOF but without shear deflection and with extra shape functions, such as SHELL63 with KEYOPT (3) = 0 when used as a quadrilateral:

$$u = \frac{1}{4}(u_I(1-s)(1-t) + u_J(1+s)(1-t)$$
$$+ u_K(1+s)(1+t) + u_L(1-s)(1+t))$$
$$+ u_1(1-s^2) + u_2(1-t^2) \quad \text{------------ (5.1)}$$

$$v = \frac{1}{4}(v_I(1-s) \ldots \text{(analogous to u)} \quad \text{------------ (5.2)}$$

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

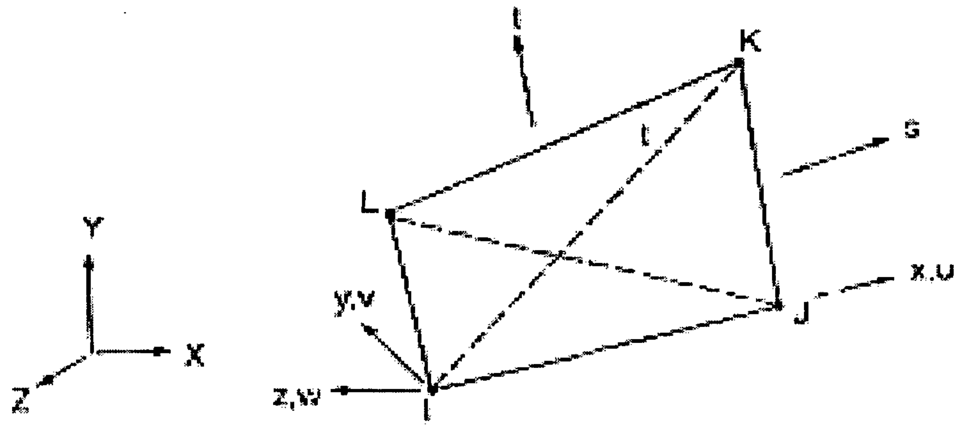


Figure 5.3 shape function

5.3.1.5 Stiffness matrix for 3D4- Node quadrilateral shells

The stiffness matrix vector for membrane stress having quadrilateral geometry the shape functions equations used are (5.1) and (5.2) having point of integration 2x2. For bending four triangles that are overlaid are used. There sub triangles are referred to equation (5.3) and point of integration in 3 (for each triangle).

5.3.1.6 Numerical integration for 3D4- Node quadrilateral shells

The numerical integration that ANSYS uses is given below.

For 4-Noded shell elements(2x2 or 3x3)

The numerical integration of shell element is given by

$$\int_{-1}^{1}\int_{-1}^{1} f(x,y)dxdy = \sum_{j=1}^{m}\sum_{i=1}^{l} H_j H_i f(x_i y_j) \qquad \text{--------------------- (5.3)}$$

Where,

f(xy)=function to be itegrated;

Hi,Hj=weighing factors and

1,m=number of integration (Gaussian points).

Table: 5.2 Gauss integration constants:

No. of Int. Points	Integration Point Locations	Weighting Factor (Hi)
1	0.00000 00000 00000	2.00000 00000 00000
2	±0.57735 02691 89626	1.00000 00000 00000
3	±0.77459 66692 41483	0.55555 55555 55555
	0.00000 00000 00000	0.88888 88888 88889

5.3.2 BEAM44 Three-Dimensional Tapered Unsymmetric Beam

Beam44 as shown in figure 5.4 has been selected for meshing of horizontal girders, vertical end girders and vertical stiffeners of the fixed wheel vertical lift gate. It is a uniaxial element with tension, compression, torsion and bending capabilities. The element is defined by two or three nodes I, J and K(optional) and it allows a different unsymmetrical geometry at each node. The element has six degrees of freedom at each node: other properties and capabilities are already mentioned at the time of element selection.

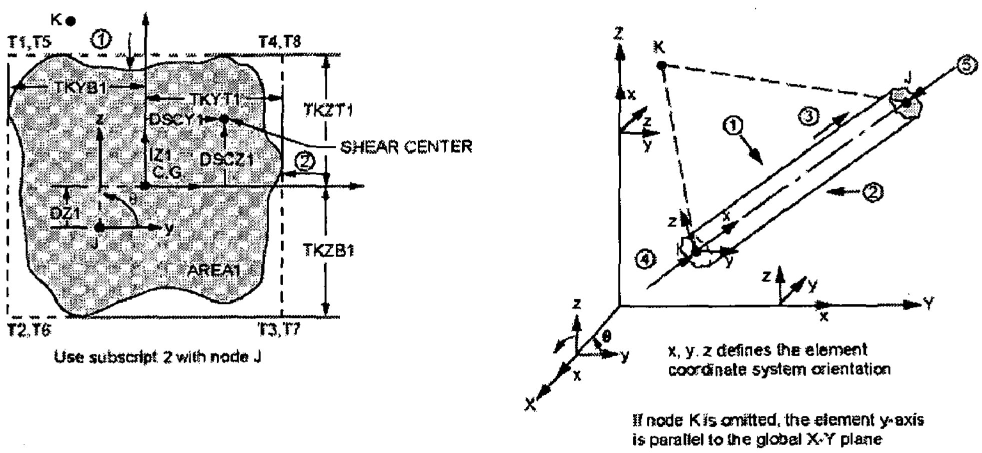


Figure 5.4 BEAM44 Three-Dimensional Tapered Unsymmetric Beam

5.3.2.1 Input data for BEAM44

The geometry, node locations, and the coordinate system for this element are shown in Figure 4.4. The element is located by a reference coordinate system (x', y', z') and offsets. The reference system is defined by nodes I, J, and K, or an orientation angle, as shown in Figure 5.4.The principal axes of the beam are in the element coordinate system (x, y, z) with x along the cross-section centroid (C.G.).

The element x-axis is oriented from node I (end 1) toward node J (end 2). For the two-node option, the default (θ=0°) orientation of the element y-axis is automatically calculated to be parallel to the global X-Y plane.

Table5.3 Input data summary for BEAM44

Element Name	BEAM44
Nodes	I, J, K (K orientation node is optional)
Degrees of Freedom	UX, UY, UZ, ROTX, ROTY, ROTZ
Real Constants	AREA1, IZ1, IY1, TKZB1, TKYB1, IX1,AREA2, IZ2, IY2, TKZB2, TKYB2, IX2,DX1, DY1, DZ1, DX2, DY2, DZ2,SHEARZ, SHEARY, TKZT1, TKYT1, TKZT2, TKYT2 The element real constants describe the beam in terms of the cross-sectional area, the area moments of inertia, the extreme fiber distance from the centroid, the centroid offset, and the shear constants. If any values at end J are blank, default to the corresponding end I
Material Properties	EX, ALPX, DENS, GXY, DAMP
Surface Loads	Pressures: face 1 (I-J) (-Z normal direction), face 2 (I-J) (-Y normal direction), face 3 (I-J) (+X tangential direction), face 4 (I) (+X axial direction), face 5 (J) (-X axial direction) (use negative value for opposite loading)

5.3.2.2 Output data for BEAM44

The solution output associated with the element is in two forms:

- nodal displacements included in the overall nodal solution
- additional element output as shown in Table 5.4

Several items are illustrated in Figure 5.5 at each cross-section; the computed output consists of the direct (axial) stress and four bending components. Then these five values are combined to evaluate maximum and minimum stresses, assuming a rectangular cross-section.
UX, UY and UZ are deflection in X, Y and Z directions respectively. In the present analysis deflection in Z direction is important and a matter of concern.

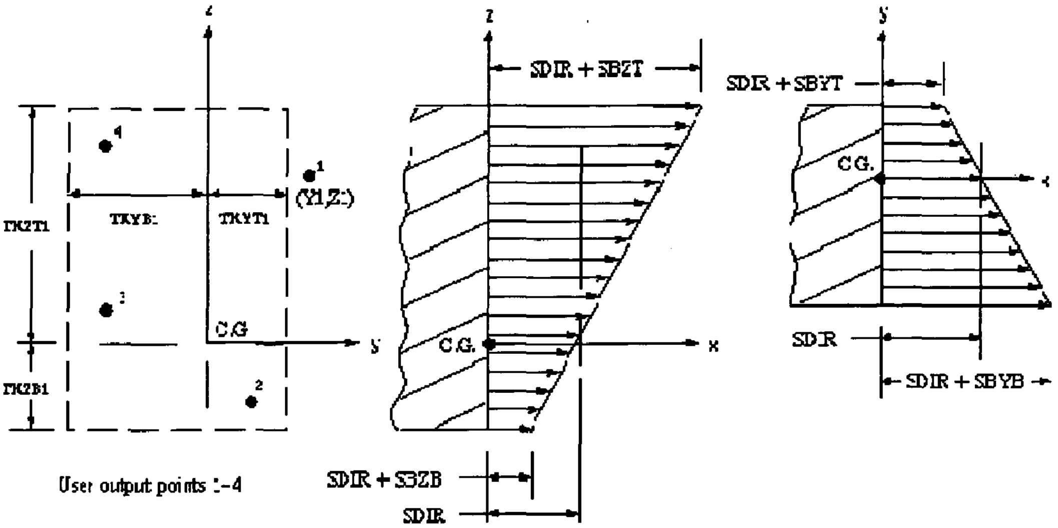


Figure5.5 BEAM44 stress Output.

TABLE:5.4 BEAM44 Element Output Definitions(partial);

Name	Definition	O	R
SDIR	Axial direct stress	1	1
SBYT	Bending stress on the element -Y side of the beam	1	1
SBZT	Bending stress on the element +Z side of the beam	1	1
SBZB	Bending stress on the element -Z side of the beam	1	1
SMAX	Maximum stress (direct stress + bending stress)	1	1
SMIN	Minimum stress (direct stress - bending stress)	1	1
MFOR(X,Y,Z)	Member forces in the element coordinate system X, Y, Z directions	1	1
MMOM(X, Y, Z)	Member moments in the element coordinate system X, Y, Z directions	1	1

For element definition table results, we have to define element table with different key options item and sequence nos.

Table: 5.5 BEAM44 (KYEOPT (9)=0) Item and sequence numbers for the ETABLE and ESOL commands:

KYEOPT (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
MFORX	SMISC		1	7
MFORY	SMISC		2	8
MFORZ	SMISC		3	9
MMOMX	SMISC		4	10
MMOMY	SMISC		5	11
MMOMZ	SMISC		6	12
SXY	SMISC		13	16

5.3.2.3 Assumptions and restrictions for beam elements

- The beam must not have a zero length, area, or moment of inertia.
- Because shear area is not calculated when using section properties to create BEAM44, no shear stresses will be output. Use of BEAM188 or BEAM189 are used to output and visualize shear stresses.
- The element thicknesses are used for locating the extreme fibers for the stress calculations.
- Tapers within an element, if any, should be gradual. If AREA2/AREA1 or I_2/I_1 is not between 0.5 and 2.0, a warning message is output. If the ratio is outside of the range of 0.1 to 10.0, an error message is output. The element should not taper to a point (zero thickness).
- The shear stresses are calculated based on the shear force rather than the shear deflection

5.3.2.4 Shape functions for beam elements

These shape functions as shown in figure 5.6 for 3-D 2-node line elements with RDOF, such as BEAM44.

$$u = \frac{1}{2}(u_I(1-s) + u_J(1+s)) \tag{5.4}$$

$$\begin{aligned} v = {} & \frac{1}{2}\left(v_I\left(1 - \frac{s}{2}(3-s^2)\right) + v_J\left(1 + \frac{s}{2}(3-s^2)\right)\right) \\ & + \frac{L}{8}(\theta_{z,I}(1-s^2)(1-s) - \theta_{z,J}(1-s^2)(1+s)) \end{aligned} \tag{5.5}$$

$$\begin{aligned} w = {} & \frac{1}{2}\left(w_I\left(1 - \frac{s}{2}(3-s^2)\right) + w_J\left(1 + \frac{s}{2}(3-s^2)\right)\right) \\ & - \frac{L}{8}(\theta_{y,I}(1-s^2)(1-s) - \theta_{y,J}(1-s^2)(1+s)) \end{aligned} \tag{5.6}$$

$$\theta_x = \frac{1}{2}(\theta_{x,I}(1-s) + \theta_{x,J}(1+s)) \tag{5.7}$$

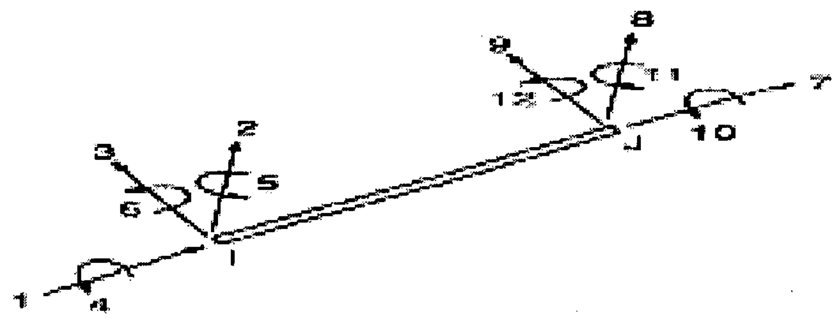


Figure 5.6 BEAM44 shape function

The stiffness matrix is derived from the shape function equations (5.4), (5.5), (5.6) and (5.7). The stress stiffness matrix is derived using equations (5.5) and 5.6), and load vector (pressure) using equations (5.4), (5.5) and (5.6).

5.3.2.5 Stiffness matrix for beam elements

A 3-D beam element has 6 DOF at each node, and 12 DOF for each element. The stiffness matrix can be derived by super-imposing the axial, bending, and torsion loadings in the XY, XZ, and YZ planes. The equation is, (Przemieniecki (28)).

$$
\underline{k} = \left[\begin{array}{cccccc|cccccc}
\frac{AE}{L} & 0 & 0 & 0 & 0 & 0 & -\frac{AE}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} & 0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} \\
0 & 0 & \frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 & 0 & 0 & -\frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 \\
0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 & 0 & 0 & 0 & -\frac{GJ}{L} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L} & 0 & -\frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} \\
\hline
-\frac{AE}{L} & 0 & 0 & 0 & 0 & 0 & \frac{AE}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} & 0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} \\
0 & 0 & -\frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 & 0 & 0 & \frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 \\
0 & 0 & 0 & -\frac{GJ}{L} & 0 & 0 & 0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} & 0 & -\frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L}
\end{array}\right] \tag{5.8}
$$

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

5.3.2.6 Stress calculation for BEAM44

The axial stresses are computed analogously to BEAM44 as below:

Centroidal stress is given by:

$$\sigma_i^{dir} = \frac{F_{x,i}}{A} \qquad \text{---------------} (5.9)$$

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

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

The bending stresses are given by:

$$\sigma_{z,i}^{bnd} = \frac{M_{y,i}}{2I_y} t_z \qquad \text{--------------} (5.10)$$

$$\sigma_{y,i}^{bnd} = \frac{M_{z,i}}{2I_z} t_y \qquad \text{--------------} (5.11)$$

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 y direction on the element –y side of the beam at end I (Output quantity SBY)

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

$M_{z,i}$ = moments 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 stress at cross-section i is computed by:

$$\sigma_i^{\max} = \max imum\_of \begin{Bmatrix} \sigma_i^{dir} + & \sigma_{zt,i}^{bnd} + & \sigma_{yt,i}^{bnd} \\ \sigma_i^{dir} + & \sigma_{zt,i}^{bnd} + & \sigma_{yb,i}^{bnd} \\ \sigma_i^{dir} + & \sigma_{zb,i}^{bnd} + & \sigma_{yb,i}^{bnd} \\ \sigma_i^{dir} + & \sigma_{zb,i}^{bnd} + & \sigma_{yt,i}^{bnd} \end{Bmatrix} \quad \text{---------} (5.12)$$

Where,

$$\sigma^{dir} = output\_quantity\_SDIR$$

$$\sigma_{yt}^{bnd} = output\_quantity\_SBYT$$

$$\sigma_{yb}^{bnd} = output\_quantity\_SBYB$$

$$\sigma_{zt}^{bnd} = output\_quantity\_SBZT$$

$$\sigma_{zb}^{bnd} = output\_quantity\_SBZB$$

The minimum stress is analogously defined.

The assumption has been made that the cross-section is a rectangle, so that maximum and minimum stresses occur at the extreme fibers.

5.3.3 SOLID95 - 3-D 20-Node Structural Solid

The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element may have any spatial orientation. The element has plasticity, creep, stress stiffening, large deflection, and large strain capabilities.

5.3.3.1 SOLID95 Input Data

The geometry, node locations, and the coordinate system for this element are shown in Figure 5.7. A prism-shaped element may be formed by defining the same node numbers for nodes K, L, and S; nodes A and B; and nodes O, P, and W. A tetrahedral-shaped element and a pyramid-shaped element may also be formed as shown in Figure 5.7

Nodes	:	I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z, A, B
Degrees of Freedom	:	UX, UY, UZ
Real Constants	:	None
Material Properties	:	EX, PRXY, DENS.....etc.
Pressures	:	face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P)

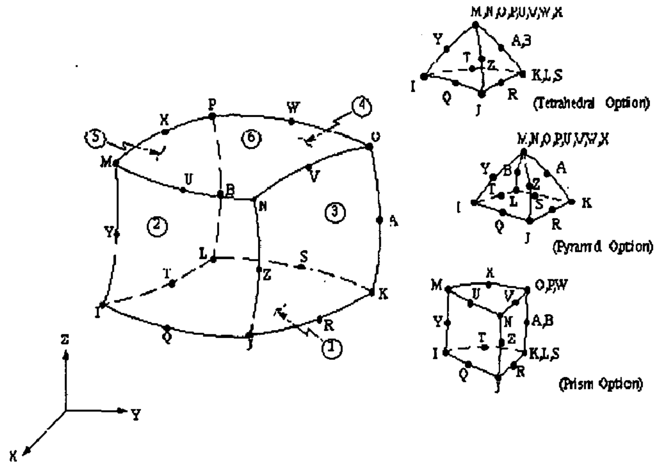


Figure 5.7 SOLID95 3-D 20-Nodes Brick Structural Solid

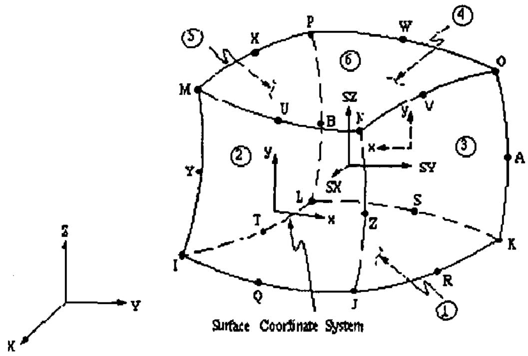


Figure 5.8 SOLID95 Stress Output

5.3.3.2 SOLID95 Output Data

The element stress directions are parallel to the element coordinate system. The surface stress outputs are in the surface coordinate systems and are available for any face (KEYOPT(6)). The coordinate systems for faces IJNM and KLPO are shown in Figure 5.8. The other surface coordinate systems follow similar orientations as indicated by the pressure face node description.

5.3.3.3 Assumption and restrictions for SOLID95

The element must not have a zero volume. Also, the element may not be twisted such that the element has two separate volumes. This occurs most frequently when the element is not numbered properly. Elements may be numbered either as shown in Figure 5.7 or may have the planes IJKL and MNOP interchanged. An edge with a removed midside node implies that the displacement varies linearly, rather than parabolically, along that edge.

5.3.3.4 Shape function for SOLID95

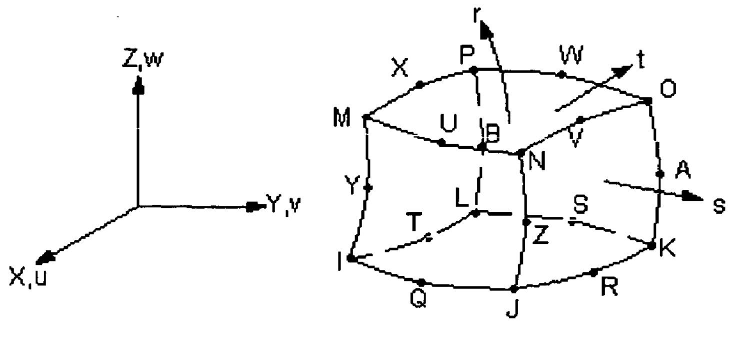


Figure 5.9: 8 Node Brick Element

These shape functions are used for 20 node solid elements such as SOLID95.

$$
\begin{aligned}
u = \frac{1}{8}(& u_I(1-s)(1-t)(1-r)(-s-t-r-2) + u_J(1+s)(1-t)(1-r)(s-t-r-2) \\
&+ u_K(1+s)(1+t)(1-r)(s+t-r-2) + u_L(1-s)(1+t)(1-r)(-s+t-r-2) \\
&+ u_M(1-s)(1-t)(1+r)(-s-t+r-2) + u_N(1+s)(1-t)(1+r)(s-t+r-2) \\
&+ u_O(1+s)(1+t)(1+r)(s+t+r-2) + u_P(1-s)(1+t)(1+r)(-s+t+r-2)) \\
&+ \frac{1}{4}(u_Q(1-s^2)(1-t)(1-r) + u_R(1+s)(1-t^2)(1-r) \\
&+ u_S(1-s^2)(1+t)(1-r) + u_T(1-s)(1-t^2)(1-r) \\
&+ u_U(1-s^2)(1-t)(1+r) + u_V(1+s)(1-t^2)(1+r) \\
&+ u_W(1-s^2)(1+t)(1+r) + u_X(1-s)(1-t^2)(1+r) \\
&+ u_Y(1-s)(1-t)(1-r^2) + u_Z(1+s)(1-t)(1-r^2) \\
&+ u_A(1+s)(1+t)(1-r^2) + u_B(1-s)(1+t)(1-r^2))
\end{aligned}
\qquad \text{------------------------ (5.13)}
$$

$$v = \frac{1}{8}(v_I(1-s)\ldots \text{(analogous to u)} \qquad \text{----------------------- (5.14)}$$

$$w = \frac{1}{8}(w_I(1-s)\ldots \text{(analogous to u)} \qquad \text{----------------------- (5.15)}$$

5.3.3.5 Stiffness, stress and pressure load matrices

The stiffness matrix, stress stiffness matrix, mass matrix are derived using shape function equations (5.13), (5.14) and (5.15) with 4 points of integration, and pressure load vector is also derived using the same equations with 3 point of integration.

5.4 ANSYS PROCEDURE OUTLINE

The ANSYS program has finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, non-linear, transient dynamic analysis in Multiphysics, Mechanical, Structural, Fluid, Thermal, Electro-magnetic etc.

A typical ANSYS analysis has three distinct steps:

i. Building the model
ii. Applying loads and obtaining the solution, and
iii. Reviewing the results.

i) Building the Model:

Building a finite element model requires more time than any other part of the analysis. This is carried out by the use of the ANSYS **PREP7** preprocessor. It includes:

- Specifying a **Job name** and **Analysis Title**;
- Setting **preference**;
- Define **element type**;
- Defining element **real constants**;
- Defining **material properties** and
- Creating the model geometry:
  - -describing the geometric shape of the model, and
  - -meshing the geometry with nodes and elements.

ii) Applying Loads and Obtaining the Solution:

In this step, the following tasks are carried out by the use of the ANSYS **SOLUTION** processor-

- Defining the Analysis type and Analysis Options;
- Applying Boundary Conditions i.e. displacement constraints;
- Applying Loads;
- Specifying Load Step Option (if needed) and
- Initiating the Solution.

iii) Reviewing the Results:

In this step, by the use of the ANSYS general Postprocessor we get:

- Deformed shapes;
- Contour display of results;
- Tabular listings to review and interpret the results of the analysis.

5.4.1 Setting Preference

In ANSYS, versatile elements are available in two-dimensional and three-dimensional analyses. In the present works, following element types are used:

For gate: -

Skin plate	:	**SHEL63** three-dimensional Elastic Shell;
Girders and stiffeners	:	**BEAM44** three-dimensional Elastic Tapered Unsymmetric Beam;
Wheel	:	**SOLID95** 3-D Structural Solid

5.4.2 Defining Real Constants

In ANSYS, depending on the element type, real constant sets are prescribed. These consist of different geometrical properties such as cross sectional area, moment of inertia, added mass per unit length, initial strain etc. thickness of element at different nodes etc.

Real constant sets used in the present work:

(a) SKIN PLATE:

Table:5.6 Real constant sets for skin plate

	SET NO.	NODE(I,J,K,L)	ELEMENT TYPE	CTOP AND CBOT
TOP UNIT	1	0.8 cm	Shell 63	0.4
BOT. UNIT	2	1.2 cm	Shell 63	0.6

(b) VERTICAL STIFFENERS

Table: 5.7 Real constant sets for vertical stiffeners

	SET NO.	A_1 (cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)
PANAL A	3	23.92	609.01	170.33	7.93	10.45	1.87	10.45
PANAL B	4	15.47	74.08	141.47	7.12	5.17	2.68	5.17
PANAL C	5	32.5	506.68	719.77	10.58	9.82	4.22	9.82
PANAL D	6	32.41	362.49	690.25	11.32	7.67	3.88	7.67
PANAL E	7	24.92	150.32	540.84	11.19	5.72	4.01	5.72
PANAL F	8	23.27	102.56	520.04	10.94	5.03	4.26	5.03

(c) END VERTICAL GIRDERS

Table: 5.8 Real constant sets for end vertical girder.

	SET NO.	A_1 (cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)
	63	219.8	1398.32	203672.18	54.09	12	42.61	12

(d) SPLICE JOINTS

Table: 5.9 Real constant sets for end splice joints

	SET NO.	A_1(cm)	I_{zz}(cm^4)	I_{yy}(cm^4)	TK_{ZB}(cm)	TK_{YB}(cm)	TK_{ZT}(cm)	TK_{YT}(cm)
	64	23	229.417	198.873	1.95	7	8.05	7

(e) BOTTOM HORIZONTAL GIRDER

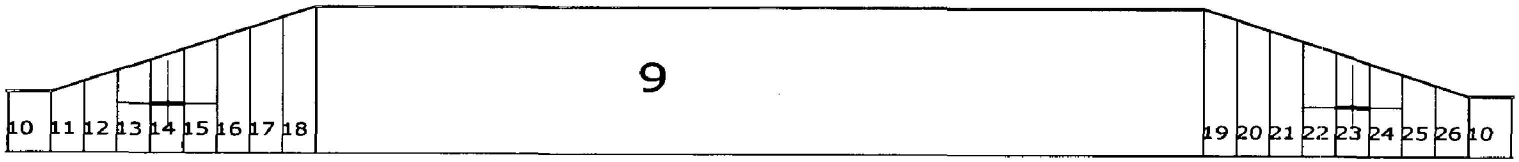


Figure 5.10: Real constant set for bottom horizontal girder

Table: 5.10 Real constant sets for bottom horizontal girder

SET NO.	NODE-I							NODE-J						
	A_1 (cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)	A_2(cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)
9	896.8	990988.16	9107032.1	119.73	105	121.47	105							
10	504.1	960775	947593	61.05	105	38.15	105							
11	504.1	960775	947593	61.05	105	38.15	105	524.5	960778	1330000	70.99	105	45.21	105
12	524.5	960778	1330000	70.99	105	45.21	105	545.5	960780	1810000	81.1	105	52.6	105
13	545.5	960780	1810000	81.1	105	52.6	105	566.5	960783	2360000	91.12	105	60.08	105
14	566.5	960783	2360000	91.12	105	60.08	105	587.5	960785	3000000	101.04	105	67.66	105
15	587.5	960785	3000000	101.04	105	67.66	105	608.5	960788	3730000	110.88	105	75.32	105
16	608.5	960788	3730000	110.88	105	75.32	105	629.5	960790	4550000	120.65	105	83.05	105
17	629.5	960790	4550000	120.65	105	83.05	105	671.5	960795	6482928	140	105	98.70	105
18	671.5	960795	6482928	140	105	98.70	105	896.8	990988.1	9107032.1	119.73	105	121.4	105
19	896.8	990988.16	9107032.1	119.73	105	121.47	105	671.5	960795	6482928	140	105	98.70	105
20	671.5	960795	6482928	140	105	98.70	105	629.5	960790	4550000	120.65	105	83.05	105
21	629.5	960790	4550000	120.65	105	83.05	105	608.5	960788	3730000	110.88	105	75.32	105
22	608.5	960788	3730000	110.88	105	75.32	105	587.5	960785	3000000	101.04	105	67.66	105
23	587.5	960785	3000000	101.04	105	67.66	105	566.5	960783	2360000	91.12	105	60.08	105
24	566.5	960783	2360000	91.12	105	60.08	105	545.5	960780	1810000	81.1	105	52.6	105
25	545.5	960780	1810000	81.1	105	52.6	105	524.5	960778	1330000	70.99	105	45.21	105
26	524.5	960778	1330000	70.99	105	45.21	105	504.1	960775	947593	61.05	105	38.15	105

(f) INTERMEDIATE HORIZONTAL GIRDER

Figure 5.11 Real constant set for intermediate horizontal girder

SET NO.	NODE-I							NODE-J						
	A_1 (cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)	A_2(cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)
27	879	478293.8	9701778	129.95	165	111.25	165							
28	648.1	3630000	1110000	69.4	165	29.8	165							
29	648.1	3630000	1110000	69.4	165	29.8	165	668.5	3630000	1560000	80.6	165	35.6	165
30	668.5	3630000	1560000	80.6	165	35.6	165	689.5	3630000	2110000	91.96	165	41.74	165
31	689.5	3630000	2110000	91.96	165	41.74	165	710.5	3630000	2770000	103.17	165	48.03	165
32	710.5	3630000	2770000	103.17	165	48.03	165	731.5	3630000	3520000	114.24	165	54.46	165
33	731.5	3630000	3520000	114.24	165	54.46	165	752.5	3630000	4380000	125.18	165	61.02	165
34	752.5	3630000	4380000	125.18	165	61.02	165	773.5	3630000	5350000	136	165	67.7	165
35	773.5	3630000	5350000	136	165	67.7	165	795.1	3630000	6460000	147	165	74.7	165
36	795.1	3630000	6460000	147	165	74.7	165	879	478293.8	9701778	129.95	165	111.25	165
37	879	478293.8	9701778	129.95	165	111.25	165	795.1	3630000	6460000	147	165	74.7	165
38	795.1	3630000	6460000	147	165	74.7	165	773.5	3630000	5350000	136	165	67.7	165
39	773.5	3630000	5350000	136	165	67.7	165	752.5	3630000	4380000	125.18	165	61.02	165
40	752.5	3630000	4380000	125.18	165	61.02	165	731.5	3630000	3520000	114.24	165	54.46	165
41	731.5	3630000	3520000	114.24	165	54.46	165	710.5	3630000	2770000	103.17	165	48.03	165
42	710.5	3630000	2770000	103.17	165	48.03	165	689.5	3630000	2110000	91.96	165	41.74	165
43	689.5	3630000	2110000	91.96	165	41.74	165	668.5	3630000	1560000	80.6	165	35.6	165
44	668.5	3630000	1560000	80.6	165	35.6	165	648.1	3630000	1110000	69.4	165	29.8	165

Table: 5.11 Real constant sets for intermediate horizontal girder

(g) TOP HORIZONTAL GIRDER

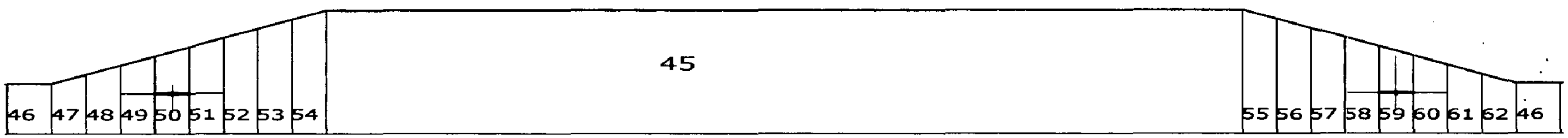


Figure 5.12 real constant set for top horizontal girder

Table: 5.12 Real constant sets for top horizontal girder

SET NO.	NODE-I							NODE-J						
	A_1 (cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)	A_2(cm)	I_{ZZ} (cm^4)	I_{YY}(cm^4)	TK_{ZB} (cm)	TK_{YB} (cm)	TK_{ZT} (cm)	TK_{YT} (cm)
45	570	1806434	4405161	158.4	150	78.6	150							
46	404.6	1810000	565990	73.02	150	26.18	150							
47	404.6	1810000	565990	73.02	150	26.18	150	425.04	1810000	816005	84.25	150	31.95	150
48	425	1810000	816005	84.25	150	31.95	150	446.04	1810000	1130000	95.54	150	38.16	150
49	446	1810000	1130000	95.54	150	38.16	150	467.04	1810000	1510000	106.61	150	44.59	150
50	467	1810000	1510000	106.61	150	44.59	150	488.04	1810000	1960000	117.47	150	51.23	150
51	488	1810000	1960000	117.47	150	51.23	150	509.04	1810000	2470000	128.17	150	58.03	150
52	509	1810000	2470000	128.17	150	58.03	150	530.04	1810000	3060000	138.7	150	65	150
53	530	1810000	3060000	138.7	150	65	150	551.64	1810000	3750000	149.4	150	72.3	150
54	551.6	1810000	3750000	149.4	150	72.3	150	570	1806434	4405161	158.4	150	78.6	150
55	570	1806434	4405161	158.4	150	78.6	150	551.64	1810000	3750000	149.4	150	72.3	150
56	551.6	1810000	3750000	149.4	150	72.3	150	530.04	1810000	3060000	138.7	150	65	150
57	530	1810000	3060000	138.7	150	65	150	509.04	1810000	2470000	128.17	150	58.03	150
58	509	1810000	2470000	128.17	150	58.03	150	488.04	1810000	1960000	117.47	150	51.23	150
59	488	1810000	1960000	117.47	150	51.23	150	467.04	1810000	1510000	106.61	150	44.59	150
60	467	1810000	1510000	106.61	150	44.59	150	446.04	1810000	1130000	95.54	150	38.16	150
61	446	1810000	1130000	95.54	150	38.16	150	425.04	1810000	816005	84.25	150	31.95	150
62	425	1810000	816005	84.25	150	31.95	150	404.64	1810000	565990	73.02	150	26.18	150

(h) Real constant set for **Wheel SOLID92 element:** not required

5.4.3 Defining Material Properties

In ANSYS available material properties options are:

Constant:

Isotropic;

Orthotropic;

Temp dependent:

Linear;

Nonlinear;

Defined material properties under study in **Isotropic**:

i. For gate made of Structural Steel:

Young's modulus, EX=2.01x10^6 kg/cm^2;

Poisson's ratio, NUXY=0.27;

Density of material, DENS=0.00785 kg/cm^3.

ii. For Wheel made of Cast Steel IS 1030-1998, Grade C:

Young's modulus, EX=2.10x10^6 kg/cm^2;

Poisson's ratio, NUXY=0.27;

Density of material, DENS=0.00785 kg/cm^3.

5.4.4 Creating the solid model geometry

The ultimate purpose of a finite element analysis is to re-create mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. In the broadest sense, this model comprises of all the nodes, element, material properties, real constants, boundary conditions, and other features that are used to represent the physical system. In ANSYS terminology, Model generation mean the process of defining the geometric configuration of the model's nodes and elements. The ANSYS program has the following approaches for model creation:

a) Creating a solid model within ANSYS;

b) Using direct generation and

c) Importing a model created in a CAD system;

a) Creating a solid model within ANSYS

In this approach, solid model can be created either by Bottom up or Top down techniques.

Bottom up means creation of solid model entities from lowest order to higher order i.e. 1^{st}. create keypoints, then use those keypoints to define lines, then areas by lines, and then volumes by areas.

Top down means generation of model using geometric primitives, which are fully defined lines, areas, and volumes. If a primitive is created, the program automatically creates all the 'lower' entities associated with it.

b) Using direct generation

Direct generation is the approach in which we can define the nodes and elements of a model directly. In some cases, this approach is suitable but usually it is inconvenient since it commonly require about ten times as many data entities to define a model as compared to solid modeling.

c) Creation of solid model geometry in the present study

For the VL gate and wheel both the models are created by bottom up approach.

Model of VL gate is shown in figure 5.13 and model of wheel is shown in figure 5.14.

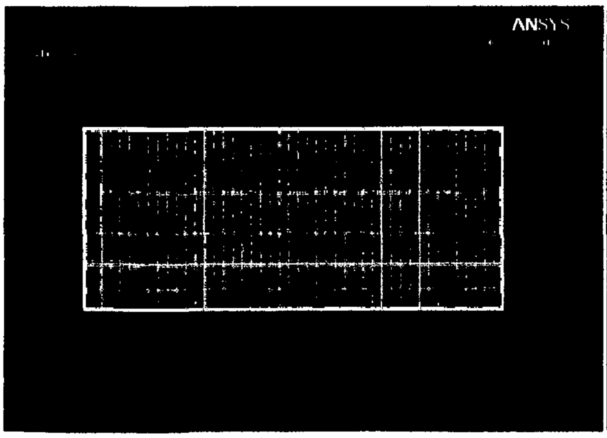


Figure 5.13 Model for VL gate

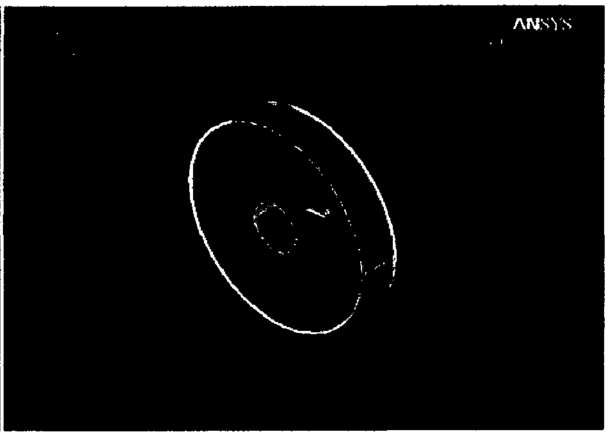


Figure 5.14 Model for wheel

5.4.5 Meshing the Solid Model Geometry

Gate: mesh sizes are controlled by setting number of divisions on the lines manually, and then areas or volume and appropriate lines are free meshed. As shown in figure 5.15.

Wheel: setting suitable control size by manual by picking all line and dividing each line in 10 no. of division and then using sweep command, the whole volume is free meshed, as shown in figure 5.16.

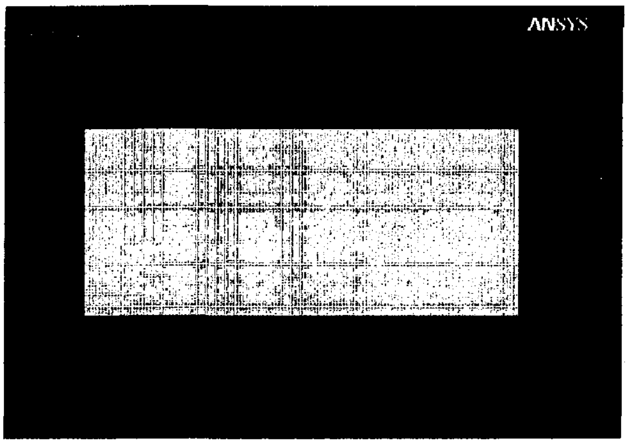


Figure 5.15 Mesh model for VL gate

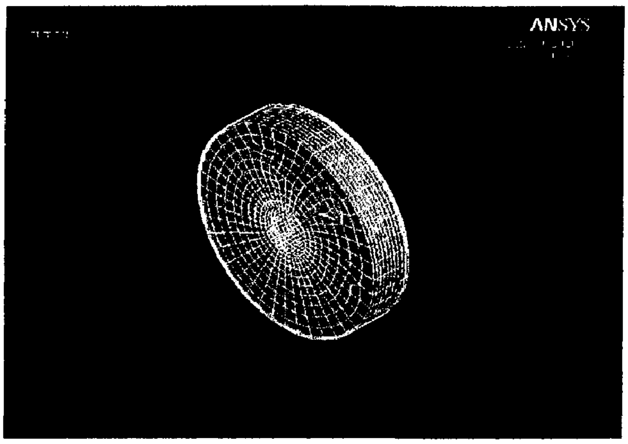


Figure 5.16 Mesh model for wheel

5.4.6 Applying Loads on the Model

The main goal of a finite element analysis is to examine how a structure responds to certain loading conditions. Specifying the proper loading condition is, therefore, a key step in the analysis. We can apply loads either on the solid model (on keypoints, lines, area) or on the finite element model (on nodes and elements).

The word loads as used in ANSYS includes boundary conditions (DOF constraints) as well as other externally and internally applied loads. They are divided into six categories:

- DOF constraints (like UX, RX...);
- Forces (such as concentrated loads);
- Body loads (such as gravity loads);
- Inertia loads (like inertia due to motion) and
- Coupled field loads

Applying loads on the model in the present study:

a) Boundary conditions and pressure applied for gate model:

for six nodes located at the wheel fixation points of the left hand side on the vertical end girder where UX, UY and UZ=0; and six nodes on the other side at the same location UY and UZ =0; which are shown in figure 5.17.

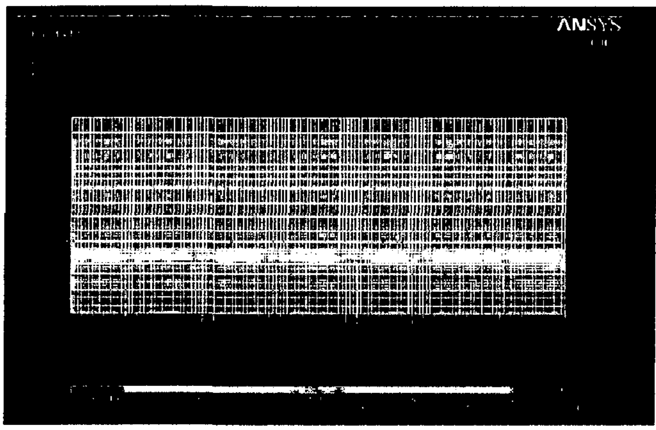


Figure 5.17 Boundary conditions and pressure applied on the GATE model

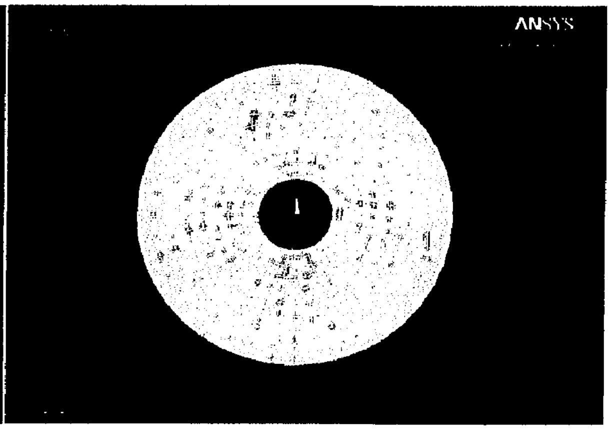


Figure 5.18 Boundary conditions and pressure applied on the WHEEL model

A hydrostatic pressure 0.84 kg/cm^2 is applied on the skin plate's SHELL63 elements (face-1) between the two vertical side seals which are shown in figure 5.17 .
The total water load on the gate comes to(0.84x840x1813/2)=639626 kg

b) Boundary conditions pressure applied for wheel model:

For the bottom and intermediate unit: On the bottom contact line, for the most left node UX, UY and UZ =0; Load on each wheel is 69959 kg. this load is coming from shaft-bearing on the wheel. It is assumed that this load will act on the bottom half area under the bearing on the wheel. So that 489.22 kg/cm^2 applied on the bottom half area of the wheel which are shown in figure 5.18.

For the top unit: On the bottom contact line, for the most left node UX, UY and UZ =0; Load on each wheel is 20397 kg. this load is coming from shaft-bearing on the wheel. It is assumed that this load will act on the bottom half area under the bearing on the wheel. So that 323.76 kg/cm^2 applied on the bottom half area of the wheel.

5.4.7 Comparison of Reactions and Applying Loads on the gate:

```
***** POST1 TOTAL REACTION SOLUTION LISTING *****

  LOAD STEP=      0  SUBSTEP=     1
   TIME=    1.0000       LOAD CASE=   0

  THE FOLLOWING X,Y,Z SOLUTIONS ARE IN THE GLOBAL COORDINATE SYSTEM

    NODE       FX            FY           FZ           MX           MY
MZ
     110                  0.0000
     113                  0.0000
     116                  0.0000
     119                  0.0000
     122                  0.0000
     125                  0.0000
     128                  0.0000
     131                  0.0000
     134                  0.0000
    1226   0.0000         0.0000      -12621.
    1227   0.0000         0.0000      -37500.
    1232   0.0000         0.0000      -39226.
    1233   0.0000         0.0000      -86606.
    1238   0.0000         0.0000      -48462.
    1239   0.0000         0.0000      -91613.
    1946                  0.0000      -12692.
    1947                  0.0000      -37411.
    1952                  0.0000      -35585.
    1953                  0.0000      -86634.
    1958                  0.0000      -48196.
    1959                  0.0000      -92793.

 TOTAL VALUES
 VALUE     0.0000       0.0000     -0.62934E+06  0.0000       0.0000
0.0000
```

The total value of the reaction is 1.6% less than the applied total loads that is within acceptable limit <=10%. The comparison indicates that the loads applied on the model have been correctly incorporated.

5.4.8 Comparison of Reactions and Applying Loads on the wheel:

For the bottom and intermediate unit:

```
      PRINT REACTION SOLUTIONS PER NODE
***** POST1 TOTAL REACTION SOLUTION LISTING *****
         LOAD STEP=      1  SUBSTEP=     1
          TIME=    1.0000       LOAD CASE=   0
THE FOLLOWING X,Y,Z SOLUTIONS ARE IN THE GLOBAL COORDINATE SYSTEM
```

NODE	FX	FY	FZ
3821	-0.18038	8536.7	-632.51
3879	0.70935E-01	7678.2	-444.24
3937	0.32904E-01	7518.4	-318.70
3995	0.29137E-01	7498.8	-148.30
4053	0.35262E-01	7494.4	0.70278E-05
4111	0.52316E-01	7498.8	148.30
4169	0.78012E-01	7518.4	318.70
4227	0.13722	7678.2	444.24
4285	-0.25540	8536.7	632.51

```
TOTAL VALUES
VALUE   -0.67121E-09  69958.     -0.75801E-04
```

The total value of the reaction is same as the total applied load.

For the top unit:

```
      PRINT REACTION SOLUTIONS PER NODE
***** POST1 TOTAL REACTION SOLUTION LISTING *****
       LOAD STEP=      0  SUBSTEP=      1
        TIME=    1.0000        LOAD CASE=   0
       THE FOLLOWING X,Y,Z SOLUTIONS ARE IN THE GLOBAL COORDINATE SYSTEM
```

NODE	FX	FY	FZ
3701	-11.773	2460.3	-167.82
3759	6.2479	2252.1	-135.94
3817	2.8477	2198.7	-94.966
3875	1.8769	2192.1	-43.696
3933	1.5864	2190.6	0.16809E-04
3991	1.8828	2192.1	43.696
4049	2.8592	2198.7	94.967
4107	6.2645	2252.1	135.94
4165	-11.792	2460.3	167.81

```
TOTAL VALUES
VALUE   -0.95419E-09  20397.     -0.24128E-04
```

The total value of the reaction is same as the total applied load.

5.4.9 Checking of Convergence of the ANSYS Results

Checking of the convergence of the ANSYS results with coarse to fine meshes is required for confirmation of the ANSYS convergence criteria. For this the gate and wheel models are meshed with three different sizes elements varying from coarse to fine and is distinguished as Model-A, B and C as stated below:

a) Convergence of the gate model results:

Model A: Total number of elements=3394 and max.stress, SEQV =601.48

Model B: Total number of elements=9889 and max.stress, SEQV =740.11

Model C: Total number of elements=12384 and max.stress, SEQV=750.80

b) Convergence of the bottom and intermediate wheel model results:

Model A: Total number of elements=2250 and max.stress, SEQV =3588

Model B: Total number of elements=3111 and max.stress, SEQV =5840

Model C: Total number of elements=3750 and max.stress, SEQV=5980

b) Convergence of the top wheel model results:

Model A: Total number of elements=2022 and max.stress, SEQV =2902

Model B: Total number of elements=2950 and max.stress, SEQV =4731

Model C: Total number of elements=3370 and max.stress, SEQV=4838

From the above is observed that the ANSYS results are convergent.

5.5 RESULTS & DISCUSSION

FEM results (deflection and stresses) are presented in contour plots (nodal &element solutions) as well as graphically in different sections as here after:

5.5.1 Deflection of Gate at Full Water Level:

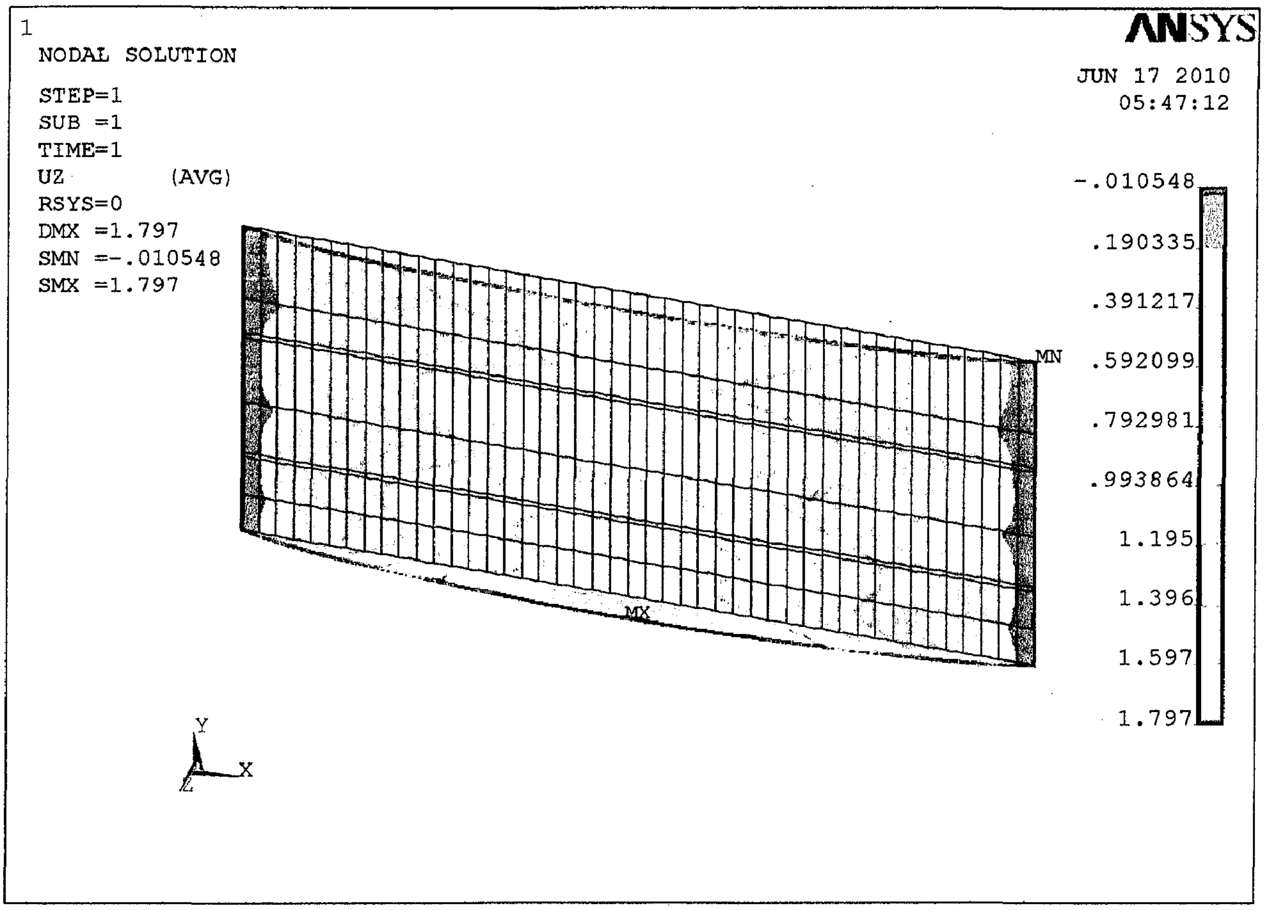


Figure 5.19(a): Gate contour plot deflections

It is seen from the Fig: 5.19(a) and contour legend that maximum deflections at the centre span of the gate in bottom portion of the gate is 1.797 cm, Limiting deflection is =2.34 cm.

Hence the value of combined deflection of gate is 23.20 % less than the permissible value.

5.5.2 Deflection of Gate at Full Water Level with Earthquake Effect:

(ref: appendix-A, sec-A.3.0)

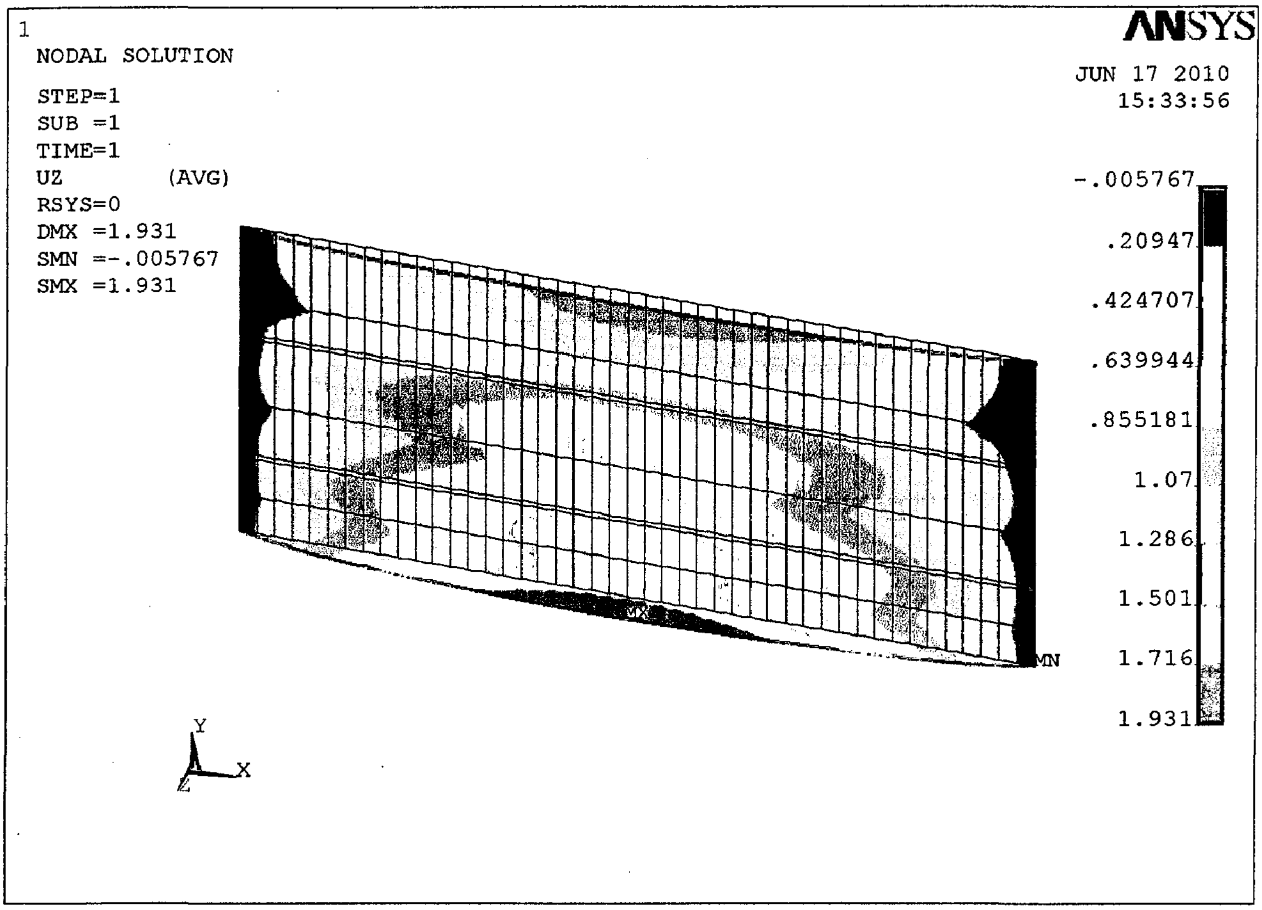


Figure 5.19(b): Gate contour plot deflections

It is seen from the Fig: 5.19(b) and contour legend that deflections at the centre span of the gate varry from top to bottom of the gate from 0.855181 to 1.931cm.

The maximum deflection due to seismic effect is 1.931 cm at the bottom of mid span of the gate and without Earthquake is 1.805 cm which is shown in Fig: 5.19(a). It is observed that deflection increases by 7% due to Earthquake effect.

5.5.3 Deflection at various head of water level:

In the upstream of Bhimgoda Barrage, the Tehri Dam has been constructed. Due to this the pond level of Bhimgoda Barrage may rise up. So that here we studied the deflection of gate at the maximum pond level, high flood level and normal water level which are shown in Fig: 5.19(c).

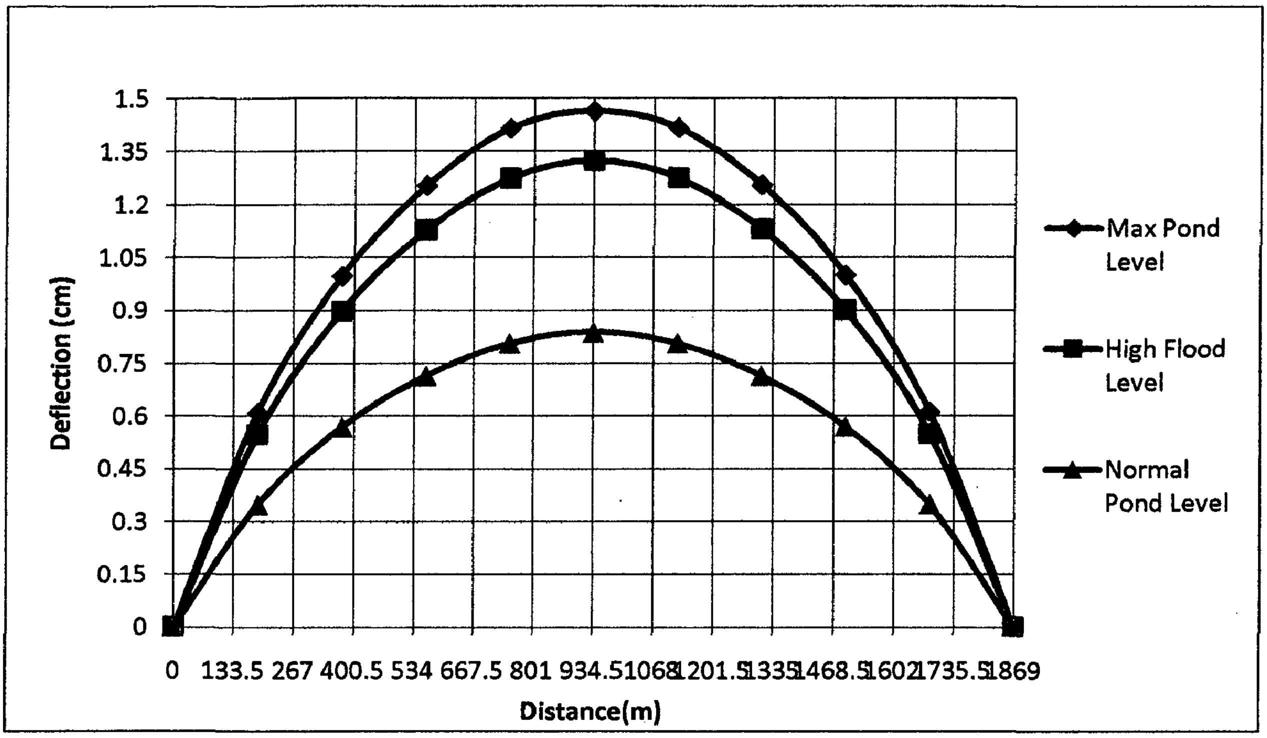


Figure 5.19(c): Deflection at various head of water level

Deflection of Gate at Maximum Pond Level (MPL):
The maximum pond level Bhimgoda barrage = 293.70 m,
Crest level of under sluice gate of Bhimgoda barrage =285.40 m
Applied pressure on the gate =0.84 kg/cm^2 (ref:Appendix-A, sec- A.1.0).
The maximum deflection= 1.46 cm at the centre of span of the gate which is shown in Fig:5.19(c)

Deflection of Gate at High Flood Level (HFL):
The HFL= 293.28 m and applied pressure on the gate = 0.78 kg/cm^2.
The maximum deflection=1.32 cm at the centre of span of the gate which is shown in Fig:5.19(c)

Deflection of Gate at Normal Pond Level (NPL):
The NPL= 290.20 m, applied pressure on the gate = 0.48 kg/cm^2.
The maximum deflection=0.84 cm at the centre of span of the gate which is shown in Fig:5.19(c)

5.5.4 Skin Plate FEM Results And Discussion:

In conventional approach the skin plate was designed as panels e.g A,B,C,D,E and F which are shown in (Fig:A.1-Appendix-A) . Maximum bending stresses occuring in skin plate panel 'C' which are mentioned in table: 5.13 for ready reference.

Table:5.13 Maximum Stress In Skin Plate (ref: Appendix-A)

Location & direction of maximum stress	Max. Value	Unit
X-direction with V stiffener (bending stress)	531.48	Kg/cm^2
Y-direction with H girder (bending stress)	363.50	Kg/cm^2

FEM results (stresses) are presented in contour plots (nodal & element solutions) as well as graphically in different sections as here after:

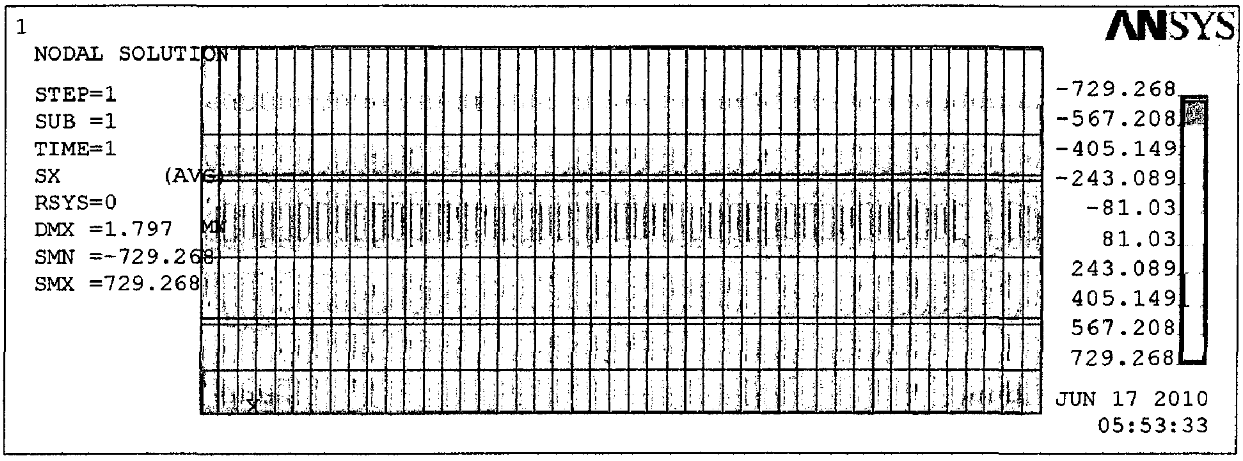


Figure 5.20(a): Skin Plate Contour Plots SX, (Nodal Solution)

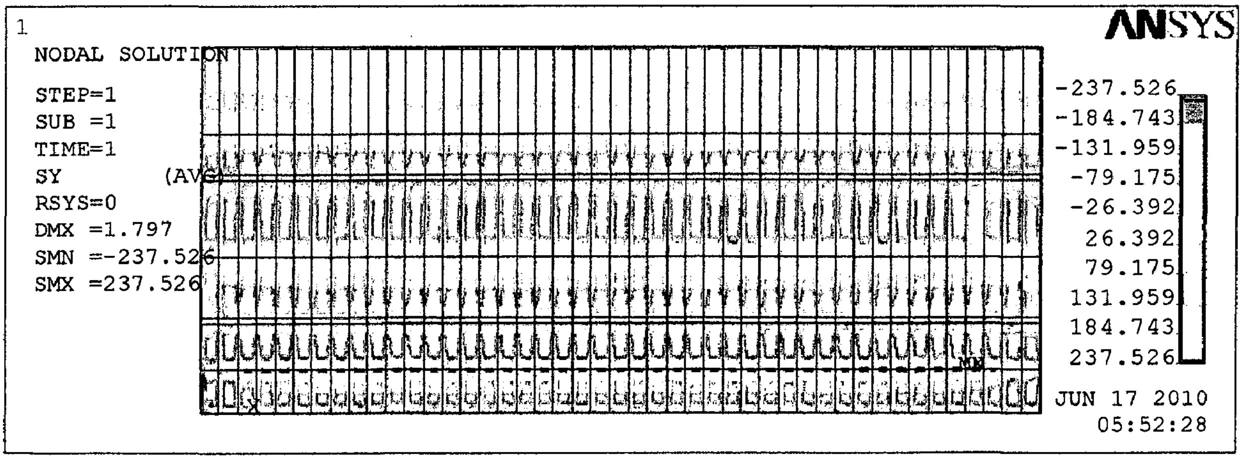


Figure 5.20(b): Skin Plate Contour Plots SY, (Nodal Solution)

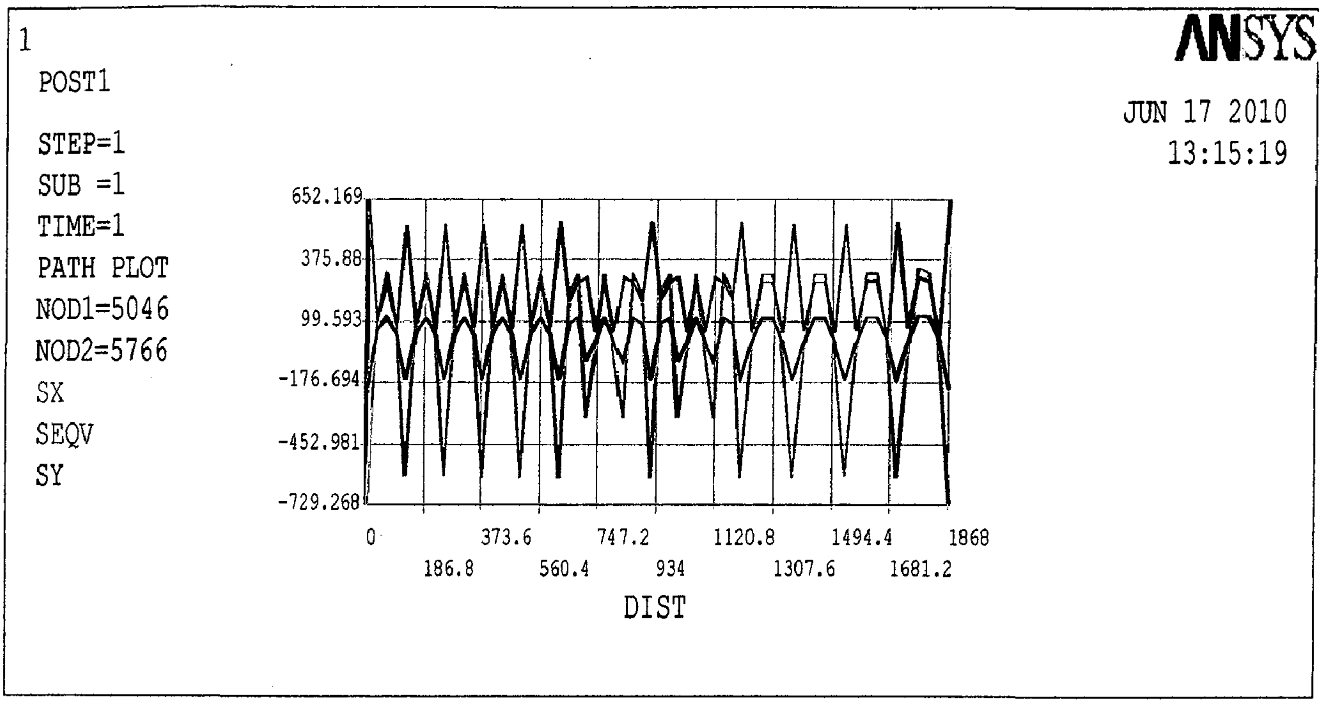


Figure 5.20(c): Skin plate stress distribution

It is visible from the Fig: 5.20(a). 5.20(b) . 5.20(c) contour legend that, maximum stresses in the X-direction is +/- 729.268 kg/cm^2 those are occurs with vertical stiffeners and in Y-direction are varying is 237.526 kg/cm^2.

A comparison between conventionally design results and FEM results of skin plate for panel 'C' at centers, with vertical stiffeners and horizontal girders is presented in table: 5.14.

Table:5.14 Comparison between conventionally design results and FEM results

Location and direction of results	Allowable stress (kg/cm^2)	Design results (kg/cm^2)	FEM results (kg/cm^2)	Variation (%)
Panel 'C' of skin plate X-direction with V stiffener (bending stress) **SX**	1080	531.48	729.268	+27.12
Y-direction with H girder (bending stress) **SY**	1080	363.50	237.526	-34.65

From the Table: 5.14 it is obvious that FEM results 'SX' (X-direction bending stress with vertical stiffener) at the center of gate span is 27.12 % more than design results and 'SY' (Y-direction bending stress with H girder) is 34.65 % less than design results. FEM results SX and SY less than the allowable stresses but SX is more conservative than SY.

5.5.4.1 Von mises stresses of gate at full water level:

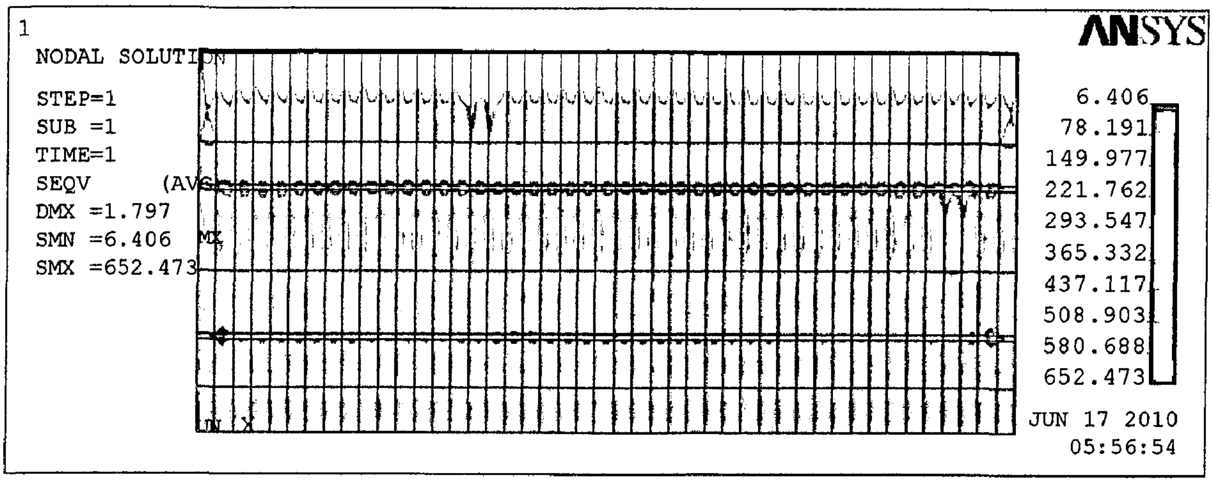


Figure 5.21(a): Skin Plate Contour Plots Von Misses E stresses SEQV, (Nodal Solution)

It is distinc from the FEM results in Fig: 5.21(a) and respective contour legends that, maximum value of Von Msises Equivalent stresses at the left point of center panel 'C' of skin plate: Seqv= 652.473 kg/cm^2(Nodal Solution). The maximum stress from design results = 611.39 kg/cm^2(ref: Appendix-A, sec-A.5.7) which slightly less than the FEM results.

5.5.4.2 Von mises stresses of gate at full water level with earthquake effect:

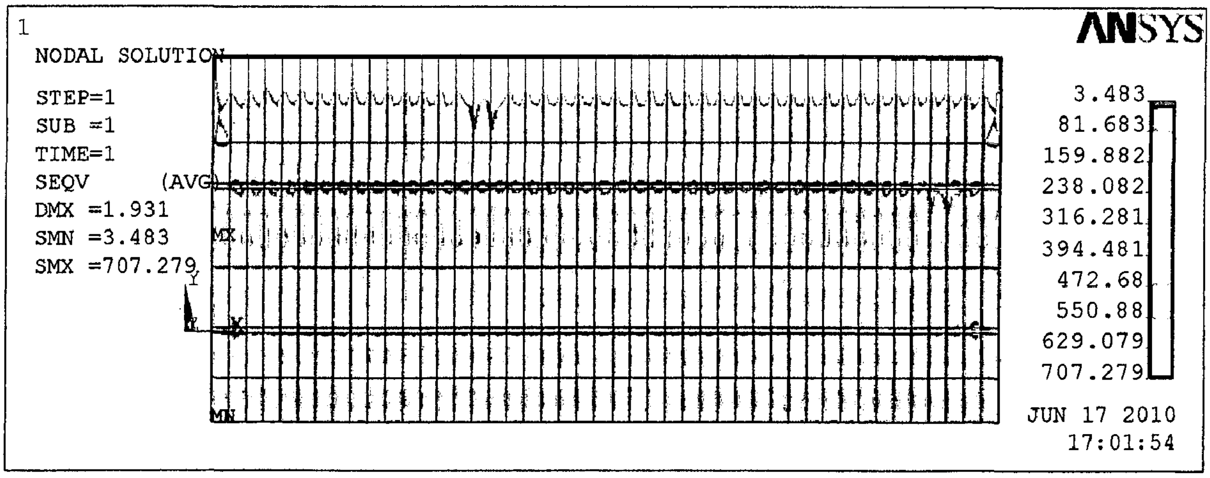


Figure 5.21(b): Skin Plate Contour Plots Von Misses E stresses SEQV, (Nodal Solution)

It is distinc from the FEM results in fig: 5.21(b) and respective contour legends that, maximum value of Von Msises Equivalent stresses due to earthquake at the left point of center panel 'C' of skin plate: Seqv= 707.279 kg/cm^2(Nodal Solution), Which are 8.40 % more than the Stresses without Earthquake cosidration.

5.5.5 Horizontal Girder FEM Resluts And Discussion:

5.5.5.1 Deflection:

Maximum value of deflection by conventional design at bottom girder =1.34cm ; intermediate girder=1.19cm and top girder =0.77cm, The permissible limit of deflection=2.34 cm (ref: Appendix-A, sec- A.6.7).

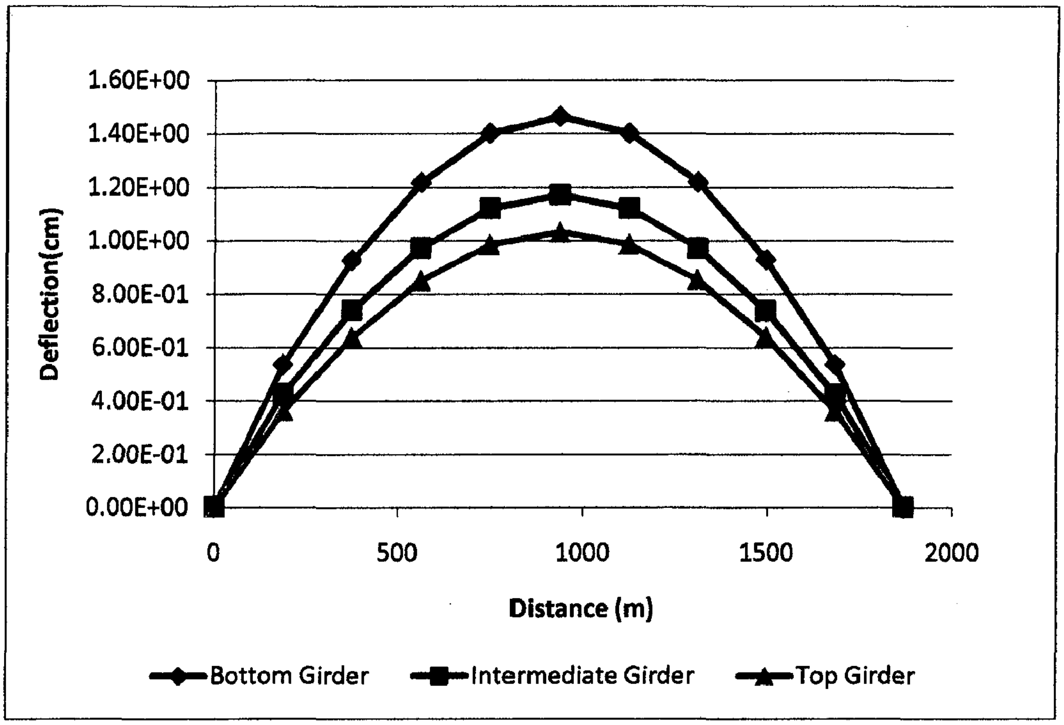


Figure 5.22: Deflection at Horizontal Girders

Table:5.15 Maximum Deflection In Horizontal Girders

S. No	Component Name	Conventional Results (cm)	Fem Results(cm)	Permissible Limit(cm)
1	Bottom Horizontal Girder	1.34	1.46	2.34
2	Intermediate Horizontal Girder	1.19	1.17	2.34
3	Top Horizontal Girder	0.77	1.03	2.34

It is observed that from the comparative stament in Table:5.15, FEM deflection of bottom and top horizontal girder are more than the design results and FEM deflection of intermediate girder is less than the design result. However, FEM results are close to design results with little variations, which are within acceptable limit.

5.5.5.2 Bending moment and shear force:

The undersluice gate under study consist of three horizontal girders. The bottom girder heavier than others (ref: appendix-A, sec-A.6.0). Therefore, for applied hydrostatic pressure, load behavior of top, bottom and intermediate girder are different. So that moment and shear force occuring on the gate are not same. For ready reference, design results bending moment and shear foce are also mentioned here under.

Bottom girder =67265579 kg-cm, 139918 kg
Intermediate girder=66873257 kg-cm, 139102 kg
Top girder =19611235 kg-cm, 40793 kg (ref: appendix-A, sec-6.0).

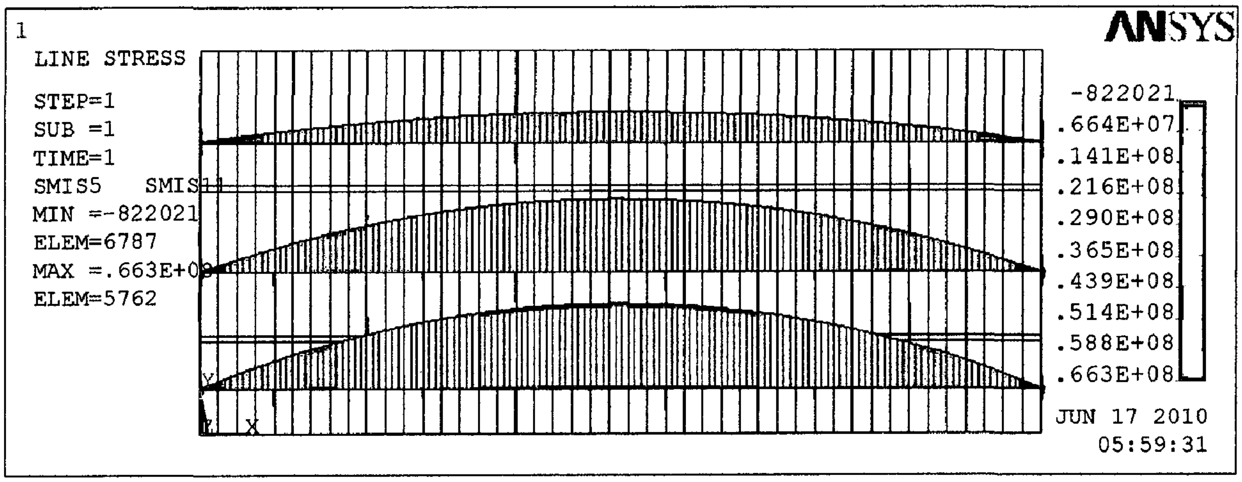


Figure 5.23(a): Horizontal Girder Contour Plots Bending Moment kg-cm

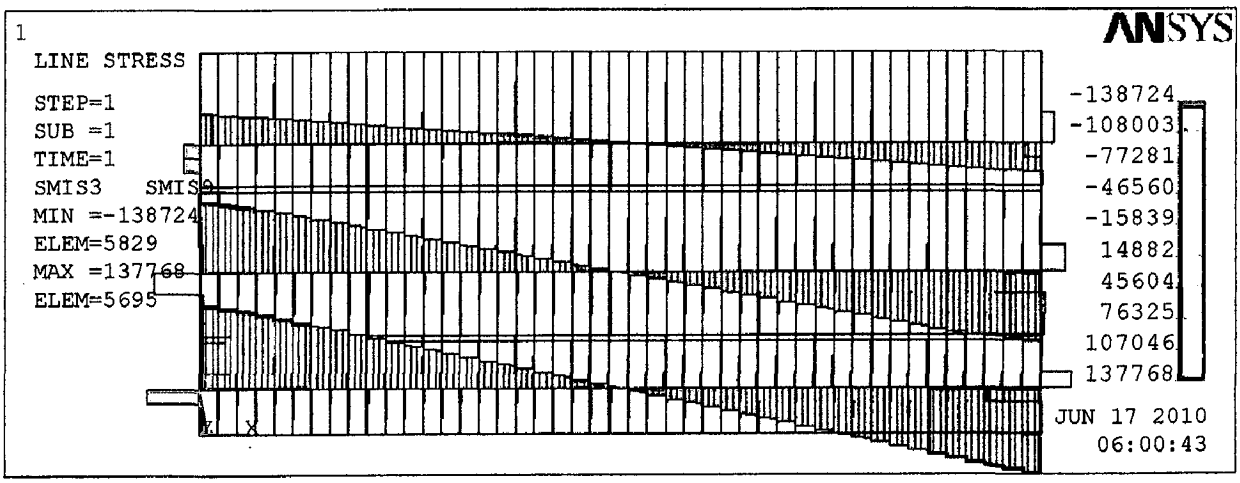


Figure 5.23(b): Horizontal Girder Contour Plots Shear Force kg.

It is evident from the Element table: 5.1, 5.2, 5.3 & Fig: 5.23(a).5.23(b) and contour legends that maximum values of bending moment is 66300000 kg-cm and shear force is 137768 kg which is at the center of gate in bottom girder.

5.5.5.3 Bending stresses:

ET:5.1 BOTTOM HORIZONTAL GIRDER
PRINT ELEMENT TABLE ITEMS PER ELEMENT

***** POST1 ELEMENT TABLE LISTING *****

STAT ELEM	MIXED LS4	MIXED LS5	MIXED SMIS3	MIXED SMIS5
5695	-10.938	17.504	0.13777E+06	-0.27168E+06
5696	66.258	-106.03	0.13738E+06	0.16458E+07
5697	143.22	-229.19	0.13699E+06	0.35575E+07
5698	221.42	-354.32	0.13355E+06	0.54997E+07
5699	295.80	-473.35	0.13313E+06	0.73472E+07
5700	369.93	-591.99	0.13273E+06	0.91887E+07
5701	375.61	-589.79	0.12784E+06	0.11050E+08
5702	435.73	-684.19	0.12742E+06	0.12818E+08
5703	495.64	-778.26	0.12701E+06	0.14581E+08
5704	475.10	-732.52	0.12146E+06	0.16348E+08
5705	523.93	-807.81	0.12105E+06	0.18029E+08
5706	572.59	-882.83	0.12063E+06	0.19703E+08
5707	544.13	-825.26	0.11497E+06	0.21374E+08
5708	584.63	-886.67	0.11456E+06	0.22965E+08
5709	624.97	-947.85	0.11415E+06	0.24549E+08
5710	589.27	-879.98	0.10856E+06	0.26128E+08
5711	623.14	-930.56	0.10814E+06	0.27630E+08
5712	656.87	-980.94	0.10773E+06	0.29125E+08
5713	618.21	-910.08	0.10220E+06	0.30615E+08
5714	646.76	-952.11	0.10179E+06	0.32029E+08
5715	675.19	-993.97	0.10138E+06	0.33437E+08
5716	635.92	-923.83	95833.	0.34840E+08
5717	660.12	-958.99	95422.	0.36166E+08
5718	684.22	-993.99	95010.	0.37486E+08
5719	590.73	-837.91	89386.	0.38801E+08
5720	609.56	-864.62	88973.	0.40038E+08
5721	628.29	-891.19	88561.	0.41268E+08
5722	566.78	-558.66	82873.	0.42493E+08
5723	582.07	-573.73	82460.	0.43640E+08
5724	597.28	-588.72	82048.	0.44780E+08
5725	612.41	-603.63	76371.	0.45914E+08
5726	626.50	-617.52	75959.	0.46971E+08
5727	640.51	-631.34	75547.	0.48021E+08
5728	654.45	-645.07	69880.	0.49066E+08
5729	667.34	-657.78	69468.	0.50033E+08
5730	680.16	-670.41	69056.	0.50994E+08
5731	692.89	-682.96	63386.	0.51948E+08
5732	704.58	-694.49	62974.	0.52825E+08
5733	716.20	-705.94	62562.	0.53696E+08
5734	727.72	-717.30	56939.	0.54560E+08
5735	738.23	-727.66	56527.	0.55348E+08
5736	748.66	-737.93	56115.	0.56130E+08
5737	759.00	-748.12	50546.	0.56905E+08
5738	768.32	-757.32	50134.	0.57604E+08
5739	777.57	-766.43	49723.	0.58297E+08
5740	786.72	-775.45	44218.	0.58983E+08
5741	794.88	-783.50	43807.	0.59595E+08
5742	802.96	-791.46	43396.	0.60201E+08
5743	810.95	-799.33	37974.	0.60800E+08
5744	817.96	-806.24	37563.	0.61325E+08
5745	824.89	-813.07	37152.	0.61845E+08
5746	831.73	-819.82	31780.	0.62358E+08
5747	837.60	-825.60	31369.	0.62798E+08
5748	843.38	-831.30	30958.	0.63231E+08
5749	849.09	-836.93	25604.	0.63659E+08
5750	853.82	-841.59	25193.	0.64014E+08
5751	858.46	-846.17	24782.	0.64362E+08
5752	863.04	-850.68	19418.	0.64705E+08
5753	866.62	-854.21	19008.	0.64974E+08
5754	870.13	-857.66	18597.	0.65237E+08
5755	873.57	-861.05	13196.	0.65494E+08
5756	876.00	-863.46	12785.	0.65677E+08
5757	878.36	-865.78	12374.	0.65854E+08
5758	880.65	-868.04	6920.6	0.66026E+08
5759	881.93	-869.30	6508.9	0.66122E+08
5760	883.13	-870.48	6097.3	0.66211E+08
5761	884.25	-871.58	640.70	0.66295E+08
5762	884.37	-871.70	229.50	0.66304E+08
5763	884.41	-871.74	-181.67	0.66307E+08
5764	884.37	-871.70	-5599.7	0.66304E+08
5765	883.34	-870.69	-6010.6	0.66227E+08
5766	882.23	-869.59	-6421.5	0.66144E+08
5767	881.05	-868.43	-11840.	0.66055E+08
5768	878.87	-866.28	-12251.	0.65892E+08
5769	876.60	-864.05	-12662.	0.65722E+08
5770	874.28	-861.75	-18119.	0.65548E+08
5771	870.94	-858.46	-18531.	0.65297E+08

ET:5.2 INTERMEDIATE HORIZONTAL GIRDER
PRINT ELEMENT TABLE ITEMS PER ELEMENT

***** POST1 ELEMENT TABLE LISTING *****

STAT ELEM	CURRENT LS4	CURRENT LS5	CURRENT SMIS3	CURRENT SMIS5
6100	8.1999	-19.096	0.11679E+06	0.30543E+06
6101	51.838	-120.72	0.11643E+06	0.19309E+07
6102	95.336	-222.02	0.11606E+06	0.35511E+07
6103	139.42	-324.70	0.11296E+06	0.51933E+07
6104	181.38	-422.40	0.11259E+06	0.67560E+07
6105	223.19	-519.77	0.11221E+06	0.83134E+07
6106	225.59	-510.74	0.10821E+06	0.98854E+07
6107	259.75	-588.08	0.10783E+06	0.11382E+08
6108	293.79	-665.15	0.10745E+06	0.12874E+08
6109	284.26	-626.28	0.10299E+06	0.14370E+08
6110	312.45	-688.37	0.10261E+06	0.15794E+08
6111	340.52	-750.23	0.10223E+06	0.17214E+08
6112	323.04	-693.90	97627.	0.18630E+08
6113	346.46	-744.20	97250.	0.19981E+08
6114	369.78	-794.31	96874.	0.21326E+08
6115	350.68	-735.62	92284.	0.22666E+08
6116	370.43	-777.05	91908.	0.23943E+08
6117	390.10	-818.31	91532.	0.25214E+08
6118	368.91	-756.80	86968.	0.26480E+08
6119	385.67	-791.19	86592.	0.27683E+08
6120	402.36	-825.42	86215.	0.28881E+08
6121	380.57	-764.52	81633.	0.30075E+08
6122	394.86	-793.23	81256.	0.31204E+08
6123	409.09	-821.80	80880.	0.32328E+08
6124	386.78	-761.13	76244.	0.33448E+08
6125	398.97	-785.13	75867.	0.34503E+08
6126	411.11	-809.01	75490.	0.35552E+08
6127	419.66	-490.20	70813.	0.36597E+08
6128	430.89	-503.32	70435.	0.37577E+08
6129	442.06	-516.37	70058.	0.38551E+08
6130	453.18	-529.35	65376.	0.39520E+08
6131	463.55	-541.46	64999.	0.40425E+08
6132	473.86	-553.51	64622.	0.41324E+08
6133	484.11	-565.49	59932.	0.42218E+08
6134	493.62	-576.59	59555.	0.43047E+08
6135	503.07	-587.63	59178.	0.43871E+08
6136	512.46	-598.60	54475.	0.44690E+08
6137	521.10	-608.69	54098.	0.45444E+08
6138	529.68	-618.72	53721.	0.46192E+08
6139	538.20	-628.67	49031.	0.46935E+08
6140	545.98	-637.75	48654.	0.47613E+08
6141	553.70	-646.77	48277.	0.48286E+08
6142	561.35	-655.71	43607.	0.48954E+08
6143	568.27	-663.79	43229.	0.49557E+08
6144	575.13	-671.80	42852.	0.50155E+08
6145	581.92	-679.74	38208.	0.50748E+08
6146	587.98	-686.82	37831.	0.51276E+08
6147	593.98	-693.83	37455.	0.51800E+08
6148	599.93	-700.77	32840.	0.52318E+08
6149	605.14	-706.85	32464.	0.52772E+08
6150	610.29	-712.87	32087.	0.53221E+08
6151	615.39	-718.83	27477.	0.53666E+08
6152	619.75	-723.92	27100.	0.54046E+08
6153	624.05	-728.94	26724.	0.54421E+08
6154	628.30	-733.91	22090.	0.54792E+08
6155	631.81	-738.01	21713.	0.55098E+08
6156	635.25	-742.03	21337.	0.55398E+08
6157	638.65	-746.00	16668.	0.55695E+08
6158	641.30	-749.09	16291.	0.55925E+08
6159	643.88	-752.11	15915.	0.56151E+08
6160	646.41	-755.07	11213.	0.56372E+08
6161	648.19	-757.14	10835.	0.56527E+08
6162	649.91	-759.15	10458.	0.56677E+08
6163	651.57	-761.09	5732.8	0.56821E+08
6164	652.48	-762.15	5355.5	0.56901E+08
6165	653.33	-763.14	4978.2	0.56975E+08
6166	654.10	-764.05	263.63	0.57042E+08
6167	654.14	-764.10	-113.40	0.57046E+08
6168	654.13	-764.08	-490.40	0.57044E+08
6169	654.03	-763.97	-5167.9	0.57036E+08
6170	653.22	-763.01	-5544.7	0.56965E+08
6171	652.34	-761.99	-5921.5	0.56888E+08
6172	651.39	-760.88	-10582.	0.56806E+08
6173	649.71	-758.93	-10959.	0.56660E+08
6174	647.98	-756.89	-11336.	0.56508E+08
6175	646.18	-754.80	-16009.	0.56352E+08
6176	643.64	-751.83	-16386.	0.56130E+08

5772	867.51	-855.09	-18943.	0.65041E+08
5773	864.01	-851.64	-24398.	0.64778E+08
5774	859.51	-847.20	-24809.	0.64441E+08
5775	854.93	-842.69	-25220.	0.64097E+08
5776	850.28	-838.10	-30629.	0.63748E+08
5777	844.63	-832.53	-31040.	0.63325E+08
5778	838.90	-826.88	-31450.	0.62895E+08
5779	833.10	-821.17	-36845.	0.62461E+08
5780	826.31	-814.47	-37256.	0.61951E+08
5781	819.43	-807.69	-37666.	0.61436E+08
5782	812.50	-800.86	-43106.	0.60916E+08
5783	804.55	-793.02	-43518.	0.60320E+08
5784	796.52	-785.11	-43929.	0.59718E+08
5785	788.44	-777.15	-49465.	0.59112E+08
5786	779.32	-768.15	-49877.	0.58428E+08
5787	770.11	-759.08	-50289.	0.57738E+08
5788	760.84	-749.94	-55891.	0.57043E+08
5789	750.53	-739.78	-56304.	0.56270E+08
5790	740.14	-729.54	-56716.	0.55491E+08
5791	729.67	-719.22	-62292.	0.54706E+08
5792	718.18	-707.89	-62703.	0.53845E+08
5793	706.61	-696.49	-63114.	0.52977E+08
5794	694.98	-685.02	-68666.	0.52105E+08
5795	682.31	-672.53	-69077.	0.51155E+08
5796	669.56	-659.97	-69488.	0.50199E+08
5797	656.77	-647.36	-75109.	0.49240E+08
5798	642.91	-633.71	-75522.	0.48202E+08
5799	628.98	-619.97	-75934.	0.47157E+08
5800	615.00	-606.19	-81662.	0.46108E+08
5801	599.93	-591.34	-82075.	0.44979E+08
5802	584.78	-576.41	-82487.	0.43843E+08
5803	569.58	-561.43	-88285.	0.42704E+08
5804	553.30	-545.37	-88698.	0.41483E+08
5805	536.93	-529.24	-89110.	0.40255E+08
5806	594.12	-842.72	-94941.	0.39024E+08
5807	574.13	-814.36	-95354.	0.37710E+08
5808	554.04	-785.88	-95766.	0.36391E+08
5809	640.07	-929.86	-0.10162E+06	0.35067E+08
5810	614.42	-892.59	-0.10203E+06	0.33662E+08
5811	588.65	-855.16	-0.10244E+06	0.32250E+08
5812	622.62	-916.57	-0.10832E+06	0.30833E+08
5813	592.37	-872.03	-0.10873E+06	0.29335E+08
5814	561.99	-827.32	-0.10914E+06	0.27831E+08
5815	593.61	-886.47	-0.11503E+06	0.26320E+08
5816	557.73	-832.88	-0.11544E+06	0.24729E+08
5817	521.71	-779.09	-0.11586E+06	0.23132E+08
5818	547.97	-831.08	-0.12169E+06	0.21525E+08
5819	505.12	-766.09	-0.12210E+06	0.19842E+08
5820	462.12	-700.87	-0.12252E+06	0.18152E+08
5821	477.89	-736.83	-0.12809E+06	0.16445E+08
5822	426.41	-657.45	-0.12850E+06	0.14673E+08
5823	374.75	-577.79	-0.12892E+06	0.12895E+08
5824	376.84	-591.73	-0.13374E+06	0.11086E+08
5825	313.96	-492.99	-0.13414E+06	0.92362E+07
5826	250.88	-393.94	-0.13456E+06	0.73804E+07
5827	220.80	-353.34	-0.13794E+06	0.54844E+07
5828	143.52	-229.67	-0.13834E+06	0.35648E+07
5829	66.004	-105.62	-0.13872E+06	0.16395E+07

MINIMUM VALUES

ELEM	5695	5718	5829	5695
VALUE	-10.938	-993.99	-0.13872E+06	-0.27168E+06

MAXIMUM VALUES

ELEM	5763	5695	5695	5763
VALUE	884.41	17.504	0.13777E+06	0.66307E+08

6177	641.04	-748.80	-16764.	0.55903E+08
6178	638.39	-745.69	-21442.	0.55672E+08
6179	634.99	-741.72	-21819.	0.55375E+08
6180	631.52	-737.68	-22196.	0.55073E+08
6181	628.01	-733.57	-26867.	0.54767E+08
6182	623.75	-728.59	-27244.	0.54395E+08
6183	619.43	-723.55	-27621.	0.54018E+08
6184	615.05	-718.44	-32299.	0.53637E+08
6185	609.93	-712.45	-32676.	0.53190E+08
6186	604.75	-706.40	-33053.	0.52738E+08
6187	599.51	-700.28	-37757.	0.52281E+08
6188	593.52	-693.28	-38133.	0.51759E+08
6189	587.47	-686.22	-38511.	0.51231E+08
6190	581.36	-679.09	-43253.	0.50699E+08
6191	574.50	-671.07	-43631.	0.50101E+08
6192	567.58	-662.99	-44008.	0.49497E+08
6193	560.59	-654.82	-48768.	0.48888E+08
6194	552.86	-645.79	-49145.	0.48213E+08
6195	545.06	-636.68	-49523.	0.47533E+08
6196	537.19	-627.48	-54249.	0.46847E+08
6197	528.58	-617.43	-54626.	0.46096E+08
6198	519.92	-607.31	-55003.	0.45341E+08
6199	511.18	-597.11	-59695.	0.44579E+08
6200	501.72	-586.05	-60072.	0.43753E+08
6201	492.19	-574.92	-60449.	0.42922E+08
6202	482.60	-563.72	-65156.	0.42086E+08
6203	472.26	-551.65	-65533.	0.41185E+08
6204	461.87	-539.50	-65910.	0.40278E+08
6205	451.41	-527.29	-70652.	0.39366E+08
6206	440.21	-514.20	-71029.	0.38389E+08
6207	428.94	-501.04	-71407.	0.37407E+08
6208	417.61	-487.81	-76172.	0.36419E+08
6209	405.53	-473.70	-76549.	0.35365E+08
6210	393.39	-459.51	-76926.	0.34306E+08
6211	384.39	-756.43	-81699.	0.33242E+08
6212	371.32	-730.71	-82077.	0.32112E+08
6213	358.19	-704.87	-82454.	0.30976E+08
6214	377.53	-758.41	-87219.	0.29834E+08
6215	362.26	-727.74	-87597.	0.28628E+08
6216	346.93	-696.93	-87974.	0.27416E+08
6217	364.94	-748.67	-92689.	0.26196E+08
6218	347.08	-712.03	-93066.	0.24914E+08
6219	329.15	-675.23	-93443.	0.23626E+08
6220	345.43	-724.60	-98002.	0.22327E+08
6221	324.45	-680.60	-98380.	0.20971E+08
6222	303.40	-636.43	-98756.	0.19610E+08
6223	316.10	-678.99	-0.10186E+06	0.18230E+08
6224	291.66	-626.50	-0.10185E+06	0.16821E+08
6225	267.23	-574.03	-0.10183E+06	0.15412E+08
6226	277.00	-610.27	-0.10472E+06	0.14003E+08
6227	248.34	-547.14	-0.10510E+06	0.12554E+08
6228	219.58	-483.77	-0.10548E+06	0.11100E+08
6229	219.68	-497.37	-0.10925E+06	0.96265E+07
6230	185.19	-419.29	-0.10963E+06	0.81152E+07
6231	150.58	-340.93	-0.11000E+06	0.65986E+07
6232	135.68	-315.99	-0.11302E+06	0.50540E+07
6233	93.459	-217.65	-0.11339E+06	0.34812E+07
6234	51.092	-118.99	-0.11375E+06	0.19031E+07

MINIMUM VALUES

ELEM	6100	6120	6234	6100
VALUE	8.1999	-825.42	-0.11375E+06	0.30543E+06

MAXIMUM VALUES

ELEM	6167	6100	6100	6167
VALUE	654.14	-19.096	0.11679E+06	0.57046E+08

ET: 5.3 TOP HORIZONTAL GIRDER
PRINT ELEMENT TABLE ITEMS PER ELEMENT

***** POST1 ELEMENT TABLE LISTING *****

STAT ELEM	CURRENT LS4	CURRENT LS5	CURRENT SMIS3	CURRENT SMIS5
6505	14.370	-40.081	46776.	0.31067E+06
6506	44.482	-124.07	46640.	0.96167E+06
6507	74.503	-207.80	46502.	0.16107E+07
6508	104.88	-292.52	45564.	0.22673E+07
6509	134.03	-373.84	45423.	0.28977E+07
6510	163.10	-454.90	45283.	0.35260E+07
6511	162.96	-429.71	43887.	0.41620E+07
6512	186.73	-492.39	43743.	0.47691E+07
6513	210.42	-554.87	43601.	0.53742E+07
6514	202.10	-505.99	41869.	0.59846E+07
6515	221.66	-554.96	41725.	0.65638E+07
6516	241.15	-603.76	41581.	0.71410E+07
6517	228.00	-545.12	39668.	0.77210E+07
6518	244.20	-583.87	39523.	0.82697E+07
6519	260.35	-622.46	39379.	0.88164E+07
6520	244.75	-561.22	37403.	0.93640E+07
6521	258.28	-592.23	37259.	0.98814E+07
6522	271.75	-623.12	37115.	0.10397E+08
6523	256.36	-566.23	35132.	0.10912E+08
6524	267.78	-591.45	34988.	0.11398E+08
6525	279.15	-616.56	34844.	0.11882E+08
6526	262.65	-560.46	32866.	0.12365E+08
6527	272.31	-581.07	32722.	0.12820E+08
6528	281.93	-601.59	32578.	0.13272E+08
6529	264.58	-546.73	30614.	0.13723E+08
6530	272.75	-563.61	30471.	0.14147E+08
6531	280.88	-580.40	30327.	0.14568E+08
6532	267.42	-538.92	28387.	0.14988E+08
6533	274.43	-553.04	28243.	0.15380E+08
6534	281.40	-567.09	28099.	0.15771E+08
6535	288.32	-581.05	26179.	0.16159E+08
6536	294.79	-594.07	26035.	0.16521E+08
6537	301.21	-607.02	25891.	0.16882E+08
6538	307.59	-619.87	23984.	0.17239E+08
6539	313.51	-631.81	23841.	0.17571E+08
6540	319.39	-643.66	23697.	0.17900E+08
6541	325.22	-655.41	21802.	0.18227E+08
6542	330.60	-666.25	21659.	0.18529E+08
6543	335.95	-677.03	21515.	0.18828E+08
6544	341.23	-687.67	19636.	0.19124E+08
6545	346.08	-697.44	19492.	0.19396E+08
6546	350.89	-707.14	19349.	0.19666E+08
6547	355.63	-716.70	17504.	0.19932E+08
6548	359.95	-725.40	17361.	0.20174E+08
6549	364.24	-734.04	17218.	0.20414E+08
6550	368.44	-742.50	15806.	0.20649E+08
6551	372.34	-750.37	15830.	0.20868E+08
6552	376.25	-758.24	15854.	0.21087E+08
6553	380.22	-766.24	14426.	0.21309E+08
6554	383.78	-773.42	14283.	0.21509E+08
6555	387.30	-780.52	14139.	0.21707E+08
6556	390.83	-787.64	12241.	0.21904E+08
6557	393.86	-793.73	12097.	0.22074E+08
6558	396.84	-799.74	11954.	0.22241E+08
6559	399.83	-805.76	9975.4	0.22409E+08
6560	402.29	-810.73	9831.1	0.22547E+08
6561	404.72	-815.61	9686.9	0.22683E+08
6562	407.14	-820.49	7656.7	0.22818E+08
6563	409.03	-824.30	7512.2	0.22924E+08
6564	410.88	-828.03	7367.8	0.23028E+08
6565	412.71	-831.73	5319.6	0.23131E+08
6566	414.03	-834.38	5175.2	0.23204E+08
6567	415.30	-836.95	5030.9	0.23276E+08
6568	416.55	-839.46	2994.4	0.23346E+08
6569	417.29	-840.96	2850.2	0.23387E+08
6570	417.99	-842.37	2706.0	0.23427E+08
6571	418.67	-843.72	692.34	0.23464E+08
6572	418.84	-844.07	548.26	0.23474E+08
6573	418.97	-844.34	404.20	0.23481E+08
6574	419.07	-844.54	-1582.6	0.23487E+08
6575	418.68	-843.75	-1726.4	0.23465E+08
6576	418.25	-842.89	-1870.3	0.23441E+08
6577	417.79	-841.96	-3831.8	0.23415E+08

STAT ELEM	CURRENT LS4	CURRENT LS5	CURRENT SMIS3	CURRENT SMIS5
6578	416.85	-840.06	-3975.5	0.23362E+08
6579	415.86	-838.08	-4119.2	0.23307E+08
6580	414.85	-836.03	-6074.1	0.23250E+08
6581	413.35	-833.01	-6217.9	0.23166E+08
6582	411.82	-829.92	-6361.6	0.23080E+08
6583	410.25	-826.77	-8334.6	0.22993E+08
6584	408.19	-822.62	-8478.5	0.22877E+08
6585	406.10	-818.40	-8622.4	0.22760E+08
6586	403.98	-814.13	-10633.	0.22641E+08
6587	401.36	-808.84	-10777.	0.22494E+08
6588	398.70	-803.48	-10921.	0.22345E+08
6589	396.00	-798.06	-12966.	0.22194E+08
6590	392.81	-791.61	-13111.	0.22015E+08
6591	389.57	-785.08	-13255.	0.21833E+08
6592	386.30	-778.49	-15310.	0.21650E+08
6593	382.52	-770.88	-15454.	0.21438E+08
6594	378.70	-763.19	-15599.	0.21224E+08
6595	374.85	-755.42	-17641.	0.21008E+08
6596	370.49	-746.65	-17785.	0.20764E+08
6597	366.10	-737.80	-17929.	0.20518E+08
6598	361.68	-728.87	-19955.	0.20270E+08
6599	356.75	-718.95	-20099.	0.19994E+08
6600	351.79	-708.95	-20243.	0.19716E+08
6601	346.79	-698.87	-22254.	0.19436E+08
6602	341.30	-687.80	-22398.	0.19128E+08
6603	335.77	-676.66	-22542.	0.18818E+08
6604	330.20	-665.44	-24537.	0.18506E+08
6605	324.14	-653.24	-24681.	0.18167E+08
6606	318.05	-640.96	-24825.	0.17825E+08
6607	311.92	-628.60	-26801.	0.17481E+08
6608	305.30	-615.27	-26945.	0.17111E+08
6609	298.65	-601.86	-27088.	0.16738E+08
6610	291.96	-588.37	-29045.	0.16363E+08
6611	284.79	-573.93	-29189.	0.15961E+08
6612	277.58	-559.41	-29333.	0.15557E+08
6613	270.34	-544.80	-31283.	0.15151E+08
6614	262.61	-529.24	-31427.	0.14718E+08
6615	254.86	-513.61	-31571.	0.14284E+08
6616	266.95	-551.63	-33526.	0.13846E+08
6617	258.01	-533.15	-33670.	0.13382E+08
6618	249.03	-514.60	-33814.	0.12917E+08
6619	264.40	-564.20	-35765.	0.12447E+08
6620	253.90	-541.77	-35909.	0.11953E+08
6621	243.34	-519.26	-36053.	0.11456E+08
6622	257.36	-568.42	-37948.	0.10954E+08
6623	245.03	-541.18	-38092.	0.10429E+08
6624	232.64	-513.84	-38236.	0.99023E+07
6625	244.88	-561.51	-40003.	0.93688E+07
6626	230.42	-528.34	-40145.	0.88154E+07
6627	215.90	-495.06	-40288.	0.82601E+07
6628	227.29	-543.43	-41917.	0.76971E+07
6629	210.17	-502.50	-42059.	0.71173E+07
6630	192.99	-461.42	-42201.	0.65354E+07
6631	200.78	-502.69	-43671.	0.59456E+07
6632	180.38	-451.62	-43813.	0.53415E+07
6633	159.91	-400.37	-43955.	0.47354E+07
6634	161.30	-425.33	-45184.	0.41196E+07
6635	136.83	-360.80	-45324.	0.34946E+07
6636	112.28	-296.06	-45465.	0.28675E+07
6637	103.16	-287.73	-46355.	0.22302E+07
6638	73.322	-204.51	-46493.	0.15852E+07
6639	43.392	-121.03	-46629.	0.93809E+06

MINIMUM VALUES

ELEM	6505	6574	6639	6505
VALUE	14.370	-844.54	-46629.	0.31067E+06

MAXIMUM VALUES

ELEM	6574	6505	6505	6574
VALUE	419.07	-40.081	46776.	0.23487E+08

A comparison between conventionally design results and FEM results of horizontal girder is presented in table: 5.16

Table:5.16 Comparison design results and FEM results of horizotal girder

Name And Location Of Maximum Value		Design Results	Fem		Variation (%)
			Results	Reference	
(a)	**Bottom girder**				
	• Bending moment(kg-cm)	67265579	66360000	Fig:5.23(a) & ET:5.1	-1.34
	• Shear force (kg)	139918	137770	Fig:5.23(b) & ET:5.1	-1.50
	• Bending stress (kg/cm^2)				
	Skin plate stress	884.36	884.41	ET:5.1	-0.005
	Flange stress	-897.14	-993.99	ET:5.1	+10.79
(b)	**Intermediate girder**				
	• Bending moment(kg-cm)	66873257	57046000	Fig:5.23(a) & ET:5.2	-14.69
	• Shear force (kg)	139102	116790	Fig:5.23(b) & ET:5.2	-16.04
	• Bending stress (kg/cm^2)				
	Skin plate stress	767	654.14	ET:5.2	-14.71
	Flange stress	-896	-825.42	ET:5.2	-7.87
(c)	**Top girder**				
	• Bending moment(kg-cm)	19611235	23487000	Fig:5.23(a)& ET:5.3	+19.76
	• Shear force (kg)	40793	46776	Fig:5.23(b)& ET:5.3	+14.66
	• Bending stress (kg/cm^2)				
	Skin plate stress	350	419.07	ET:5.3	+19.73
	Flange stress	-705	-844.54	ET:5.3	+19.79

From the table: 5.16 it obvious that FEM bending moment, shear force as well bending stress on bottom girder and intermediate girder (excluding flange stress in bottom girder)is less than design values whereas on the top girder FEM results are more than the design results.

5.5.6 Vertical End Girder FEM Resluts And Discussion:

The vertical lift gate under study consist of two vertical end girders at the left and right most end of the gate. In all respect, such as, geometry, loads, both the vertical end girders are same (ref: appendix-A, sec-A.10.0). Therefore, load behavior of both the girders is same, and in that case FEM results presented only for the left/right girder. For ready reference, maximum value of the design results are mentioned here.

Bending moment=3497950 kg-cm ,

Bending stress =731.88 kg/cm^2, 929 kg/cm^2

Allowable stress (kg/cm^2)=1080

(ref: appendix-A, sec-A.10)

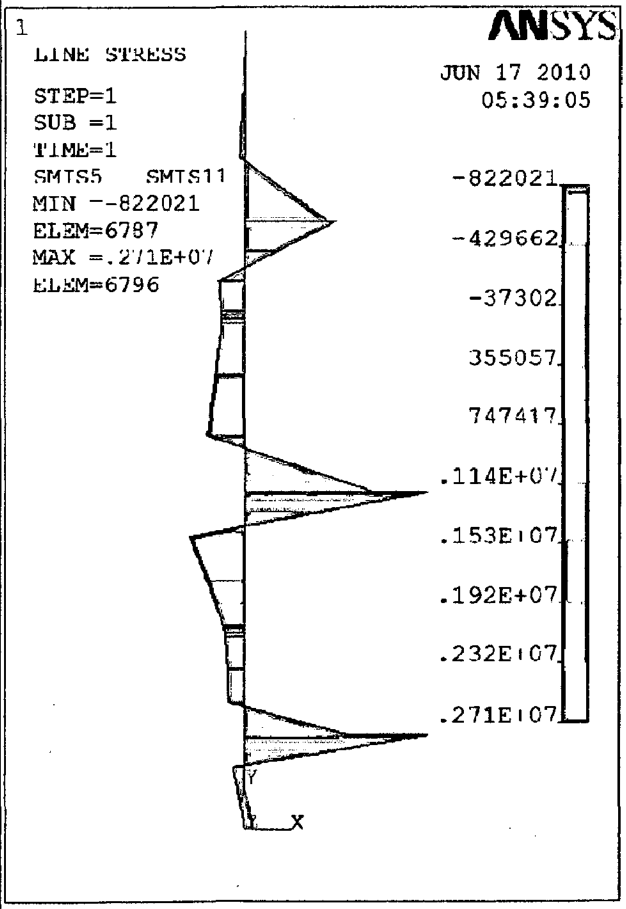


Figure 5.24(a): End V. Girder Bending Moment kg-cm

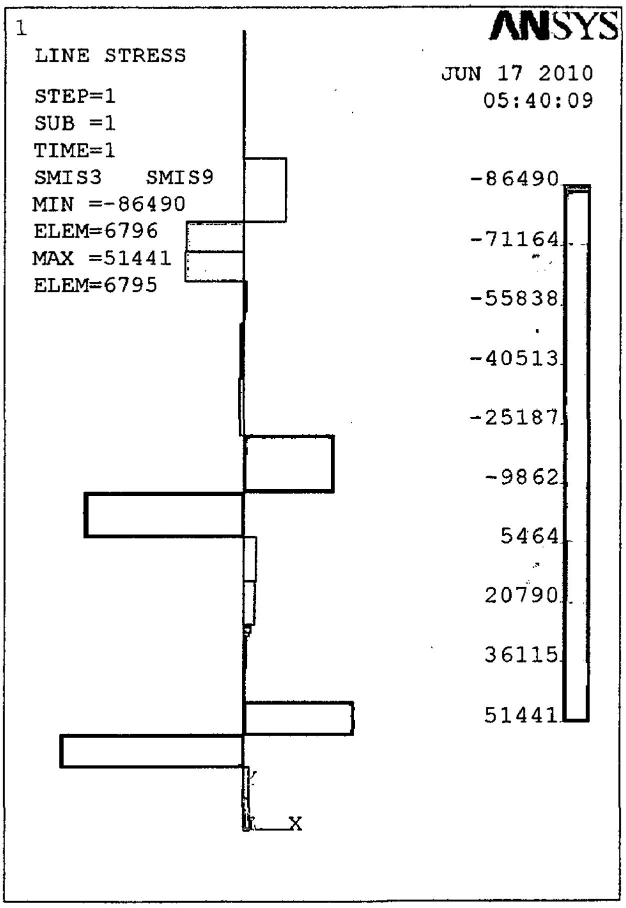


Figure 5.24(b): End V. Girder Shear Force kg

ET: 5.4 PRINT ELEMENT TABLE ITEMS PER ELEMENT (END VERTICAL GIEDER BENDING STRESSES)

***** POST1 ELEMENT TABLE LISTING *****

STAT	MIXED	MIXED	MIXED	MIXED
ELEM	LS4	LS5	SMIS3	SMIS5
6775	-0.14172	0.17978	-556.99	-676.93
6776	-7.9123	10.037	-666.48	-37793.
6777	-17.223	21.847	19459.	-82265.
6778	279.05	-353.99	-27377.	0.13329E+07

6779	99.479	-126.19	-27523.	0.47517E+06
6780	-81.074	102.85	999.52	-0.38726E+06
6781	-72.879	92.449	304.82	-0.34811E+06
6782	-72.636	92.141	179.29	-0.34695E+06
6783	-72.500	91.968	45.992	-0.34630E+06
6784	-71.799	91.079	-1616.2	-0.34295E+06
6785	-91.915	116.60	-2113.8	-0.43904E+06
6786	-118.27	150.03	41587.	-0.56494E+06
6787	561.67	-712.49	-75373.	0.26828E+07
6788	-172.04	218.24	5677.1	-0.82176E+06
6789	-116.79	148.15	5038.7	-0.55785E+06
6790	-67.566	85.709	2997.7	-0.32273E+06
6791	-65.045	82.512	2783.3	-0.31069E+06
6792	-62.709	79.549	2571.1	-0.29953E+06
6793	-61.399	77.886	1019.0	-0.29327E+06
6794	-53.978	68.473	516.61	-0.25783E+06
6795	-50.276	63.777	51441.	-0.24015E+06
6796	567.19	-719.50	-86490.	0.27092E+07
6797	-36.327	46.082	2738.9	-0.17352E+06
6798	-17.238	21.867	2175.6	-82339.

MINIMUM VALUES

ELEM	6788	6796	6796	6788
VALUE	-172.04	-719.50	-86490.	-0.82176E+06

MAXIMUM VALUES

ELEM	6796	6788	6795	6796
VALUE	567.19	218.24	51441.	0.27092E+07

Table:5.17 Comparison design results and FEM results of end vertical girder.

Location and direction of results	Design results	FEM results	Variation (%)
(a)Maximum Bending moment. (kg-cm)	3497950	2709200 (Fig: 5.24(a), ET:5.4)	22.54
(b)Maximum Bending stresses in (kg/cm^2)			
Skin plate stress	731.88	567.19 (ET:5.4)	-22.50
flange	929.00	-719.50 (ET:5.4)	-22.55

From the Table: 5.17 it appears that FEM bending moment and stresses is less than the design stresses. So that FEM results is more conservative than design results.

5.5.7 Wheel FEM Resluts And Discussion:

5.5.7.1 Bottom and Intermediate Unit : In conventional approach the wheel was designed as flat wheel with line contact in accordance with procedure given in Annex-F of IS: 4622. For ready reference maximum value of contact stress, f_c=9200 kg/cm^2 and permissible =9300 kg/cm^2. (ref: appendix-A, sec-A.7.2)

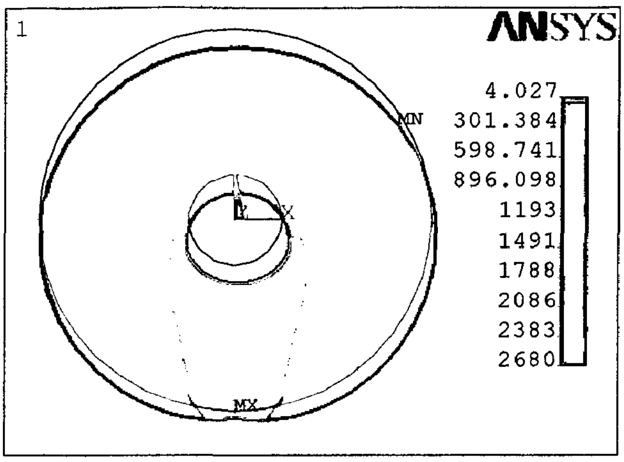


Figure 5.25(a): Wheel Contour Plots Von Misses Seqv.

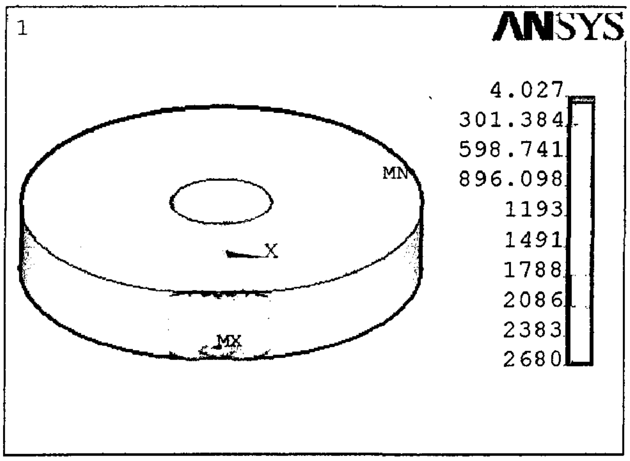


Figure 5.25(b): Wheel Contour Plots at the bottom Von Misses

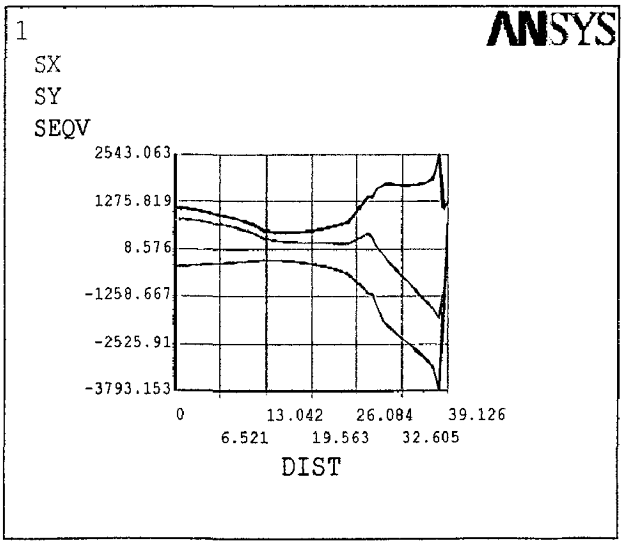


Figure 5.26(a): Stress Distribution at the front of wheel

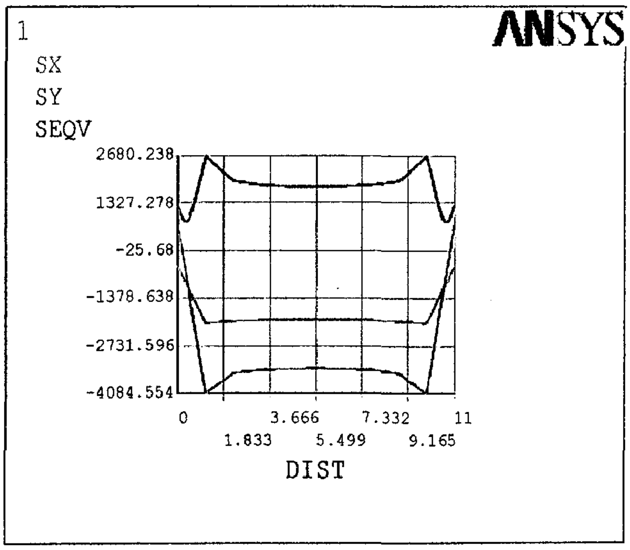


Figure 5.26(b): Stress Distribution at the bottom of wheel

From the Fig: 5.25(a), 5.25(b), contour legend its noticeable that, maximum cotact stress: Sqev=2680 kg/cm^2 and deformation: DMX=0.010466 cm and the Fig: 5.26(b) ANSYS graphical (path) results along the line of contact of the wheel SY=-4084.554 kg/cm^2 in Y direction, which is less than the design stress.

5.5.7.2 Top Unit : In conventional approach the wheel was designed as flat wheel with line contact in accordance with procedure given in Annex-F of IS: 4622. For ready reference maximum value of contact stress, f_c=7800 kg/cm^2 and permissible 9300 kg/cm^2 (ref: appandix-a sec-A.7.3).

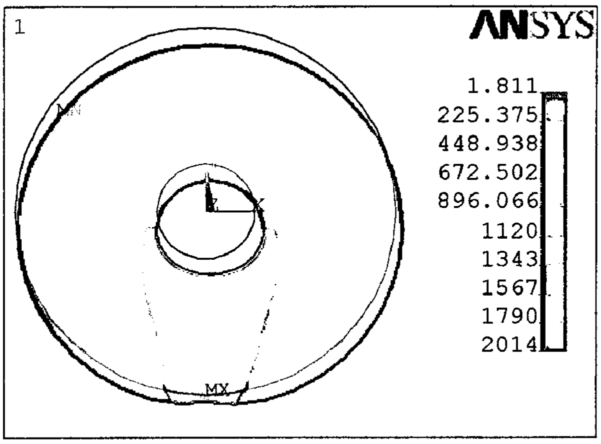


Figure 5.27(a): Wheel Contour Plots at the front Von Misses Seqv.

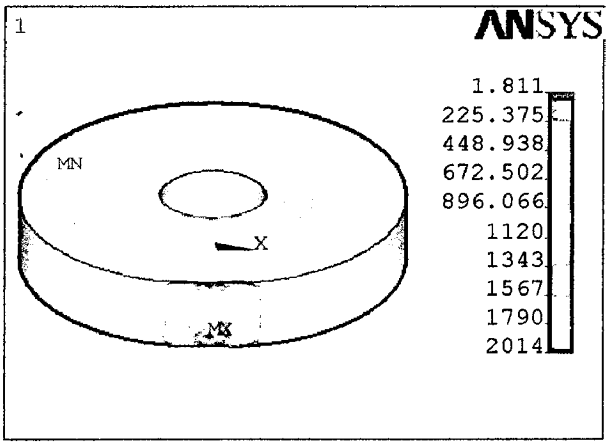


Figure 5.27(b): Wheel Contour Plots at the bottom Von Misses

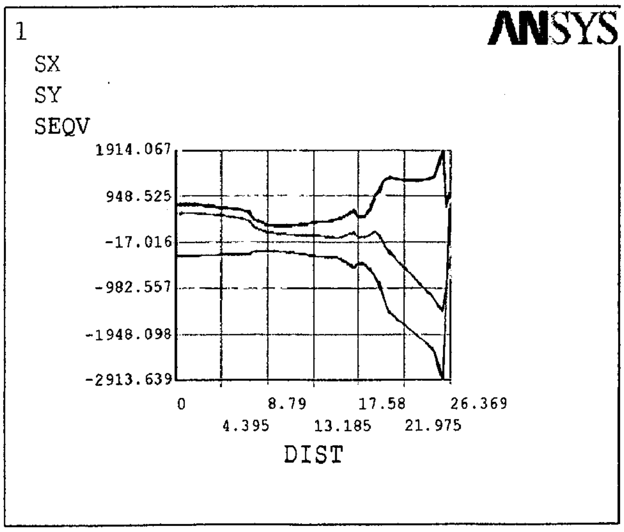


Figure 5.28(a): Stress Distribution at the front of wheel

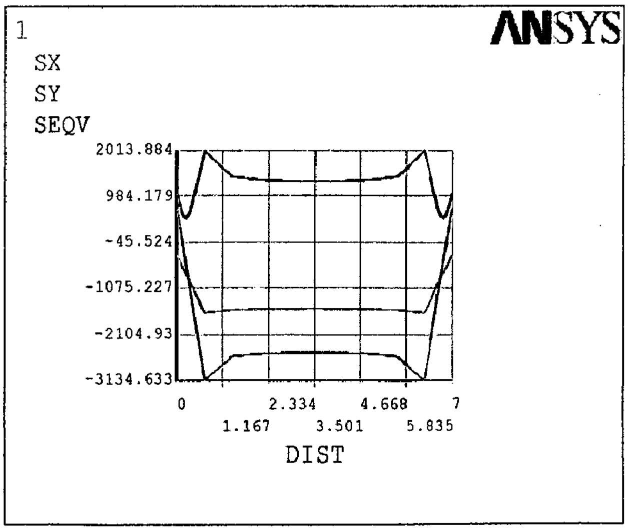


Figure 5.28(b): Stress Distribution at the bottom of wheel

From the Fig: 5.27(a).5.27(b), contour legend its noticeable that, maximum cotact stress: Sqev=2014 kg/cm^2 and the Fig: 5.28(b) ANSYS graphical (path) results along the line of contact of the wheel SY=-3134.633 kg/cm^2 in Y direction, which is less than the design stress.

5.6 SUMMARY OF COMPARISON OF THE CONVENTIONAL DESIGN & FEM RESULTS

a) Comparison of the Stresses between Conventional Design & FEM Results of Skin Plate

Table:5.18 Comparison of the stresses between conventionally design results and FEM results.

Location and direction of results	Allowable stress (kg/cm^2)	Design results (kg/cm^2)	FEM results (kg/cm^2)	Variation (%)
Panel 'C' of skin plate X-direction with V stiffener (bending stress) SX	1080	531.48	729.268	+27.12
Y-direction with H girder (bending stress) SY	1080	363.50	237.526	-34.65

b) Comparison of the bending moment, shear force and bending stresses between Conventional Design & FEM Results of Horizontal Girders.

Table:5.19 Comparison of the bending moment, shear force and bending stresses between conventionally design results and FEM results of horizotal girders.

	Name And Location Of Maximum Value	Design Results	FEM		Variation (%)
			Results	Reference	
(a)	**Bottom girder**				
	• Bending moment(kg-cm)	67265579	66360000	Fig:5.23(a) & ET:5.1	-1.34
	• Shear force (kg)	139918	137770	Fig:5.23(b) & ET:5.1	-1.50
	• Bending stress (kg/cm^2)				
	Skin plate stress	884.36	884.41	ET:5.1	-0.005
	Flange stress	-897.14	-993.99	ET:5.1	+10.79
(b)	**Intermediate girder**				
	• Bending moment(kg-cm)	66873257	57046000	Fig:5.23(a) & ET:5.2	-14.69
	• Shear force (kg)	139102	116790	Fig:5.23(b) & ET:5.2	-16.04
	• Bending stress (kg/cm^2)				
	Skin plate stress	767	654.14	ET:5.2	-14.71
	Flange stress	-896	-825.42	ET:5.2	-7.87
(c)	**Top girder**				
	• Bending moment(kg-cm)	19611235	23487000	Fig:5.23(a)& ET:5.3	+19.76
	• Shear force (kg)	40793	46776	Fig:5.23(b)& ET:5.3	+14.66
	• Bending stress (kg/cm^2)				
	Skin plate stress	350	419.07	ET:5.3	+19.73
	Flange stress	-705	-844.54	ET:5.3	+19.79

c) Comparison of the bending moment and bending stresses between Conventional Design & FEM Results of End Vertical Girder.

Table:5.20 Comparison bending moment and stresses between conventionally design results and FEM results of end vertical girder.

Location and direction of results	Design results	FEM results	Variation (%)
(a)Maximum Bending moment. (kg-cm)	3497950	2709200 (Fig: 5.24(a), ET:5.4)	-22.54
(b)Maximum Bending stresses in (kg/cm^2)			
• Skin plate stress	731.88	567.19 (ET:5.4)	-22.50
• flange	929.00	-719.50 (ET:5.4)	-22.55

d) Comparison of Line Contact stresses between Conventional Design & FEM Results of Wheel

Table:5.21 Comparison of line contact stresses between design results and FEM results of wheels.

Name And Location of Maximum Value	Design Results kg/cm^2	FEM		Variation (%)
		Results kg/cm^2	**References**	
Bottom and Intermediate Unit Line contact stress (SY)	9200	-4084.554 (SY)	Fig: 5.26(b)	-55.60
Top Unit Line contact stress (SY)	7800	-3134.533	Fig: 5.27(b)	-59.81

e) Maximum Deflection at Various Water Levels on the Gate

Table:5.22 Maximum Deflection In Gate

S. No	Component Name	FEM Results(cm)	Permissible Limit (cm)	References
1	Combined deflection of the Gate	1.797	2.34	Fig: 5.19(a)
2	Combined deflection of the Gate (with earthquake consideration)	1.931	2.34	Fig: 5.19(b)
3	Deflection at Maximum Pond Level	1.46	2.34	Fig: 5.19(c)
4	Deflection at High Flood Level	1.32	2.34	Fig: 5.19(c)
5	Deflection at Normal Pond Level	0.84	2.34	Fig: 5.19(c)

f) Maximum Deflection on the Horizontal Girders of the Gate

Table:5.23 Maximum Deflection In Horizontal Girders

S. No	Component Name	Conventional Results (cm)	FEM Results(cm)	Permissible Limit(cm)	References
1	Bottom Horizontal Girder	1.34	1.46	2.34	Fig: 5.22
2	Intermediate Horizontal Girder	1.19	1.17	2.34	Fig: 5.22
3	Top Horizontal Girder	0.77	1.03	2.34	Fig: 5.22

OPTIMAL DESIGN OF UNDER SLUICE GATE OF BHIMGODA BARRAGE

6.1 INTRODUCTION:

Gates are provided for regulating the flow in the reservoir to the downstream without damaging the dam or the downstream bed and help to store water in the reservoir for its use in the lean period. Under sluice gates are normally closed during non-flood season and are partly or fully open during flood season. Fixed wheel Vertical lift gate is normally used for controlling the flow of water through the under sluice. It is desired that the cost of the gate should be minimum with lesser weight of gate and hoisting capacity. To achieve these goals, the design of various components of the gates is to be optimized. The number of horizontal girders which control the skin plate thickness as well as section of vertical stiffeners and number of wheels control the section of end vertical girder. Hence the quantity of steel for the vertical lift gate depends on all these factors for a given water head.

Design optimization includes structural analysis, stress and displacement analysis on structure nested in the process of optimization.

6.2 MATHEMATICAL MODEL TO OPTIMIZATION:

Optimization variables: $x=[x_1, x_2 \ldots\ldots x_n]^T$

Object: $W(X) \longrightarrow \min$

S.T $\quad [\sigma \min] \leq \sigma \leq [\sigma \max]$

$\delta \max \leq [\delta \max]$

Where,

W(X) is the minimize the weight of gate

x is the number of horizontal girder and thickness of skin plate

σ, $[\sigma \min]$, $[\sigma \max]$ are the stress of gate, minimum and maximum permissible stress.

$\delta \max$, $[\delta \max]$ are the maximum of displacement and permissible deflection.

6.3 OPTIMAL NUMBER OF HORIZONTAL GIRDERS:

The width of gate is 18m and height is 8.4m. Symmetry between two supports is considered, 4-design sets of gate are investigated. These design sets are given in appendix-B. The calculation of stress and deflection is done by ANSYS which are shown here after.

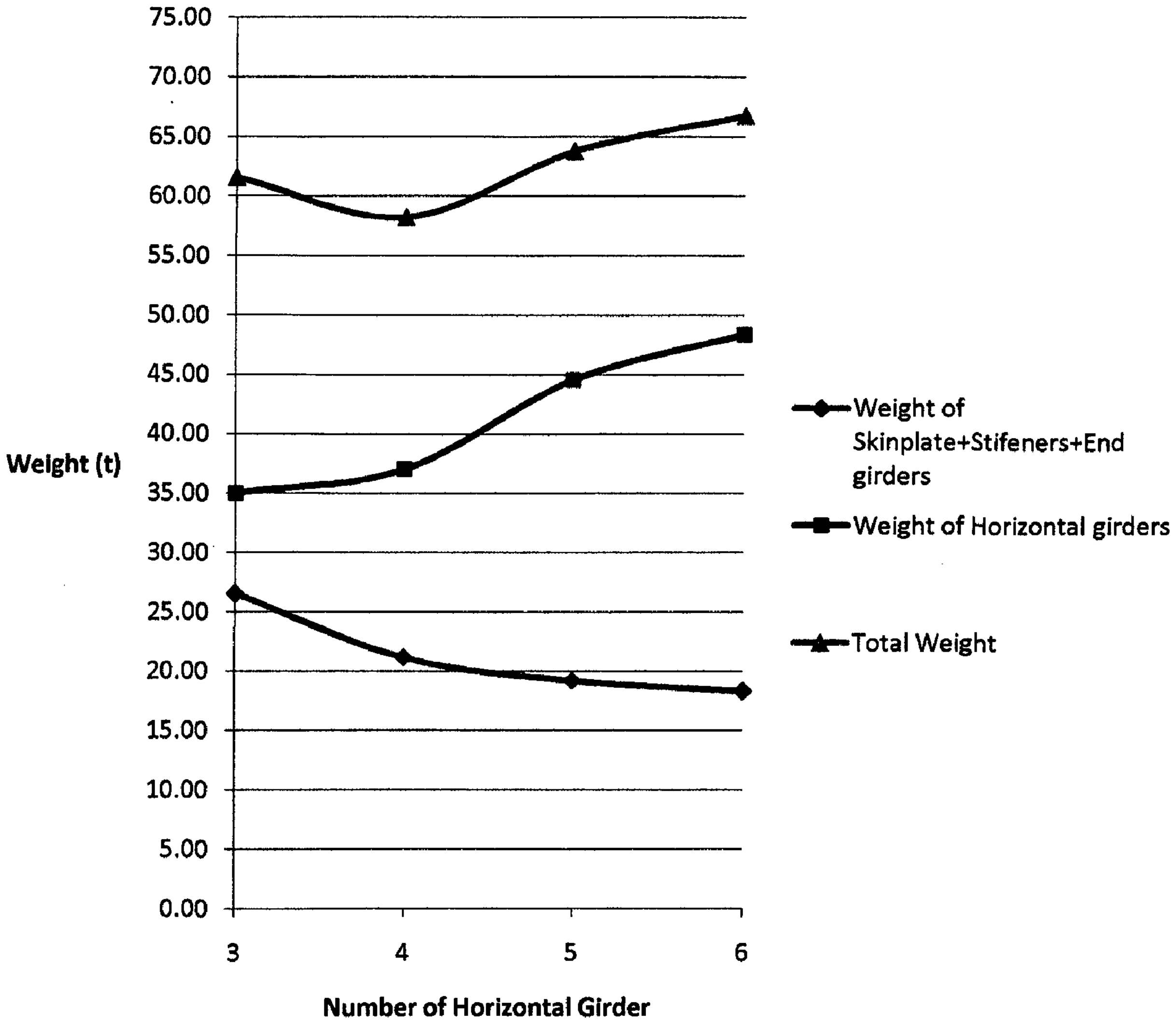


Figure : 6.1 Optimal number of horizontal girders

From the Fig. 6.1 & Table 5, appendix-B, it is observed that the minimum weight of the gate is 58.22 t in design set-2 when 4 number of girders are used. In the original design weight of the gate is 61.56 t when 3 numbers of girders used. Hence the steel quantity may be decreased by 5.42%.

6.4 COMPARISON OF DEFLECTION ON THE GATE BEFORE OPTIMIZATION AND AFTER OPTIMIZATION:

6.4.1 Deflection of the gate (before optimization)

FEM results (deflection and stresses) are presented in contour plots. as well as graphically in different sections as here after:

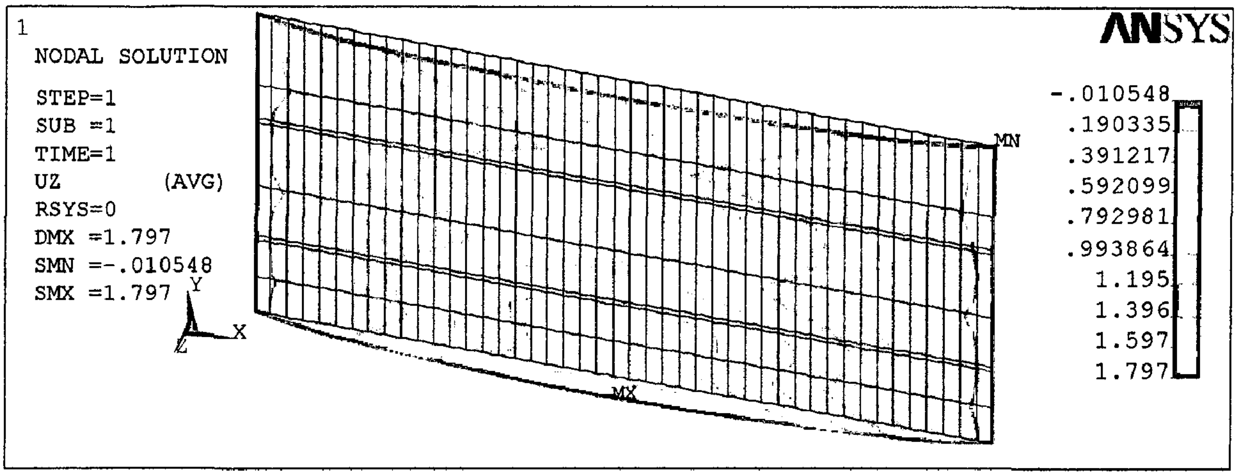


Figure: 6.2 the deflection of the gate full of water (before optimization)

6.4.2 Deflection of the gate (after optimization)

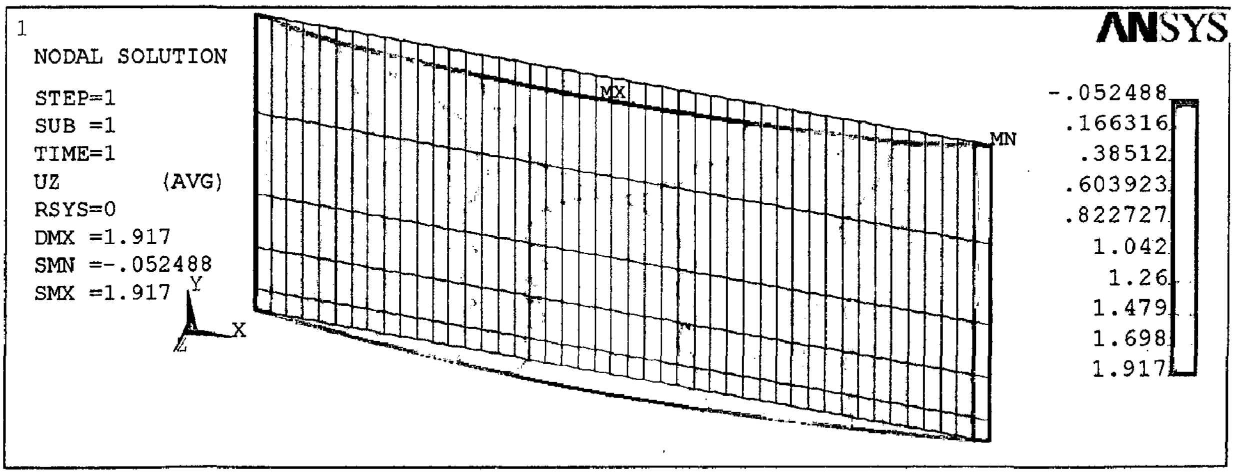


Figure: 6.3 the deflection of the gate full of water (after optimization)

It is distinct from the Fig: 6.2 & Fig: 6.3 and contour legends that maximum value of deflection of the gate (before optimization) is 1.797 cm and deflection of the gate (after optimization) is 1.917 cm. There is very little difference between the results and both the results are less than the limiting deflection=2.34 cm.

6.4.3 Deflection of the gate at different head (before optimization)

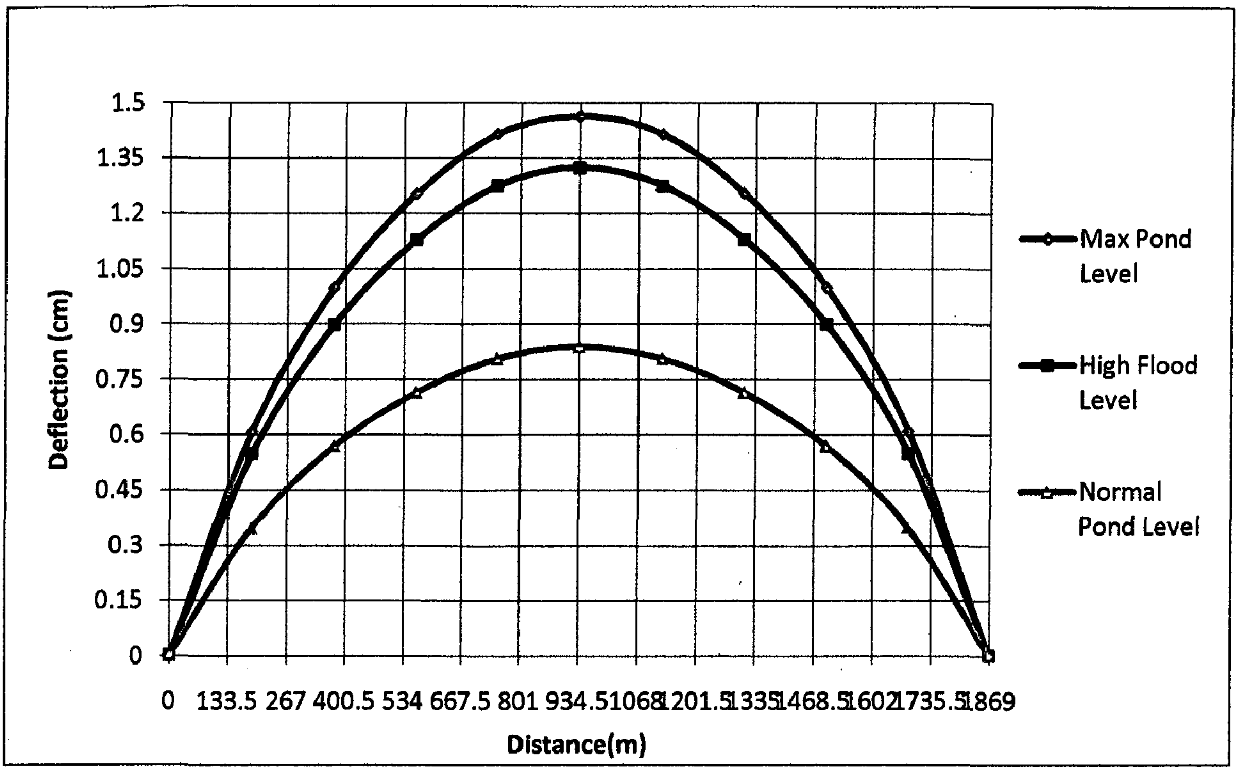


Figure: 6.4 Deflection of the gate at different head (before optimization)

6.4.4 Deflection of the gate at different head (after optimization)

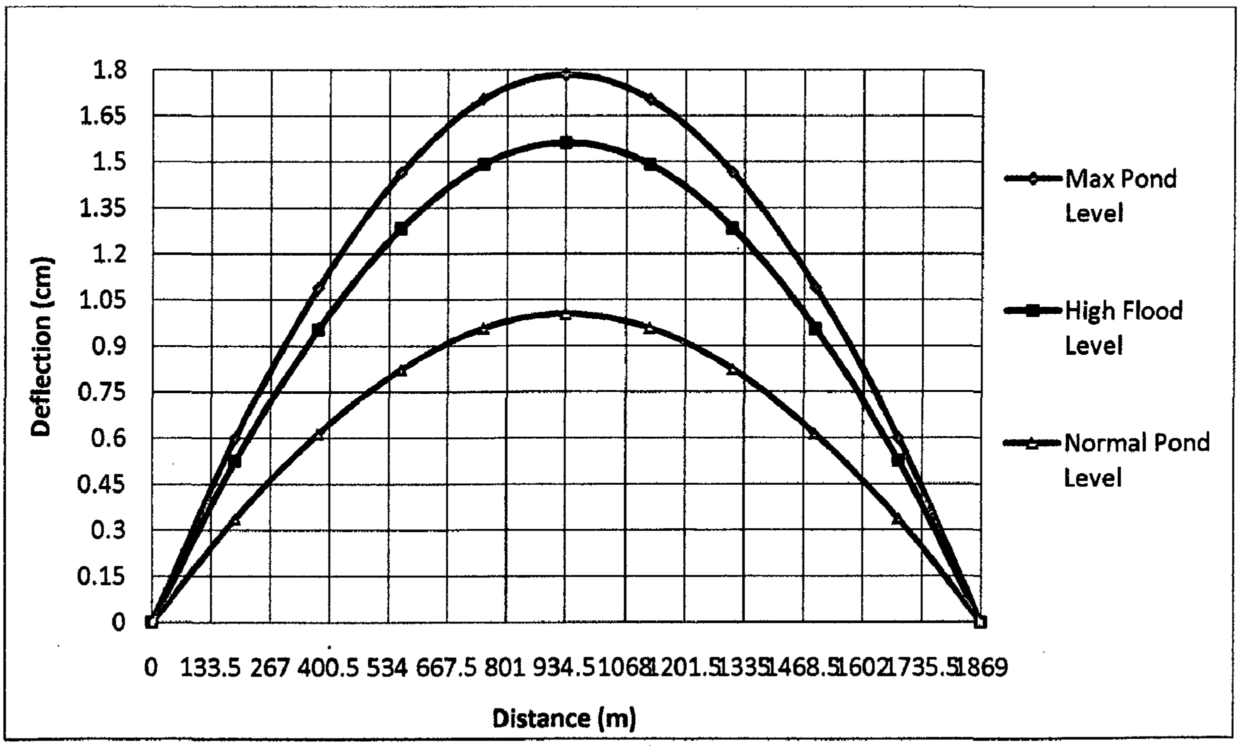


Figure: 6.5 Deflection of the gate at different head (after optimization)

Table: 6.1 Deflection of the gate at different head (before optimization)

DISTANCE (m)	DEFLECTION AT MAX POND LEVEL(cm)	DEFLECTION AT HIGH FLOOD (cm)	DEFLECTION AT NORMAL POND LEVEL (cm)
0	0.0018	0.0017	0.0010
186.8	0.6097	0.5487	0.3475
373.6	0.9982	0.8984	0.569
560.4	1.2531	1.1278	0.7142
747.2	1.4152	1.2737	0.8066
934	1.4641	1.3239	0.8384
1120.8	1.4161	1.2745	0.8071
1307.6	1.2547	1.1292	0.7151
1494.4	1.0003	0.9002	0.5701
1681.2	0.6114	0.5503	0.3485
1868	0.0018	0.0017	0.0010

Table: 6.2 Deflection of the gate at different head (after optimization)

DISTANCE (m)	DEFLECTION AT MAX POND LEVEL(cm)	DEFLECTION AT HIGH FLOOD (cm)	DEFLECTION AT NORMAL POND LEVEL (cm)
0	0	0	0.0000
186.8	0.60044	0.52538	0.3377
373.6	1.0905	0.95421	0.61342
560.4	1.4655	1.2823	0.82434
747.2	1.7037	1.4907	0.9583
934	1.785	1.5619	1.0041
1120.8	1.7036	1.4907	0.95828
1307.6	1.4654	1.2822	0.8243
1494.4	1.0904	0.95413	0.61337
1681.2	0.60037	0.52533	0.33771
1868	0.0000	0.0000	0.0000

From the Graph.6.2&6.3.Table.6.1&6.2 it is clear that maximum deflection at bottom girder of the gate is 1.4152cm (before optimization) and 1.785cm (after optimization). Hence both are less than the permissible limit=2.34 cm.

6.5 COMPARISON OF STRESSES ON THE GATE BEFORE OPTIMIZATION AND AFTER OPTIMIZATION:

6.5.1 Maximum Von Mises Stress of the Gate (Before Optimization)

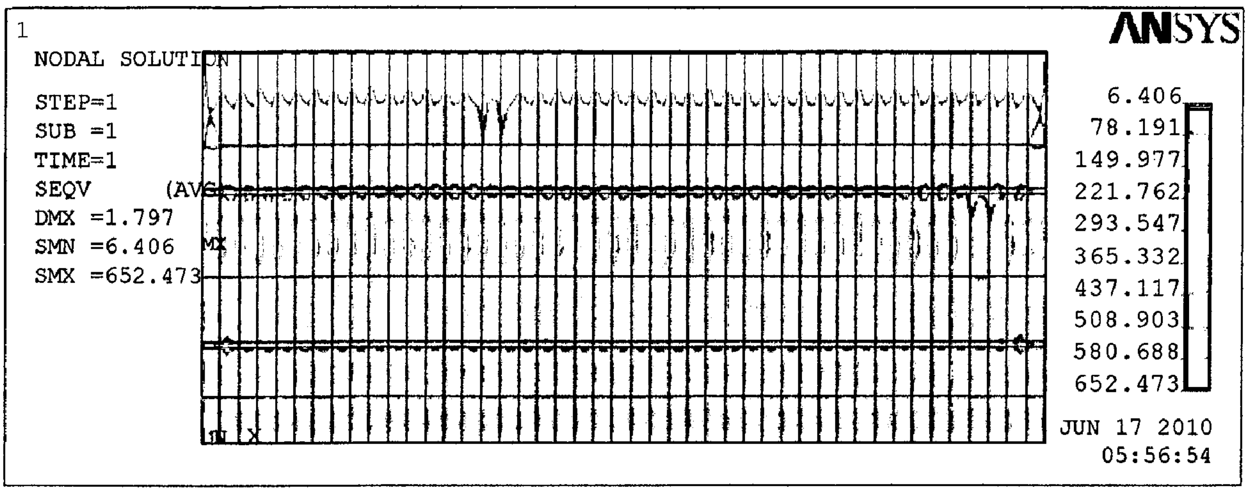


Figure: 6.6 Von Mises chart of the gate full of water (before optimization)

6.5.2 Maximum Von Mises Stress of the Gate (After Optimization)

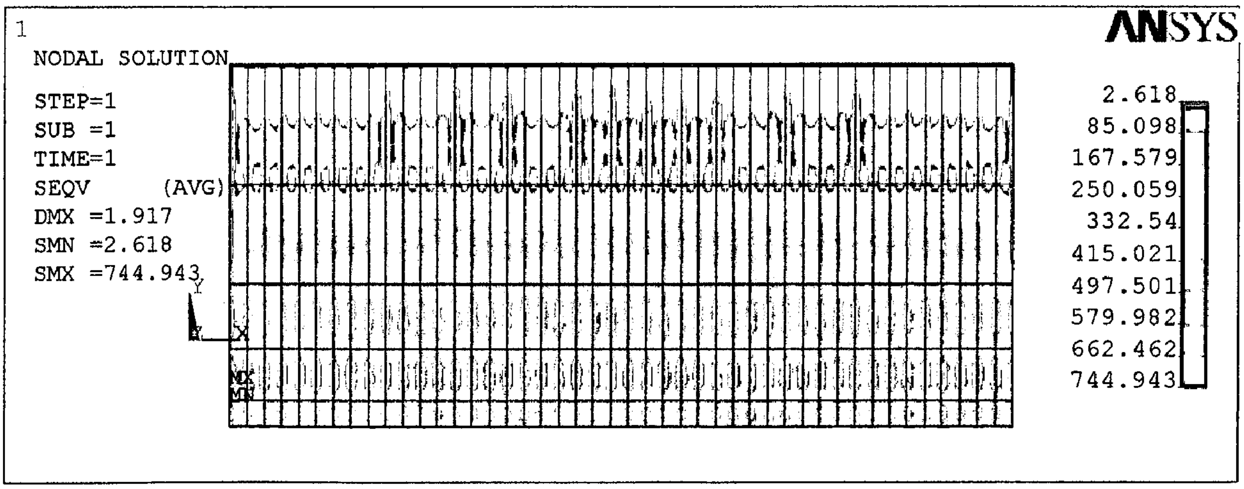


Figure: 6.7 Von Mises chart of the gate full of water (after optimization)

It is distinct from the Fig: 6.5, 6.6, 6.7 and Fig: 6.8 and contour legends that maximum value of Von Mises stress of the gate (before optimization) is 652.473 kg/cm^2 and Von Mises stress of the gate (after optimization) is 744.943 kg/cm^2. There is very little difference between two results. It is obvious that the value of Von Mises stress of the gate (after optimization) is more than the value of Von Mises stress of the gate (before optimization) but value is still less than the permissible stress=1080 kg/cm^2.

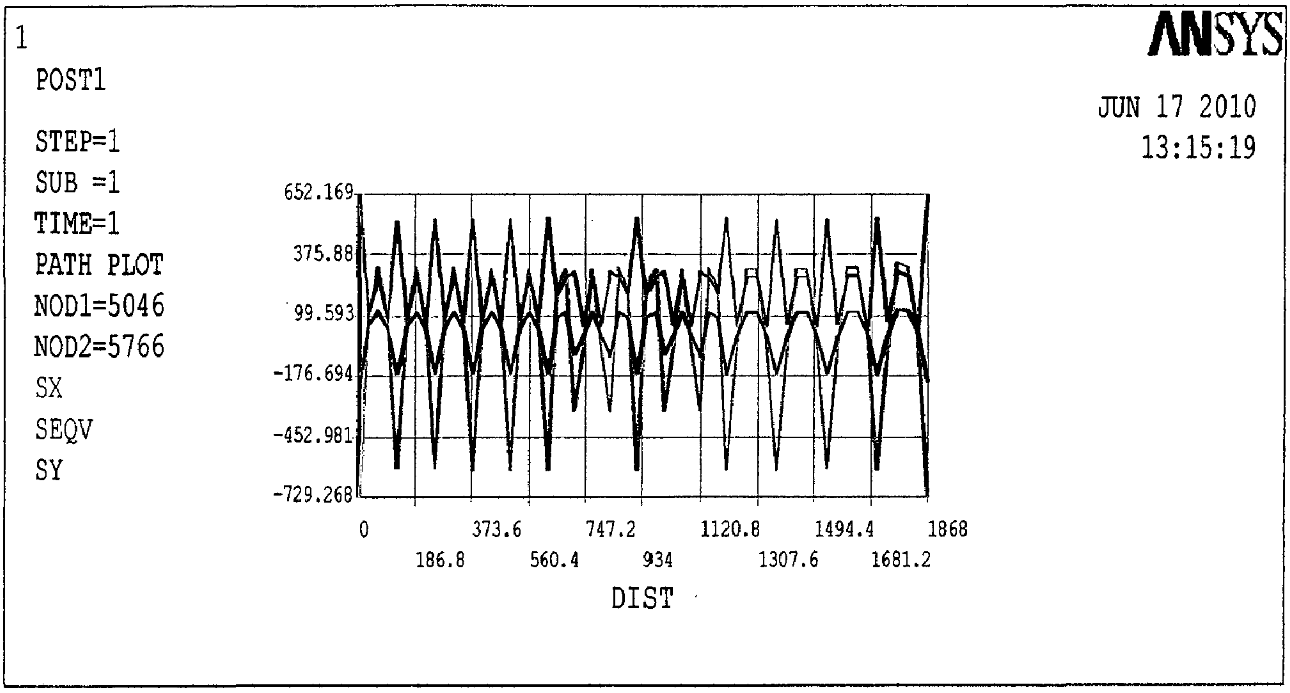


Figure: 6.8 Maximum Von Mises Stresses on the gate (before optimization)

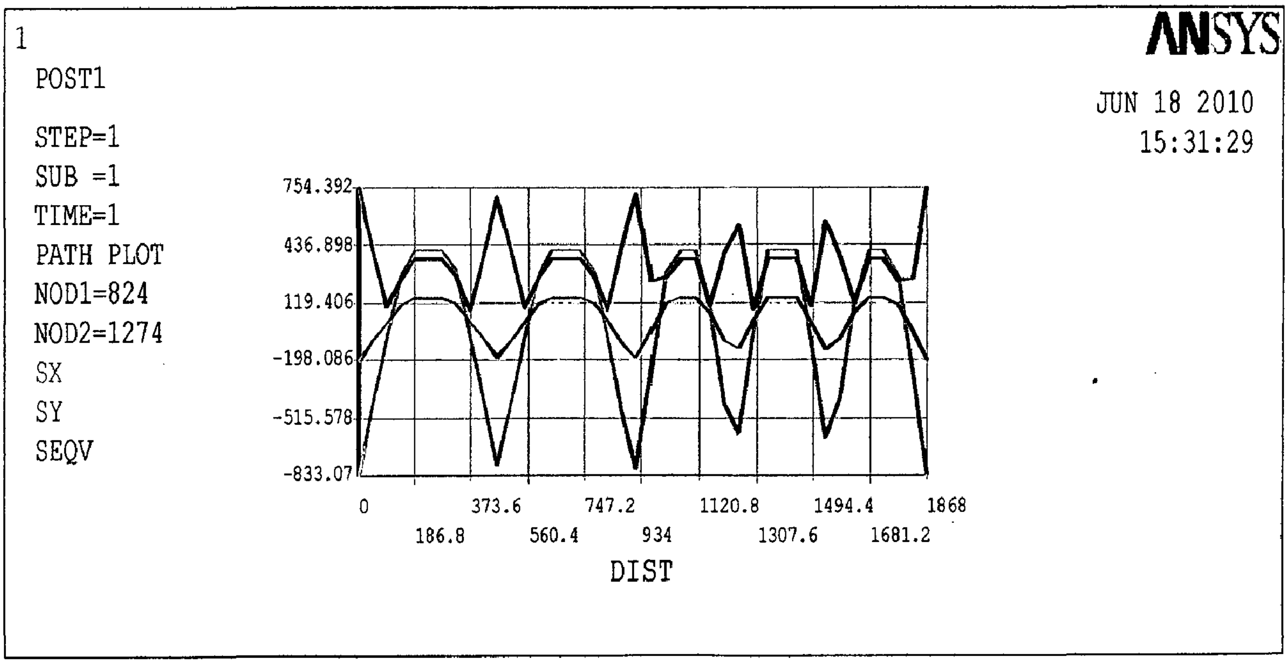


Figure: 6.9 Maximum Von Mises Stresses on the gate (after optimization)

6.6 OPTIMAL NUMBER OF WHEEL:

The width of gate is 18m and height is 8.4m. Symmetry between two supports is considered, In Excel we have made program for designing the end vertical girder and wheel which are brought forward in appendix-B. The calculation of stress and deflection is finished by ANSYS which are shown here after.

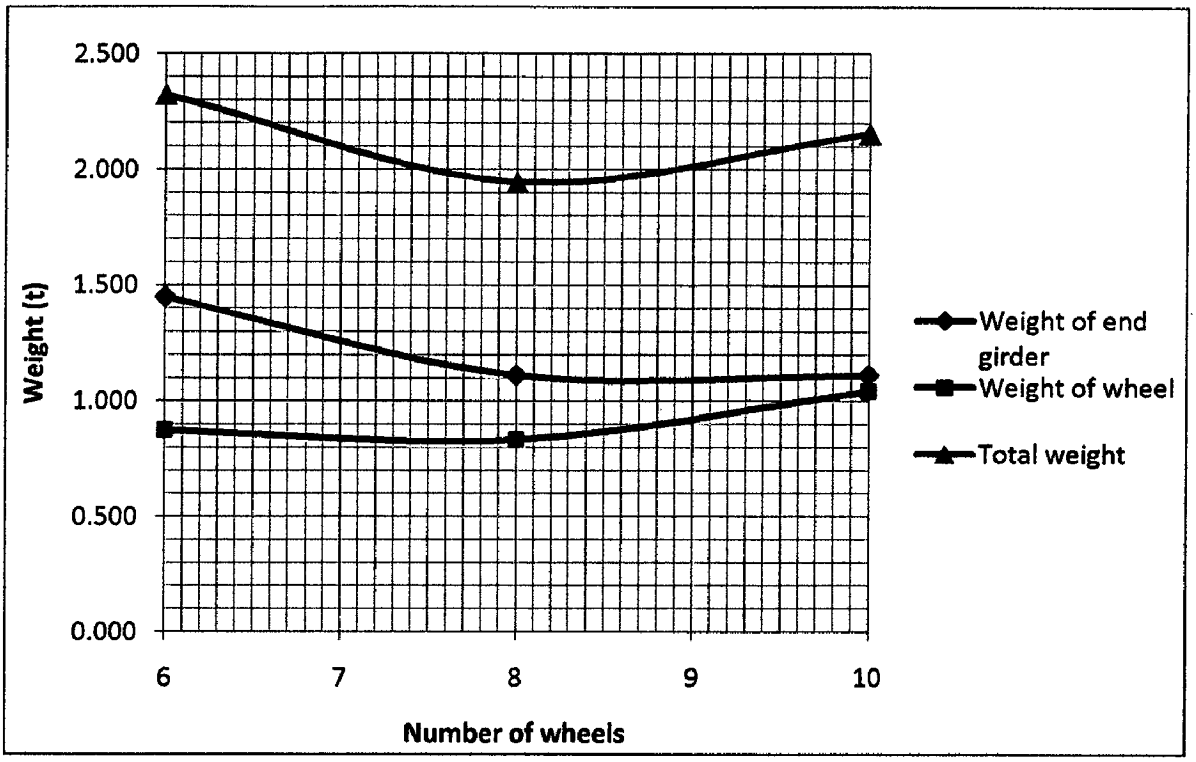


Figure: 6.10 Optimal number of wheels

Table: 6.3 Comparing the weight of wheel original design (before optimization) and optimal design (after optimization)

Name of Item	Number of wheels One side		Weight of end vertical girder (t)	Weight of wheel (t)	Total weight (t)
Design Set-1 (original design)	6	Ref: appendix-A, sec 7.4&10.1	1.4490	0.8735	2.3225
Design Set-2 (optimal design)	8	Ref: appendix-B, sec B.2.9	1.1130	0.8340	1.9470
Design Set-3	10	Ref: appendix-B, sec B.3.8	0.9810	1.0425	2.1555

The total steel weight of optimum design of wheels is 0.8340 t as compared to the original design where the weight is 0.8735 t. Thus the steel weight decreases by 4.52%.

6.6.1 COMPARISON OF STRESS ON WHEEL BEFORE OPTIMIZATION AND AFTER OPTIMIZATION:

Stress on the wheel before optimization: Equal number of wheels (six wheels) provided in each side. The size of wheel provided is 550 mm ф with 110 mm tread width contact for Bottom and center unit (ref: Appendix-A, sec-A.7.0). Here we have taken wheel of bottom and center unit because it is more heavily stressed than the wheel of top unit (ref: Chapter-5, sec-5.5.7).

Stress on the wheel before optimization: Equal number of wheels (eight wheels) provided in each side. The size of wheel provide is 450 mm ф with 90 mm tread width contact (ref: Appendix-A, sec-2.5).

Figure: 6.11 stress (before optimization)

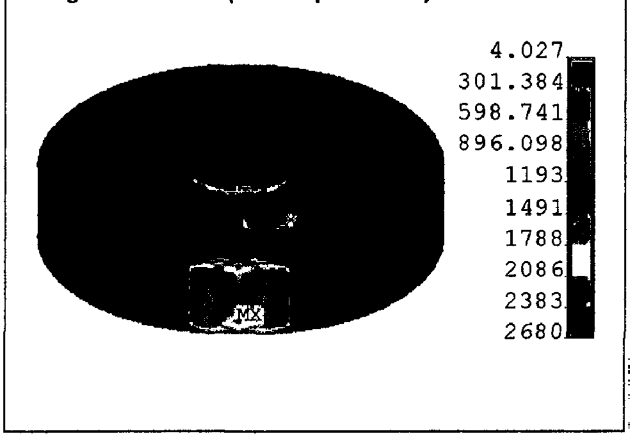


Figure: 6.12 stress (after optimization)

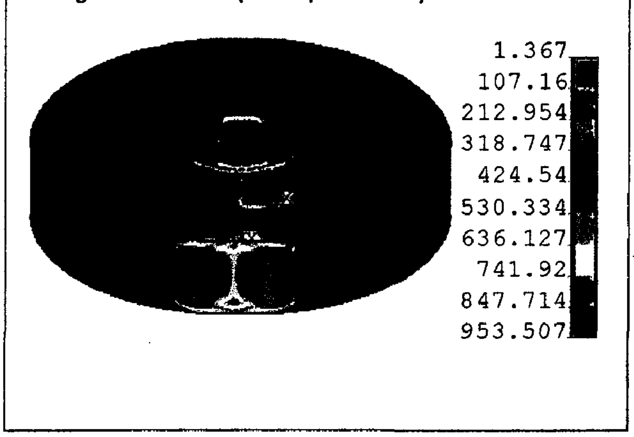


Figure: 6.13 Stress curve (before optimization)

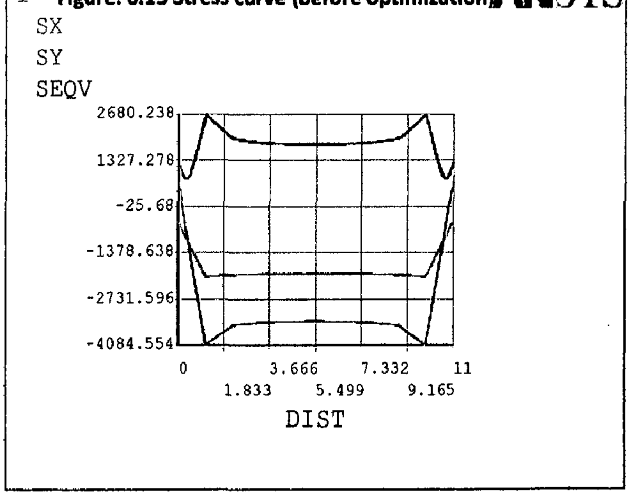
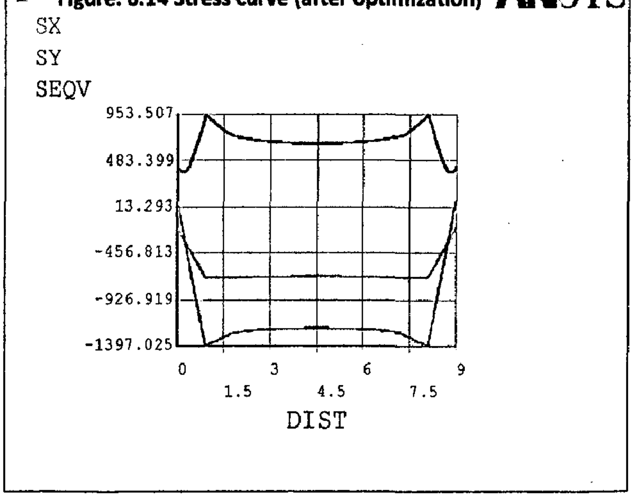


Figure: 6.14 Stress curve (after optimization)



The optimization result is shown in Fig.6.12, 6.14 and original design is shown in Fig.6.11, 6.13 is the stress charts of original design and optimization design. Comparing them, it is observed that the stress in the optimized design is more reasonable.

6.7 SUMMARY OF COMPARISON OF THE ORIGINAL DESIGN & OPTIMAL DESIGN RESULTS

6.7.1 COMPARISONS OF STRESSES BETWEEN ORIGINAL DESIGN AND OPTIMAL DESIGN

Table:6.4 Comparisons of Stresses between original design and optimal design.

Location and direction of results	Allowable stress (kg/cm^2)	Original Design		Optimal design results (kg/cm^2)		Variation (%)
			Ref:		Ref:	
Gate (Skin plate-Panel 'C') Equivalent Von Mises stress (SEQV)	1080	652.473	Fig:6.6	744.943	Fig:6.7	+14.17
Wheel Equivalent Von Mises stress (SEQV)	9300	2680.00	Fig:6.11	953.507	Fig:6.13	-64.42
Line contact stress (SY)		-4084.554	Fig:6.12	-1397.02	Fig:6.14	-65.79

6.7.2 COMPARISONS OF DEFLECTION BETWEEN ORIGINAL DESIGN AND OPTIMAL DESIGN

Table:6.5 Comparisons of Deflection In Gate between original design and optimal design.

S. No	Component Name	Permissible Limit (cm)	Original Design		Optimal design		Variation (%)
			results (cm)	Reference	results (cm))	Reference	
1	Combined deflection of the Gate	2.34	1.797	Fig: 6.2	1.9170	Fig: 6.3	+6.67
2	Deflection Maximum Pond Level	2.34	1.460	Fig: 6.4	1.7850	Fig: 6.5	+22.26
3	Deflection High Flood Level	2.34	1.320	Fig: 6.4	1.5619	Fig: 6.5	+18.32
4	Deflection Normal Pond Level	2.34	0.840	Fig: 6.4	1.0041	Fig: 6.5	+19.50

6.7.3 COMPARISONS OF WEIGHT BETWEEN ORIGINAL DESIGN AND OPTIMAL DESIGN

Table:6.6 Comparisons Weight of the Gate And Wheels between original design and optimal design.

S. No	Component Name	Original Design weight (t)	Optimal design weight (t)	Variation (%)	Reference
1	**Gate**	61.56	58.22	**-5.42**	Fig: 6.1
2	**Wheels**	0.8735	0.8340	**-4.52**	Fig: 6.10

CONCLUSIONS

7.1 GENERAL CONCLUSIONS:

Following general conclusions are drawn from this study of FEM analysis through ANSYS of under sluice gate of Bhimgoda barrage and its comparison with conventional design results while ensuring the safety of gate.

1. The maximum bending stresses (SX) in skin plate with vertical stiffeners occurs at panel-c (upper portion of gate unit second) which is 27% more than the conventional design result.

2. The FEM results of bending moment, shear force and bending stress in bottom horizontal girder are very close to conventional design results but in intermediate horizontal girder the results are around 14% less than the conventional design results.

3. In the case of top horizontal girder the bending moment, shear force are 19% more than the conventional design results and bending stress is 14% more than the conventional design results.

4. Bending moment and bending stress in the end vertical girder are 22 % less than the conventional design results. So that conventional design results are more conservative.

5. Line contact stress in the wheel of the bottom and intermediate unit are 55% less than the conventional design results and the same in top unit wheel is 59% less than the conventional design results.

6. An interesting observation derived from point 1 & 5; is that, the skin plate stresses are more than the conventional design method but stresses in the wheel are very less than the conventional design method. Conventional method uses a formula for calculating the line contact stress which is empirical and it was established in 1930 as reported in Univ. of Illinois engineering experiment station Bull.212 pp21 after Jhomas & Hoersch, in Hand book applied hydraulics page 396 by Calvin Victor Davis, McGraw hill, 1952.

7. The deflection at bottom and intermediate horizontal girders are very close to the conventional design results but in top girder the FEM results are 33% more than the conventional design results.

Overall, it is obvious from the FEM ANSYS study that, the conventional design results of under sluice gate of Bhimgoda barrage is quite safe but we should take care of the top horizontal girder and Skin plate Panel-C (upper portion of second unit of gate).

Following conclusions are drawn from optimization study of under sluice gate of Bhimgoda barrage.

1. Optimization studies related to number of horizontal girders reveal that the total steel quantity may be decreased by 5.42% with 4 numbers of horizontal girders. Four horizontal girder is the optimum number as against 3 girders provided in the existing gate.

2. Optimization studies related to number of wheels reveal that the total steel quantity may be decreased by 4.52% with 8 numbers of wheels on each side, which is optimum number of wheels as against 6 wheels on each side in the existing gate.

7.2 SCOPE FOR FURTHER WORK:

1. Similar optimization studies using FEM could be done for vertical lift type intake gates where head at top of the gate is not zero.

2. Similar optimization FEM analysis could also be done for radial gates.

3. Physical model studies of the gate may give more insight to stresses in various components of the gate including wheels.

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APPENDIX-A

DESIGN OF UNDER SLUICE GATE OF BHIMGODA BARRAGE

A.1.0 DESIGN DATA OF BHIMGODA BARRAGE:

1)	Type of gate	=	Fixed wheel vertical lift gate
2)	No. of openings	=	7
3)	No. of gates required	=	Right side (4 nos. Bays) Left side (3 nos. Bays)
4)	Clear width of opening	=	18.000 m
5)	Clear gate height / opening	=	8.400 m
6)	Sill Elevation	=	EL. 285.400 m
7)	Top of gate	=	EL. 293.800 m
8)	Right side (4 nos. Bays)	=	18 M x 8.40 M
9)	Left side (3 nos. Bays)	=	18 M x 8.40 M

A.2.0 PERMISSIBLE STRESSES:

Structural Steel (IS: 2062):

a. Y.P. = 2600 kg/cm^2 (for thickness Ł 20 mm)

b. Y.P. = 2400 kg/cm^2 (for thickness between 20mm and 40mm)

c. Y.P. = 2350 kg/cm^2 (for thickness Ƒ 40mm)

d. U.T.S = 4200 kg/cm^2 (for all thickness.)

Wet & accessible condition:

i.	Direct compression	0.45Y.P.	1080
ii.	Compression / tension in bending	0.45Y.P.	1080
iii.	Direct tension	0.45 Y.P.	1080
iv.	Shear Stress	0.35 Y.P.	840
v.	Combined Stress	0.60 Y.P.	1440
vi.	Bearing Stress	0.65 Y.P.	1560

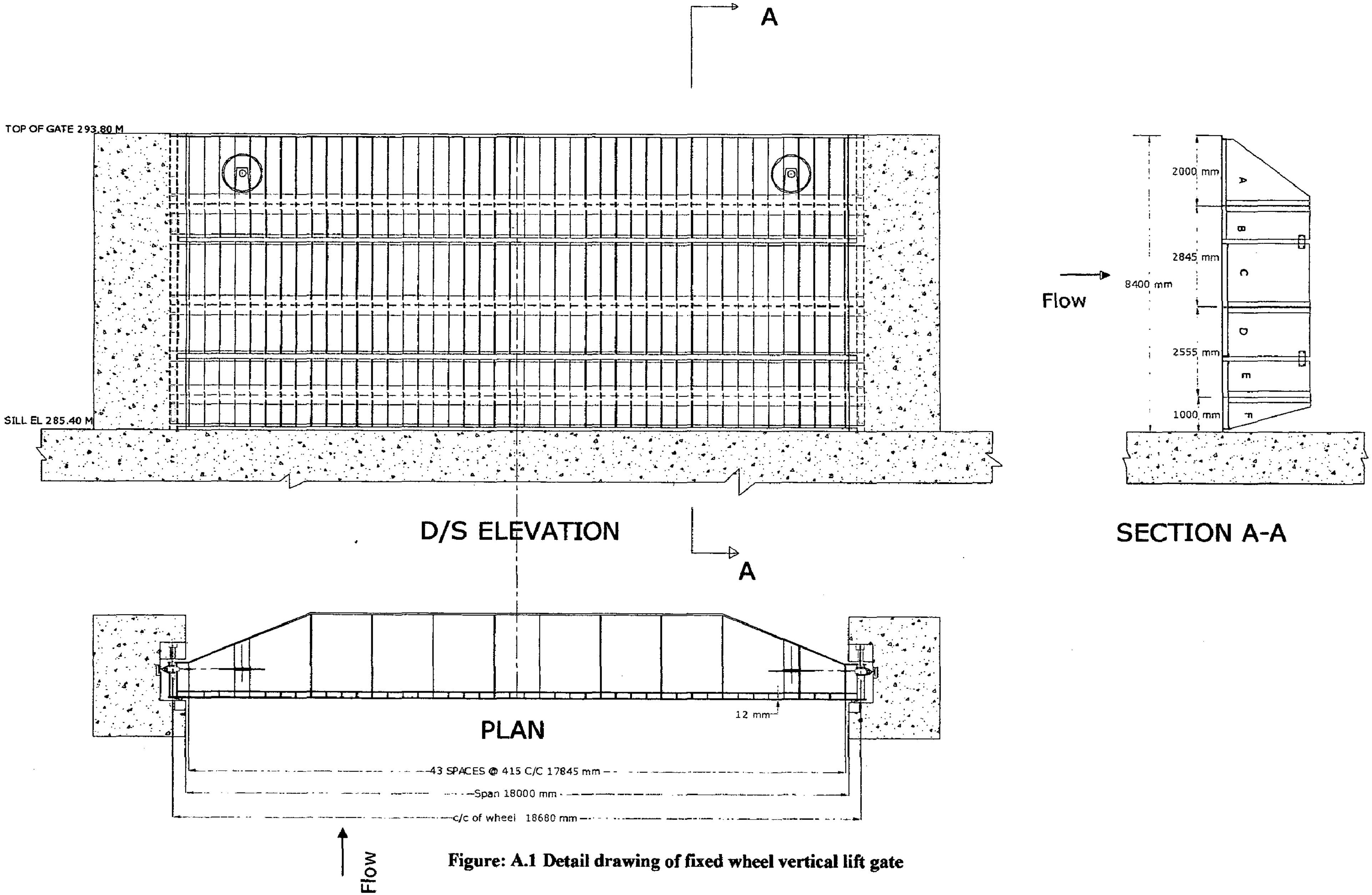


Figure: A.1 Detail drawing of fixed wheel vertical lift gate

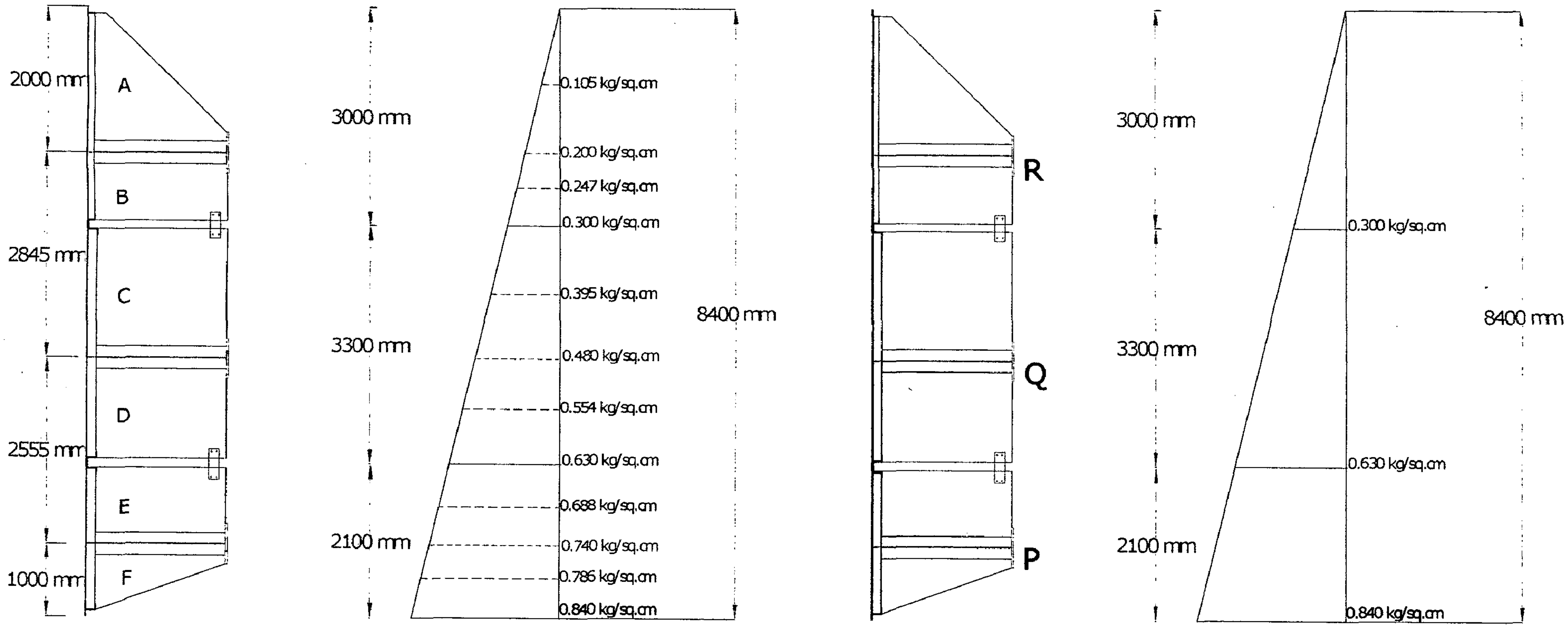


Figure: A.2 Pressure triangle diagram of the gate

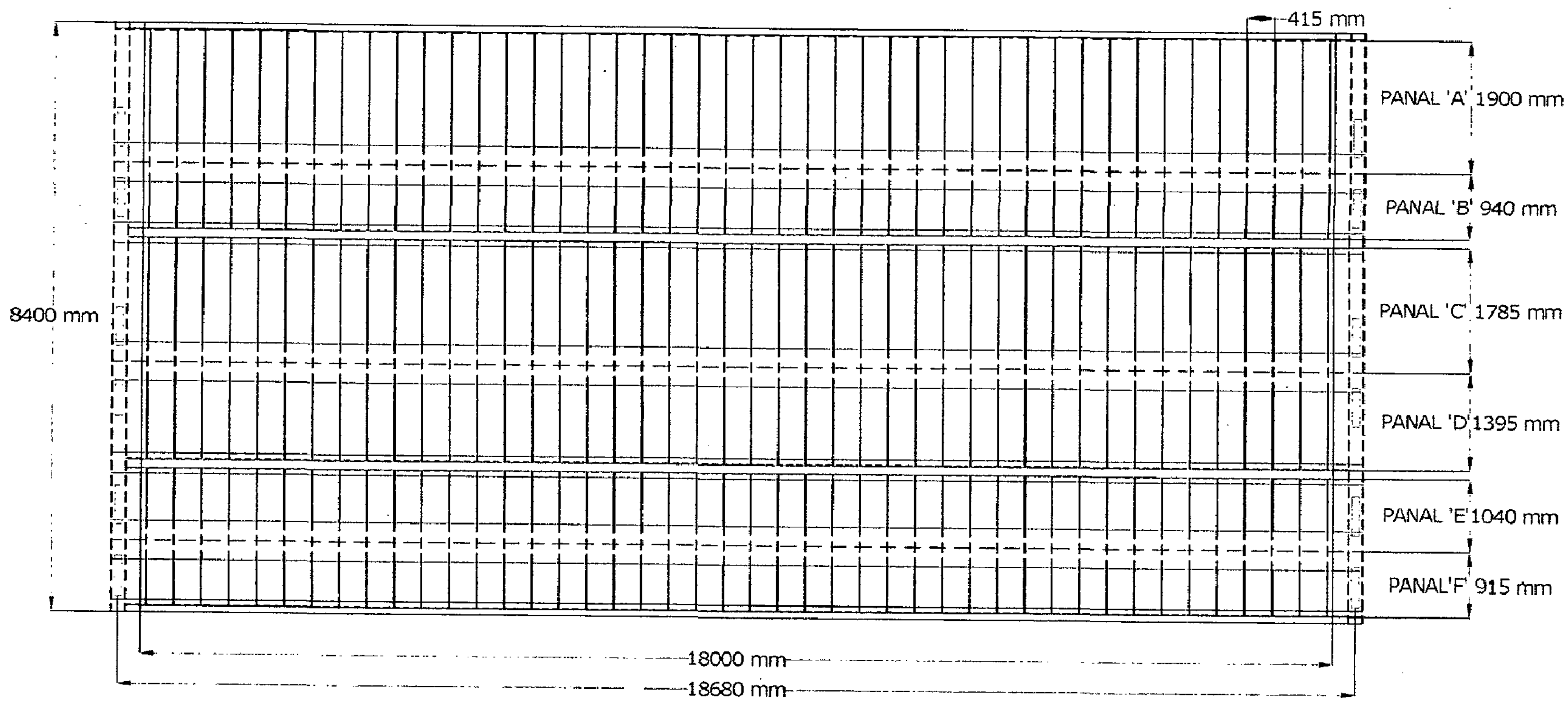


Figure: A.3 Skin plate panels of the gate

A.3.0 EFFECT OF HORIZONTAL EARTHQUAKE ACCELERATION ON GATE:

(Refer IS: 1893-1984 - Criteria for Earthquake Resistant Design of Structures –Clause 7.2)

Hydrodynamic pressure at depth y below the reservoir surface is given by:

p = $C_S.\alpha_h.W.h$ ---------------- (3.1)

Where p = hydro-dynamic pressure in kg/cm^2 at depth y

C_S = Co-efficient which varies with shape and depth

α_h = design horizontal seismic coefficient.

W = unit weight of water in kg/m^3 = 1000 kg/m^3 =1 t/m^3

$$C_S = \frac{C_m}{2}\left[\frac{y}{h}\left(2-\frac{y}{h}\right)+\sqrt{\frac{y}{h}\left(2-\frac{y}{h}\right)}\right] \quad \text{---------------- (3.2)}$$

y =depth below surface in meters

h =depth of reservoir in m = 8.40 m

∴ C_m =0.70 (for vertical surface)

α_h = $\beta I \alpha_o$ ---------------- (3.3)

β =a coefficient depending upon the soil foundation system (ref: table 3 IS 1893-1984) =1

I =a factor depending upon the importance of the structure (ref: table 4 IS 1893-1984) =2

α_o =basic horizontal seismic coefficient (ref: table 2 IS 1893-1984) =0.05

Put the above value in equation (3.3), we gat

α_h =0.10

Additional water pressure shall be computed at every one meter height.

When Y=1

$$C_S = \frac{0.7}{2}\left[\frac{1}{8.4}\left(2-\frac{1}{8.4}\right)+\sqrt{\frac{1}{8.4}\left(2-\frac{1}{8.4}\right)}\right]$$

C_S =0.244

∴ p =0.244× 0.10 × 1 × 1

=0.0244 t/m^2

=0.0244/1 x 100

=2.44% of water pressure

When Y=2

$$C_S = \frac{0.7}{2}\left[\frac{2}{8.4}\left(2-\frac{2}{8.4}\right)+\sqrt{\frac{2}{8.4}\left(2-\frac{21}{8.4}\right)}\right]$$

C_S =0.374

∴ p =0.374× 0.10 × 1 × 2

=0.0748 t/m^2

=0.0748/2 x 100

=3.74 % of water pressure

When Y=3

$C_S \quad = \frac{0.7}{2}\left[\frac{31}{8.4}\left(2-\frac{3}{8.4}\right)+\sqrt{\frac{3}{8.4}\left(2-\frac{3}{8.4}\right)}\right]$

$C_S \quad =0.473$

$\therefore \quad p \quad =0.473\times 0.10 \times 1 \times 3$

$=0.1419\ t/m^2$

$=0.1419/3 \times 100$

=4.73% of water pressure

When Y=4

$C_S \quad = \frac{0.7}{2}\left[\frac{4}{8.4}\left(2-\frac{4}{8.4}\right)+\sqrt{\frac{4}{8.4}\left(2-\frac{4}{8.4}\right)}\right]$

$C_S \quad =0.552$

$\therefore \quad p \quad =0.552\times 0.10 \times 1 \times 4$

$=0.02208\ t/m^2$

$=0.2208/4 \times 100$

=5.52% of water pressure

When Y=5

$C_S \quad = \frac{0.7}{2}\left[\frac{5}{8.4}\left(2-\frac{5}{8.4}\right)+\sqrt{\frac{5}{8.4}\left(2-\frac{5}{8.4}\right)}\right]$

$C_S \quad =0.613$

$\therefore \quad p \quad =0.613\times 0.10 \times 1 \times 5$

$=0.3065\ t/m^2$

$=0.3065/5 \times 100$

=6.13% of water pressure

When Y=6

$C_S \quad = \frac{0.7}{2}\left[\frac{6}{8.4}\left(2-\frac{6}{8.4}\right)+\sqrt{\frac{6}{8.4}\left(2-\frac{6}{8.4}\right)}\right]$

$C_S \quad =0.6568$

$\therefore \quad p \quad =0.6568\times 0.10 \times 1 \times 6$

$=0.0244\ t/m^2$

$=0.394/6 \times 100$

=6.57% of water pressure

When Y=7

$$C_S = \frac{0.7}{2}\left[\frac{7}{8.4}\left(2-\frac{7}{8.4}\right)+\sqrt{\frac{7}{8.4}\left(2-\frac{7}{8.4}\right)}\right]$$

C_S =0.685

∴ p =0.685× 0.10 × 1 × 7

=0.4795 t/m^2

=0.4795/7 x 100

=6.85% of water pressure

When Y=8

$$C_S = \frac{0.7}{2}\left[\frac{8}{8.4}\left(2-\frac{8}{8.4}\right)+\sqrt{\frac{8}{8.4}\left(2-\frac{8}{8.4}\right)}\right]$$

C_S =0.699

∴ p =0.699× 0.10 × 1 × 8

=0.5592 t/m^2

=0.5592/8 x 100

=6.99% of water pressure

When Y=8.4

$$C_S = \frac{0.7}{2}\left[\frac{8.4}{8.4}\left(2-\frac{8.4}{8.4}\right)+\sqrt{\frac{8.4}{8.4}\left(2-\frac{8.4}{8.4}\right)}\right]$$

C_S =0.7

∴ p =0.7× 0.10 × 1 × 8.4

=0.588 t/m^2

=0.588/8.4 x 100

=7% of water pressure

It will be seen that maximum increase in water pressure is only 7%, while the permissible increase in stresses during earth quake is $33\frac{1}{3}$% (IS: 4622).

So that $33\frac{1}{3}\% > 7\%$

Therefore the stresses during earth quack will be within safe limit.

A.4.0 DESIGN OF SKIN PLATE - (Refer Fig. – A.1, A.2, A.3)
The skin plate is supported on three Horizontal Girders and the Vertical Stiffeners placed @ 415 mm c/c .Skin plate is designed as panel construction supported on all the four edges.

The bending Stresses in Flat-plate is computed from the following formula (IS 4622)

$$\sigma = \frac{k}{100} \times p \times \frac{a^2}{s^2} \quad \text{------------------------- (1)}$$

Where

σ	=	Bending Stress in flat plate in kg/cm^2
k	=	Non dimensional constant depending upon values of a and b
p	=	Water pressure in kg/cm^2 (Relative to the plate centre)
a, b	=	Bay width in cm
s	=	Plate thickness in cm.

Here in our case all the edges are rigidly fixed. Therefore coefficients shall be as per IS-4622.
Adopted thickness of skin plate in panel –A-B-C=8 mm
Adopted thickness of skin plate in panel –D-E-F =12 mm

A.4.1 Design of Panel –A:

b = 190 cm
a = 41.5 cm
Avg. p = 0.105 kg/cm^2 (Fig A.2)
S = 0.80 cm.
∴b/a = 190 / 41.5 = 4.58

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}	σ_{4y}
4.58	25	7.5	50	34.2

Above values put in equation no. (1)

σ_{2x} = 70.64 kg/cm^2
σ_{2y} = 21.19 kg/cm^2
σ_{3x} = 141.28 kg/cm^2 < 1080 kg/cm^2
$\sigma_{3y}=0.3\,\sigma_{3x}$ = 42.38 kg/cm^2
σ_{4y} = 96.63 kg/cm^2 < 1080 kg/cm^2

A.4.2 Design of Panel –B:

b = 94 cm a = 41.5 cm
∴b/a = 94 / 41.5 = 2.26
Avg. p = 0.247 kg/cm^2
S = 0.8 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}	σ_{4y}
2.26	24.7	9.5	49.85	34.3

Above values put in equation no. (1)

σ_{2x} = 164.18 kg/cm^2
σ_{2y} = 63.14 kg/cm^2
σ_{3x} = 331.34 kg/cm^2 < 1080 kg/cm^2

σ_{3y} = 99.40 kg/cm^2
σ_{4y} = 227.99 kg/cm^2 < 1080 kg/cm^2

A.4.3 Design of Panel –C:

b = 178.5 cm   a = 41.5 cm
∴ b/a = 178.5 / 41.5 = 4.30
Avg. p = 0.395 kg/cm^2 (Fig A.2)
S = 0.8 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}	σ_{4y}
4.30	25	7.5	50	34.2

Above values put in equation no. (1)

σ_{2x} = 265.64 kg/cm^2
σ_{2y} = 79.72 kg/cm^2
σ_{3x} = 531.48 kg/cm^2 < 1080 kg/cm^2
σ_{3y} = 159.44 kg/cm^2
σ_{4y} = 363.50 kg/cm^2 < 1080 kg/cm^2

A.4.4 Design of Panel –D:

b = 139.5 cm   a = 41.5 cm
∴ b/a = 139.5 / 41.5 = 3.36
Avg. p = 0.554 kg/cm^2 (Fig A.2)
S = 1.20 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}	σ_{4y}
4.58	25	7.5	50	34.2

Above values put in equation no. (1)

σ_{2x} = 165.65 kg/cm^2
σ_{2y} = 49.69 kg/cm^2
σ_{3x} = 331.29 kg/cm^2 < 1080 kg/cm^2
σ_{3y} = 99.38 kg/cm^2
σ_{4y} = 226.61 kg/cm^2 < 1080 kg/cm^2

A.4.5 Design of Panel –E:

b = 104 cm   a = 41.5 cm
∴ b/a = 104 / 41.5 = 2.5
Avg. p = 0.688 kg/cm^2 (Fig A.2)
S = 1.20 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}	σ_{4y}
4.58	25	8	50	34.3

Above values put in equation no. (1)

σ_{2x} = 205.71 kg/cm^2
σ_{2y} = 65.83 kg/cm^2
σ_{3x} = 411.43 kg/cm^2 < 1080 kg/cm^2

σ_{3y} = 123.42 kg/cm^2

σ_{4y} = 274.03 kg/cm^2 < 1080 kg/cm^2

A.4.6 Design of Panel –F:

b = 91.5 cm a = 41.5 cm

∴b/a = 91.5 / 41.5 = 2.20

Avg. p = 0.789 kg/cm^2 (Fig A.2)

S = 1.20 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}	σ_{4y}
4.58	24.8	9.4	49.82	34.3

Above values put in equation no. (1)

σ_{2x} = 232.84 kg/cm^2

σ_{2y} = 88.25 kg/cm^2

σ_{3x} = 468.34 kg/cm^2 < 1080 kg/cm^2

σ_{3y} = 140.50 kg/cm^2

σ_{4y} = 323.67 kg/cm^2 < 1080 kg/cm^2

A.4.7 Check For Corrosion Allowance Taking Into Consideration:

Consider corrosion allowance = 1.5 mm

So, effective thickness of skin plate = 6.5 mm or 0.65 cm (panel-A-B-C)

A.4.7.1 Design of Panel –A:

b = 190 cm

a = 41.5 cm

Avg. p = 0.105 kg/cm^2

S = 0.65 cm.

∴b/a = 190 / 41.5 = 4.58

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
4.58	25	7.5	50

Above values put in equation no. (1)

σ_{2x} = 107.00 kg/cm^2

σ_{2y} = 32.10 kg/cm^2

σ_{3x} = 214.01 kg/cm^2

$\sigma_{3y}=0.3\,\sigma_{3x}$ = 64.20 kg/cm^2

A.4.7.2 Design of Panel –B:

b = 94 cm a = 41.5 cm

∴ b/a = 94 / 41.5 =2.26

Avg. p = 0.247 kg/cm^2

S =0.65 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
4.58	24.7	9.5	49.85

Above values put in equation no. (1)

σ_{2x} = 248.69 kg/cm^2

σ_{2y} = 95.65 kg/cm^2

σ_{3x} = 501.92 kg/cm^2

σ_{3y} = 150.57 kg/cm^2

A.4.7.3 Design of Panel –C:

b = 178.5 cm a = 41.5 cm

∴ b/a = 178.5 / 41.5 =4.30

Avg. p = 0.395 kg/cm^2

S =0.65 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
4.58	25	7.5	50

Above values put in equation no. (1)

σ_{2x} = 402.54 kg/cm^2

σ_{2y} = 120.76 kg/cm^2

σ_{3x} = 805.04 kg/cm^2

σ_{3y} = 241.52 kg/cm^2

Consider corrosion allowance = 1.5 mm

So, effective thickness of skin plate = 10.5 mm or 0.105 cm (panel-D-E-F)

A.4.7.4 Design of Panel –D:

b = 139.5 cm a = 41.5 cm

∴ b/a = 139.5 / 41.5 = 3.36

Avg. p = 0.554 kg/cm^2

S =1.05 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{4x}
4.58	25	7.5	50

Above values put in equation no. (1)

σ_{2x} = 216.36 kg/cm^2

σ_{2y} = 64.91 kg/cm^2

σ_{3x} = 432.71 kg/cm^2

σ_{3y} = 129.81 kg/cm^2

A.5.2 Stiffener For Panel-B:

Average Pressure = 0.247 kg/cm^2

Length= 41.5 cm

W = 10.251 kg/cm.lenght

Span = 94 cm

R_A=R_B = 481.8 kg

Maximum B.M =$wl^2/8$ 11322 kg.cm

The effective width of skin plate.

1. B+40t = 32.8 cm
2. c/c of span= 41.5 cm
3. 0.11xspan = 10.34 cm

least of above = 10.34 cm

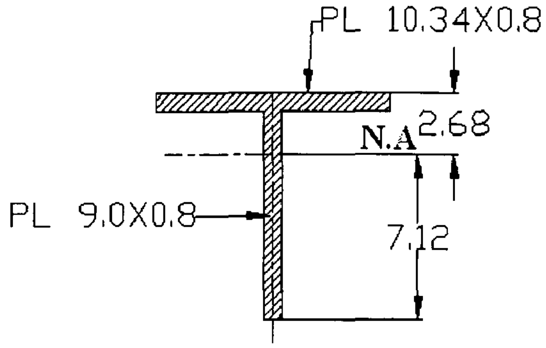


Figure: A.5 Section of vertical stiffener for panel-B

Table: A.2 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
		b(cm)	h(cm)	(bxh)	dist. From X	(cm3)	(cm4)	(bh3/12)
1	skin plate	10.34	0.8	8.272	0.4	3.3088	1.32352	0.441173
2	web	0.8	9.0	7.2	5.3	38.16	202.248	48.6
				15.472		**41.4688**	**203.5715**	**49.04117**

Y_t=sum(AY)/sum(A) = 2.68 cm Y=h_1+h_2= 9.8 cm

Y_c=(Y-Y_t)= 7.12 cm M= 11322 kg-cm

I_{zz}=skin plate($hxb^3/12$)+web($hxb^3/12$)= 74.08 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 141.47 cm^4

$Z_t=I_{yy}/Y_t$ = 52.78 cm^3

$Z_c=I_{yy}/Y_c$= 19.87 cm^3

Skin Plate Stress σ_t=M/Z_t= 214.50 kg/cm^2 ok < 1080 kg/cm^2

Stiffener Stress σ_c=M/Z_c= 569.80 kg/cm^2 ok < 1080 kg/cm^2

A.4.7.2 Design of Panel –B:

b = 94 cm a = 41.5 cm

∴ b/a = 94 / 41.5 =2.26

Avg. p = 0.247 kg/cm^2

S =0.65 cm.

Maximum value of 'k' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
4.58	24.7	9.5	49.85

Above values put in equation no. (1)

σ_{2x} = 248.69 kg/cm^2

σ_{2y} = 95.65 kg/cm^2

σ_{3x} = 501.92 kg/cm^2

σ_{3y} = 150.57 kg/cm^2

A.4.7.3 Design of Panel –C:

b = 178.5 cm a = 41.5 cm

∴ b/a = 178.5 / 41.5 =4.30

Avg. p = 0.395 kg/cm^2

S =0.65 cm.

Maximum value of 'k' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
4.58	25	7.5	50

Above values put in equation no. (1)

σ_{2x} = 402.54 kg/cm^2

σ_{2y} = 120.76 kg/cm^2

σ_{3x} = 805.04 kg/cm^2

σ_{3y} = 241.52 kg/cm^2

Consider corrosion allowance = 1.5 mm

So, effective thickness of skin plate = 10.5 mm or 0.105 cm (panel-D-E-F)

A.4.7.4 Design of Panel –D:

b = 139.5 cm a = 41.5 cm

∴ b/a = 139.5 / 41.5 = 3.36

Avg. p = 0.554 kg/cm^2

S =1.05 cm.

Maximum value of 'k' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{4x}
4.58	25	7.5	50

Above values put in equation no. (1)

σ_{2x} = 216.36 kg/cm^2

σ_{2y} = 64.91 kg/cm^2

σ_{3x} = 432.71 kg/cm^2

σ_{3y} = 129.81 kg/cm^2

A.4.7.5 Design of Panel –E:

b = 104 cm a = 41.5 cm

∴ b/a = 104 / 41.5 = 2.5

Avg. p = 0.688 kg/cm^2

S =1.05 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{4x}
4.58	25	8	50

Above values put in equation no. (1)

σ_{2x} = 268.69 kg/cm^2

σ_{2y} = 85.98 kg/cm^2

σ_{3x} = 537.37 kg/cm^2

σ_{3y} = 161.21 kg/cm^2

A.4.7.6 Design of Panel –F:

b = 91.5 cm a = 41.5 cm

∴ b/a = 91.5 / 41.5 = 2.20

Avg. p = 0.789 kg/cm^2

S =1.05 cm.

Maximum value of '**k**' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{4x}
4.58	24.8	9.4	49.82

Above values put in equation no. (1)

σ_{2x} = 305.67 kg/cm^2

σ_{2y} = 115.86 kg/cm^2

σ_{3x} = 614.04 kg/cm^2

σ_{3y} = 184.21 kg/cm^2

A.5.0 DESIGN OF VERTICAL STIFFENERS:

A.5.1 Stiffener For Panel-A:

Average Pressure = 0.105 kg/cm^2

Length= 41.5 cm

W = 4.358 kg/cm.lenght

Span = 190 cm

$R_A=R_B$ = 414.0 kg

Maximum B.M $=wl^2/8$ 19663 kg.cm

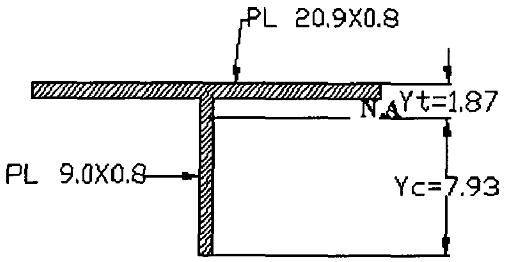


Figure: A.4 Section of vertical stiffener for panel-A

The effective width of skin plate.

1. B+40t = 32.8 cm
2. c/c of span= 41.5 cm
3. 0.11xspan = 20.9 cm

least of above = 20.9 cm

Table: A.1 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
		b(cm)	h(cm)	(bxh)	dist. From X	(cm3)	(cm4)	(bh3/12)
1	skin plate	20.9	0.8	16.72	0.4	6.688	2.6752	0.891733
2	web	0.8	9.0	7.2	5.3	38.16	202.248	48.6
				23.92		**44.848**	**204.9232**	**49.49173**

Y_t=sum(AY)/sum(A) = 1.87 cm Y=h_1+h_2= 9.8 cm

$Y_c=(Y-Y_t)$= 7.93 cm M= 19663 kg-cm

I_{zz}=skin plate$(hxb^3/12)$+web$(hxb^3/12)$= 609.01 cm^4

$I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2$ = 170.33 cm^4

$Z_t=I_{yy}/Y_t$ = 90.85 cm^3

$Z_c=I_{yy}/Y_c$= 21.49 cm^3

Skin Plate Stress $\sigma_t=M/Z_t$= 216.45 kg/cm^2 ok < 1080 kg/cm^2

Stiffener Stress $\sigma_c=M/Z_c$= 914.89 kg/cm^2 ok < 1080 kg/cm^2

A.5.2 Stiffener For Panel-B:

Average Pressure =	0.247	kg/cm^2
Length=	41.5	cm
W =	10.251	kg/cm.lenght
Span =	94	cm
R_A=R_B =	481.8	kg
Maximum B.M =$wl^2/8$	11322	kg.cm

The effective width of skin plate.

1.	B+40t =	32.8	cm
2.	c/c of span=	41.5	cm
3.	0.11xspan =	10.34	cm

least of above = 10.34 cm

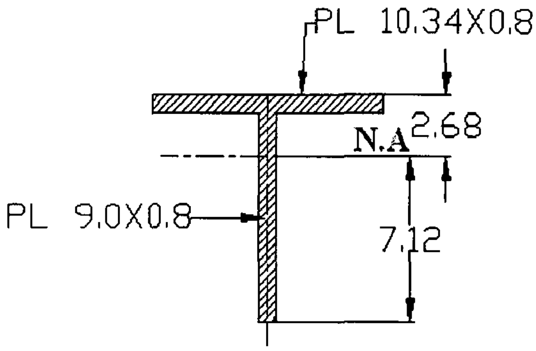


Figure: A.5 Section of vertical stiffener for panel-B

Table: A.2 Calculation of Neutral Axis and Modulus of section:

Item No	**Item**	**Size**		**A(cm^2)**	**Y(cm)**	**A.Y**	**A.Y^2**	**I_{self}(cm^4)**
		b(cm)	**h(cm)**	**(bxh)**	**dist. From X**	**(cm3)**	**(cm4)**	**(bh3/12)**
1	skin plate	10.34	0.8	8.272	0.4	3.3088	1.32352	0.441173
2	web	0.8	9.0	7.2	5.3	38.16	202.248	48.6
				15.472		**41.4688**	**203.5715**	**49.04117**

Y_t=sum(AY)/sum(A) = 2.68 cm Y=h_1+h_2= 9.8 cm

Y_c=(Y-Y_t)= 7.12 cm M= 11322 kg-cm

I_{zz}=skin plate($hxb^3/12$)+web($hxb^3/12$)= 74.08 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 141.47 cm^4

$Z_t=I_{yy}/Y_t$ = 52.78 cm^3

$Z_c=I_{yy}/Y_c$= 19.87 cm^3

Skin Plate Stress	σ_t=M/Z_t=	214.50	kg/cm^2	**ok**	< 1080	kg/cm^2
Stiffener Stress	σ_c=M/Z_c=	569.80	kg/cm^2	**ok**	< 1080	kg/cm^2

A.5.3 Stiffener For Panel-C:

Average Pressure =	0.395	kg/cm^2
Length=	41.5	cm
W =	16.393	kg/cm.lenght
Span =	178.5	cm
$R_A=R_B$ =	1463.0	kg
Maximum B.M $=wl^2/8$	65288	kg.cm

The effective width of skin plate.

1.	B+40t =	33.2	cm
2.	c/c of span=	41.5	cm
3.	0.11xspan =	19.635	cm

least of above = 19.635 cm

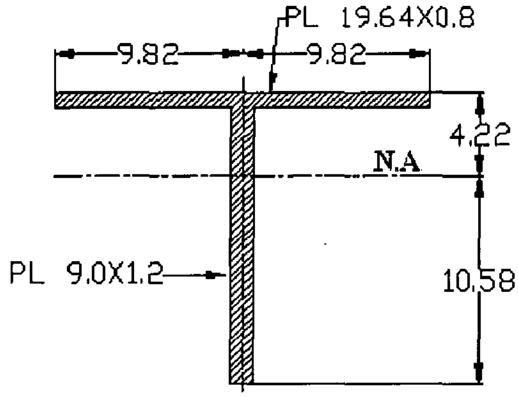


Figure: A.6 Section of vertical stiffener for panel-C

Table: A.3 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
		b(cm)	h(cm)	(bxh)	dist. From X	(cm3)	(cm4)	(bh3/12)
1	skin plate	19.635	0.8	15.708	0.4	6.2832	2.51328	0.83776
2	web	1.2	14.0	16.8	7.8	131.04	1022.112	274.4
				32.508		**137.3232**	**1024.625**	**275.2378**

Y_t=sum(AY)/sum(A) = 4.22 cm $Y=h_1+h_2$= 14.8 cm

$Y_c=(Y-Y_t)$= 10.58 cm M= 65288 kg-cm

I_{zz}=skin plate($hxb^3/12$)+web($hxb^3/12$)= 506.68 cm^4

$I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2$ = 719.77 cm^4

$Z_t=I_{yy}/Y_t$ = 170.39 cm^3

$Z_c=I_{yy}/Y_c$= 68.06 cm^3

Skin Plate Stress	$\sigma_t=M/Z_t$=	383.17	kg/cm^2	ok	< 1080	kg/cm^2
Stiffener Stress	$\sigma_c=M/Z_c$=	959.28	kg/cm^2	ok	< 1080	kg/cm^2

A.5.4 Stiffener For Panel-D:

Average Pressure = 0.554 kg/cm^2
Length= 41.5 cm
W = 22.991 kg/cm.lenght

Span = 139.5 cm
$R_A=R_B$ = 1603.6 kg
Maximum B.M $=wl^2/8$ 55926 kg.cm

The effective width of skin plate.

1. B+40t = 49 cm
2. c/c of span= 41.5 cm
3. 0.11xspan = 15.345 cm

least of above = 15.345 cm

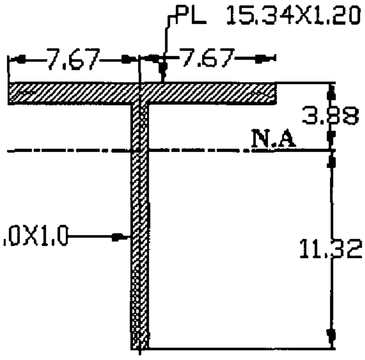


Figure: A.7 **Section of vertical stiffener for panel-D**

Table: A.4 Calculation of Neutral Axis and Modulus of section:

Item No	**Item**	**Size**		**A(cm^2)**	**Y(cm)**	**A.Y**	**A.Y^2**	**I_{self}(cm^4)**
		b(cm)	**h(cm)**	**(bxh)**	**dist. From X**	**(cm3)**	**(cm4)**	**(bh3/12)**
1	skin plate	15.345	1.2	18.414	0.6	11.0484	6.62904	2.20968
2	web	1	14.0	14	8.2	114.8	941.36	228.6667
				32.414		**125.8484**	**947.989**	**230.8763**

Y_t=sum(AY)/sum(A) = 3.88 cm $Y=h_1+h_2$= 15.2 cm

$Y_c=(Y-Y_t)$= 11.32 cm   M= 55926 kg-cm

I_{zz}=skin plate($hxb^3/12$)+web($hxb^3/12$)= 362.49 cm^4

$I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2$ = 690.25 cm^4

$Z_t=I_{yy}/Y_t$ = 177.78 cm^3

$Z_c=I_{yy}/Y_c$= 60.99 cm^3

Skin Plate Stress $\sigma_t=M/Z_t$= 314.57 kg/cm^2 **ok** < 1080 kg/cm^2

Stiffener Stress $\sigma_c=M/Z_c$= 916.97 kg/cm^2 **ok** < 1080 kg/cm^2

A.5.5 Stiffener For Panel-E:

Average Pressure =	0.688	kg/cm^2
Length=	41.5	cm
W =	28.552	kg/cm.lenght
Span =	104	cm
$R_A=R_B$ =	1484.7	kg
Maximum B.M $=wl^2/8$	38602	kg.cm

The effective width of skin plate.

1. B+40t =	48.8	cm
2. c/c of span=	41.5	cm
3. 0.11xspan =	11.44	cm

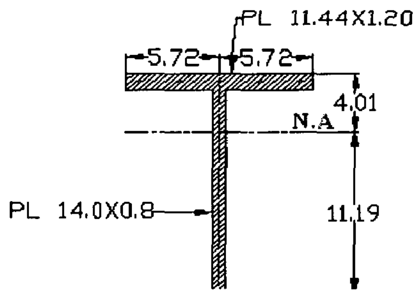


Figure: A.8 Section of vertical stiffener for panel-E

least of above = 11.44 cm

Table: A.5 Calculation of Neutral Axis and Modulus of section:

Item No	**Item**	**Size**		**A(cm²)**	**Y(cm)**	**A.Y**	**A.Y²**	**I_self(cm⁴)**
		b(cm)	**h(cm)**	**(bxh)**	**dist. From X**	**(cm3)**	**(cm4)**	**(bh3/12)**
1	skin plate	11.44	1.2	13.728	0.6	8.2368	4.94208	1.64736
2	web	0.8	14.0	11.2	8.2	91.84	753.088	182.9333
				24.928		**100.0768**	**758.0301**	**184.5807**

Y_t=sum(AY)/sum(A) = 4.01 cm $Y=h_1+h_2$= 15.2 cm

$Y_c=(Y-Y_t)$= 11.19 cm   M= 38602 kg-cm

I_{zz}=skin plate$(hxb^3/12)$+web$(hxb^3/12)$= 150.32 cm^4

$I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2$ = 540.84 cm^4

$Z_t=I_{yy}/Y_t$ = 134.72 cm^3

$Z_c=I_{yy}/Y_c$= 48.35 cm^3

Skin Plate Stress	$\sigma_t=M/Z_t$=	286.54	kg/cm^2	ok	$<$ 1080	kg/cm^2
Stiffener Stress	$\sigma_c=M/Z_c$=	798.35	kg/cm^2	ok	$<$ 1080	kg/cm^2

A.5.6 Stiffener For Panel-F:

Average Pressure =	0.786	kg/cm^2
Length=	41.5	cm
W =	32.619	kg/cm.lenght
Span =	91.5	cm
$R_A=R_B$ =	1492.3	kg
Maximum B.M $=wl^2/8$	34137	kg.cm

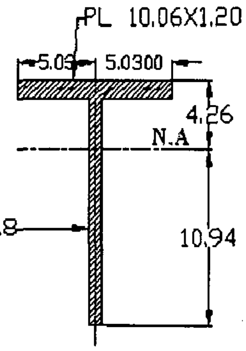


Figure: A.9 Section of vertical stiffener for panel-F

The effective width of skin plate.

1. B+40t = 48.8 cm
2. c/c of span= 41.5 cm
3. 0.11xspan = 10.065 cm

least of above = 10.065 cm

Table: A.6 Calculation of Neutral Axis and Modulus of section:

Item No	**Item**	**Size**		**A(cm^2)**	**Y(cm)**	**A.Y**	**A.Y^2**	**I_{self}(cm^4)**
		b(cm)	**h(cm)**	**(bxh)**	**dist. From X**	**(cm3)**	**(cm4)**	**(bh3/12)**
1	skin plate	10.065	1.2	12.078	0.6	7.2468	4.34808	1.44936
2	web	0.8	14.0	11.2	8.2	91.84	753.088	182.9333
				23.278		**99.0868**	**757.4361**	**184.3827**

Y_t=sum(AY)/sum(A) = 4.26 cm $Y=h_1+h_2$= 15.2 cm

$Y_c=(Y-Y_t)$= 10.94 cm M= 34137 kg-cm

I_{zz}=skin plate($hxb^3/12$)+web($hxb^3/12$)= 102.56 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 520.04 cm^4

$Z_t=I_{yy}/Y_t$ = 122.17 cm^3

$Z_c=I_{yy}/Y_c$= 47.52 cm^3

Skin Plate Stress	$\sigma_t=M/Z_t$=	279.42 kg/cm^2	ok	< 1080	kg/cm^2
Stiffener Stress	$\sigma_c=M/Z_c$=	718.35 kg/cm^2	ok	< 1080	kg/cm^2

A.5.7 Combined Stresses in Vertical Stiffeners:

The stresses shall be combined in accordance with IS 4622.

The permissible combined stress is 1440 kg/cm^2.

PANAL 'A'

Total stress in 'X' direction
Stress in Skin Plate due to skin plate bending $fx= \sigma_{3x}$ =141.28 kg/cm^2
Total stress in 'Y' direction
Stress in skin plate due to stiffener bending $fy= \sigma_{t}+ \sigma_{3y}$ = 258.83 kg/cm^2
Shear stress fxy=0
The combined stresses shall be calculated on the following basis.
Combined stress fc= sqrt (fx^2 + fy^2-fx.fy+3fxy^2) =224.46 kg/cm^2

PANAL 'B'

Stress in Skin Plate due to skin plate bending = fx =331.34 kg/cm^2
Stress in skin plate due to stiffener bending =fy = 313.90 kg/cm^2
Shear stress =fxy =0
Combined stress fc= sqrt (fx^2 + fy^2-fx.fy+3fxy^2) =322.97 kg/cm^2

PANAL 'C'

Stress in Skin Plate due to skin plate bending = fx =531.48 kg/cm^2
Stress in skin plate due to stiffener bending =fy = 543.61kg/cm^2
Shear stress =fxy =0
Combined stress fc= sqrt (fx^2 + fy^2-fx.fy+3fxy^2) =611.39 kg/cm^2

PANAL 'D'

Stress in Skin Plate due to skin plate bending = fx =331.29 kg/cm^2
Stress in skin plate due to stiffener bending = fy = 413.95kg/cm^2
Shear stress =fxy =0
Combined stress fc= sqrt (fx^2 + fy^2-fx.fy+3fxy^2) =379.43 kg/cm^2

PANAL 'E'

Stress in Skin Plate due to skin plate bending = f_x =411.43 kg/cm^2
Stress in skin plate due to stiffener bending = f_y = 409.96 kg/cm^2
Shear stress =fxy =0
Combined stress fc= sqrt (fx^2 + fy^2-fx.fy+3fxy^2) =410.69 kg/cm^2

PANAL 'F'

Stress in Skin Plate due to skin plate bending = f_x =468.34 kg/cm^2

Stress in skin plate due to stiffener bending = f_y = 437.92 kg/cm^2

Shear stress =fxy =0

Combined stress fc= sqrt (fx^2 + fy^2-fx.fy+3fxy^2) =453.90 kg/cm^2

6.0 DESIGN OF HORIZONTAL GIRDER: (Refer Fig A.2, A.10, A.11)

Distance c/c of wheel	=18000+340+340=18680 mm	=1868 cm	
Distance c/c of seal	=18000+65+65	=18130 mm	=1813 cm

Load acting on the bottom unit	= [(0.63+0.84)/2]x210	=154.35 kg/cm
Load acting on the intermediate unit	= [(0.30+0.63)/2]x330	=153.45 kg/cm
Load acting on the top unit	= [(0.0+0.30)/2]x300	=45.00 kg/cm

A.6.1 Design of bottom Horizontal Girder:

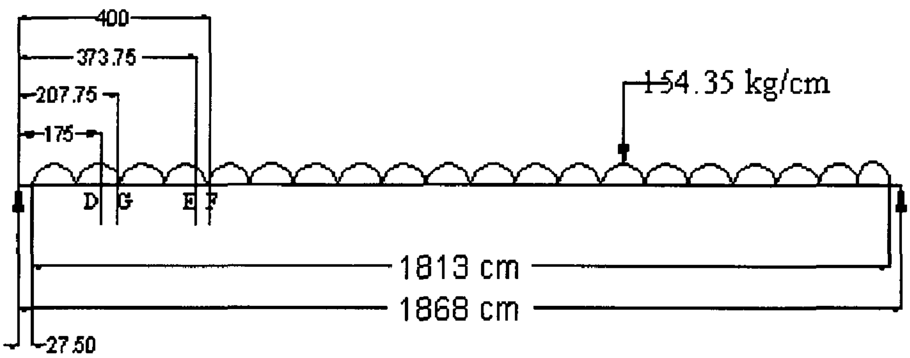


Figure: A.10 Loading diagram of bottom horizontal girder

R_F =154.35x1813/2 =139918

B.M at the centre =139918[(1868/2)-(1813/4)] =67265579

B.M at "F" =139918x400-154.25(400-27.50)^2/2 =45458687 kg cm

Shear force at "D"	=139918-154.35(175-27.5)	=117151 kg
Shear force at "G"	=139918-154.35(207.75-27.5)	=112096 kg
Shear force at "E"	=139918-154.35(373.75-27.5)	=86475 kg

Table: A.7 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		A(cm^2)	Y(cm)	A.Y	A.Y^2	I_{self}(cm^4)
		b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	(bh^3/12)
1	skin plate	210.0	1.2	252.0	0.6	151.2	90.7	30.2
2	web	1.6	235.0	376.0	118.7	44631.2	5297723.4	1730383.3
3	Flange	55.0	2.5	137.5	237.5	32649.4	7752594.1	71.6
4	Flange Plate	52.5	2.5	131.3	240.0	31493.4	7556850.3	68.4
				896.8		**108925.2**	**20607258.6**	**1730553.5**

Y_t=sum(AY)/sum(A) = 121.47 cm $Y=h_1+h_2+h_3+h_4=$ 241.2 cm

$Y_c=(Y-Y_t)=$ 119.73 cm

I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})+plate(I_{zz})= 990988.16 cm^4

$I_{N.A}=\mathbf{I}_{yy}$=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 9107032.18 cm^4

$Z_{min}=I_{yy}/Y_t$ = 74975.58 cm^3

$Z_{max}=I_{yy}/Y_c$= 76060.94 cm^3

Flange Stress	σ_t=M/Z_t=	897.17	kg/cm^2	ok	< 1080	kg/cm^2
Skin plate stress	σ_c=M/Z_c=	884.36	kg/cm^2	ok	< 1080	kg/cm^2

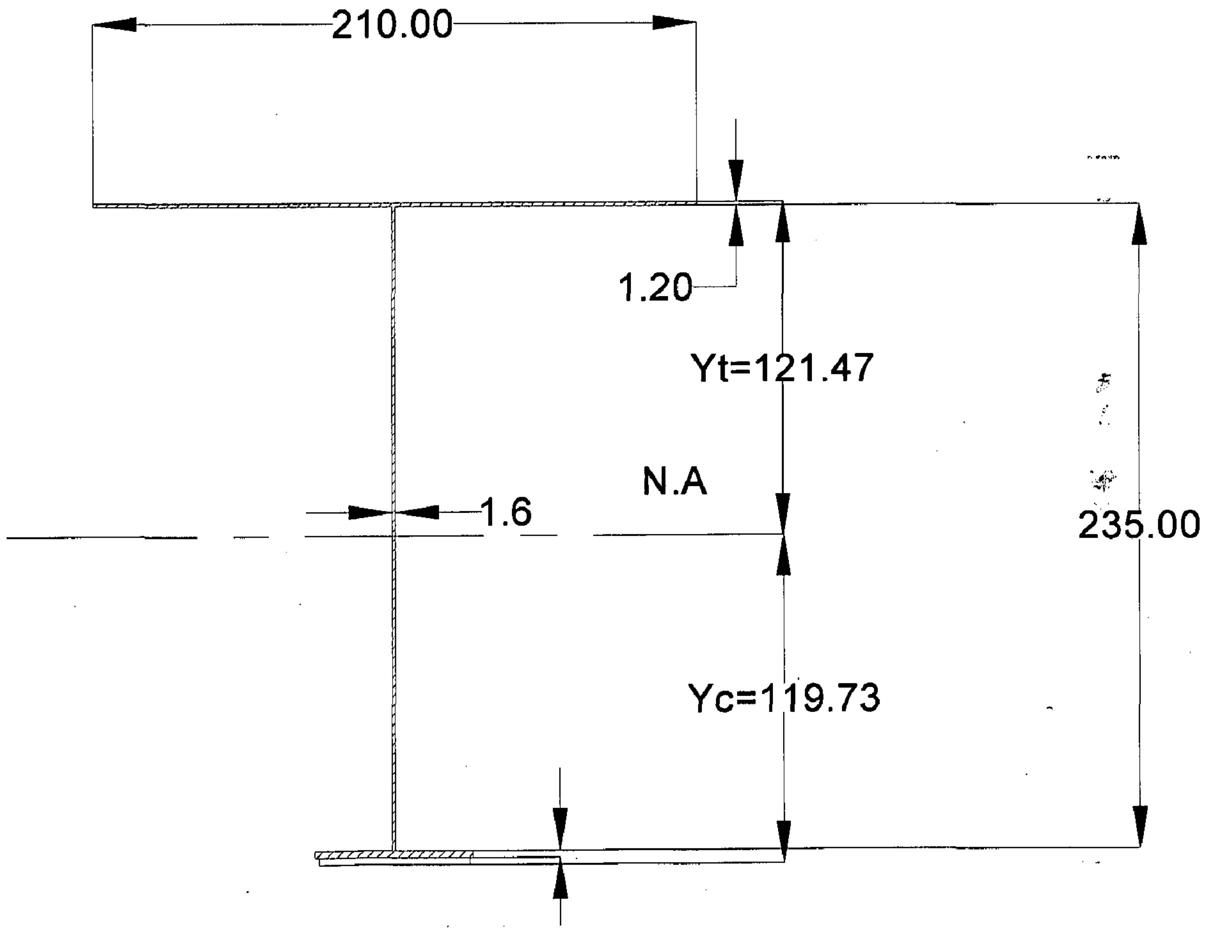


Figure: A.11 Section of bottom horizontal girder

A.6.2 Curtailing Portion:

R_F =154.35x1813/2 =139918

B.M at the centre =139918x400-154.35[(400-27.5)2-]/2 =45258687

Table: A.8 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
		b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	$(bh^3/12)$
1	skin plate	210.0	1.2	252.0	0.6	151.2	90.7	30.2
2	web	1.2	235.0	282.0	118.7	33473.4	3973292.6	1297787.5
3	Flange	55.0	2.5	137.5	237.5	32649.4	7752594.1	71.6
				671.5		**66274.0**	**11725977.4**	**1297889.4**

Y_t=sum(AY)/sum(A) = 98.70 cm $Y=h_1+h_2+h_3+h_4$= 238.7 cm

$Y_c=(Y-Y_t)$= 140.00 cm

I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})+plate(I_{zz})= 960795.30 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 6482928.90 cm^4

$Z_t=I_{yy}/Y_t$ = 65686.22 cm^3

$Z_c=I_{yy}/Y_c$= 46305.12 cm^3

Skin Plate Stress $\sigma_t=M/Z_t$= 689.01 kg/cm^2 **ok** < 1080 kg/cm^2

Flange Stress $\sigma_c=M/Z_c$= 977.40 kg/cm^2 **ok** < 1080 kg/cm^2

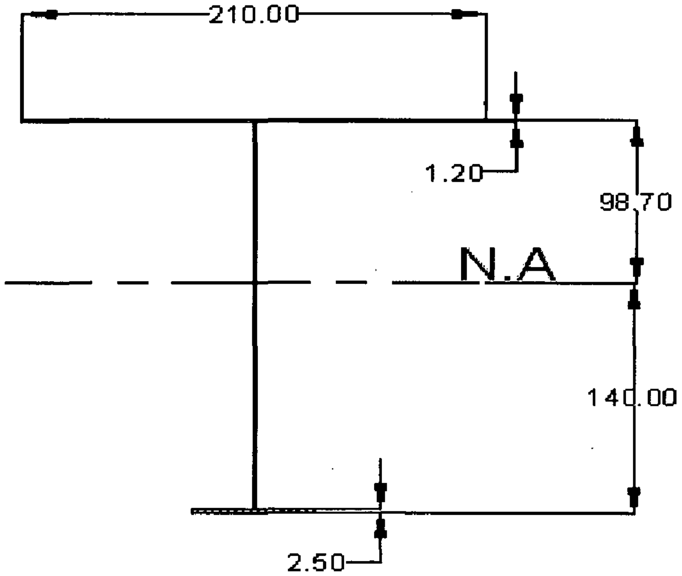


Figure: A.12 Section of bottom horizontal girder (curtailment)

A.6.3 Design of Intermediate Horizontal Girder (ref Fig: A.2, A.13, A.14)

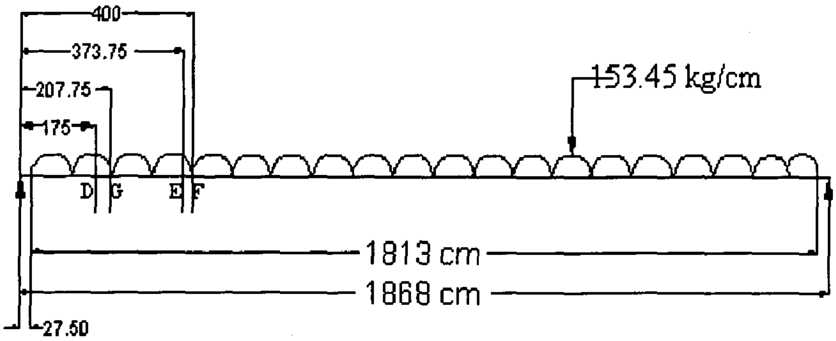


Figure: A.13 Loading diagram of intermediate girder

$R_A = R_B$ =153.45x1813/2 =139102 kg

B.M at the centre =139102[(1868/2)-(1813/4)] =66873257 kg-cm

B.M at the 'F' =139102(400)-153.45(400-27.50)^2/2 =44994727 kg-cm

Shear force at 'B' =139102-153.45(373.75-27.5) =85970 kg

Shear force at 'D '=139102-153.45(175-27.5) =116468 kg

The section of the girder is shown in fig:21

Table: A.9 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		A(cm^2)	Y(cm)	A.Y	A.Y^2	I_{self}(cm^4)
		b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	(bh^3/12)
1	skin plate	160.5	1.2	192.6	0.6	115.6	69.3	23.1
		169.5	0.8	135.6	0.4	54.2	21.7	7.2
2	web	1.2	235.0	282.0	118.7	33473.4	3973292.6	1297787.5
3	Flange	55.0	2.5	137.5	237.5	32649.4	7752594.1	71.6
4	Flange Plate	52.5	2.5	131.3	240.0	31493.4	7556850.3	68.4
				879.0		**97786.0**	**19282828.0**	**1297957.8**

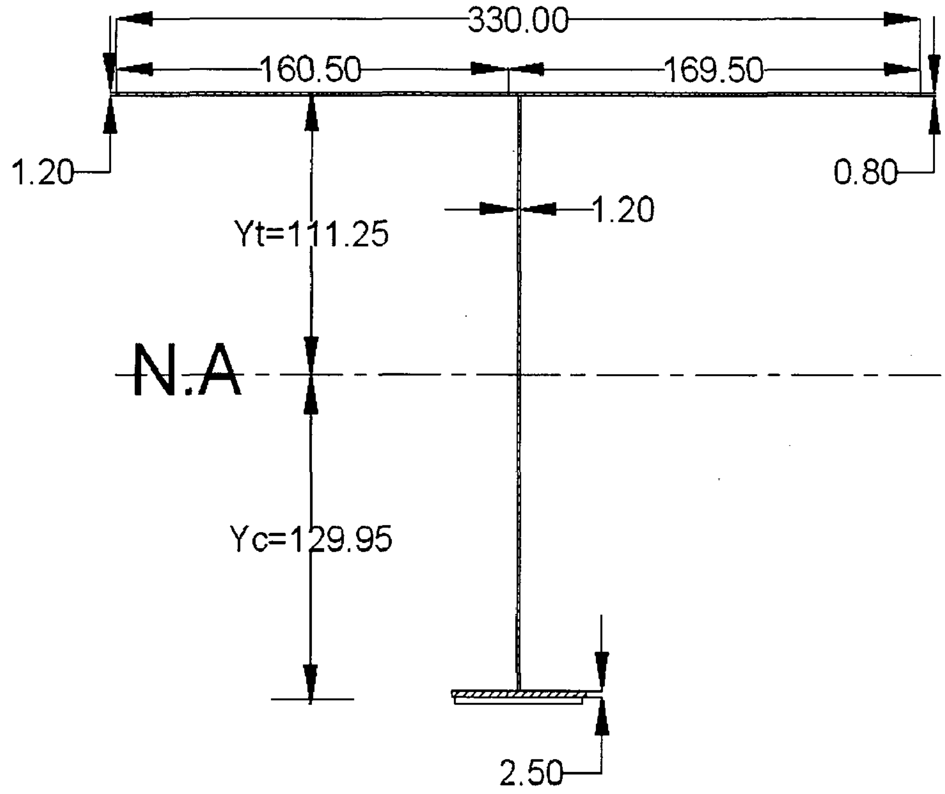


Figure: A.14 Section of intermediate girder

Y_t=sum(AY)/sum(A) =	111.25	cm	$Y=h_1+h_2+h_3+h_4$=	241.2	cm
$Y_c=(Y-Y_t)$=	129.95	cm			
I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})+plate(I_{zz})=			478293.80	cm^4	
$I_{N.A}=I_{yy}$=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ =			9701777.67	cm^4	

$Z_t=I_{yy}/Y_t$ =	87204.47	cm^3
$Z_c=I_{yy}/Y_c$=	74659.62	cm^3

Skin Plate Stress	$\sigma_t=M/Z_t$=	767	kg/cm^2	ok	< 1080	kg/cm^2
Flange Stress	$\sigma_c=M/Z_c$=	896	kg/cm^2	ok	< 1080	kg/cm^2

A.6.4 Curtailing Portion:

R_A=R_B =153.45x1813/2 =139102

B.M at F =139102x400-153.45[(400-27.5)^2]/2 =44994727

Table: A.10 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
		b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	$(bh^3/12)$
1	skin plate	160.5	1.2	192.6	0.6	115.6	69.3	23.1
		169.5	0.8	135.6	0.4	54.2	21.7	7.2
2	web	1.2	235.0	282.0	118.7	33473.4	3973292.6	1297787.5
3	Flange	55.0	2.5	137.5	237.5	32649.4	7752594.1	71.6
				747.7		**66292.6**	**11725977.7**	**1297889.5**

Y_t=sum(AY)/sum(A) = 88.66 cm $Y=h_1+h_2+h_3+h_4$= 238.7 cm

$Y_c=(Y-Y_t)$= 150.04 cm

I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})+plate(I_{zz})= 448147.31 cm^4

$I_{N.A}=I_{yy}$=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 7146235.09 cm^4

$Z_t=I_{yy}/Y_t$ = 80600.88 cm^3

$Z_c=I_{yy}/Y_c$= 47629.50 cm^3

Skin Plate Stress $\sigma_t=M/Z_t$= 558 kg/cm^2 **Ok** < 1080 kg/cm^2

Flange Stress $\sigma_c=M/Z_c$= 945 kg/cm^2 **Ok** < 1080 kg/cm^2

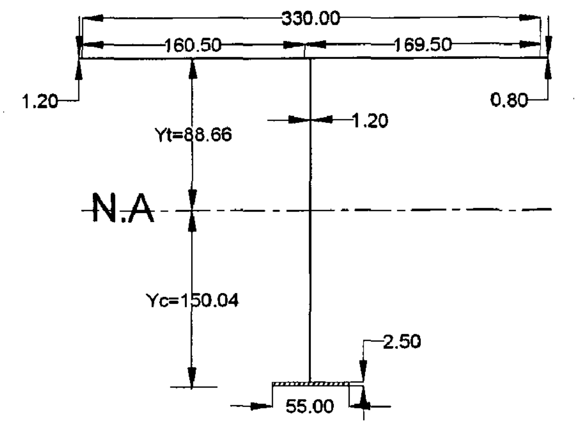


Figure: A.15 Section of intermediate girder (curtailment)

A.6.5 Design of Top Horizontal Girder (ref Fig:A.2, A.16, A.17)

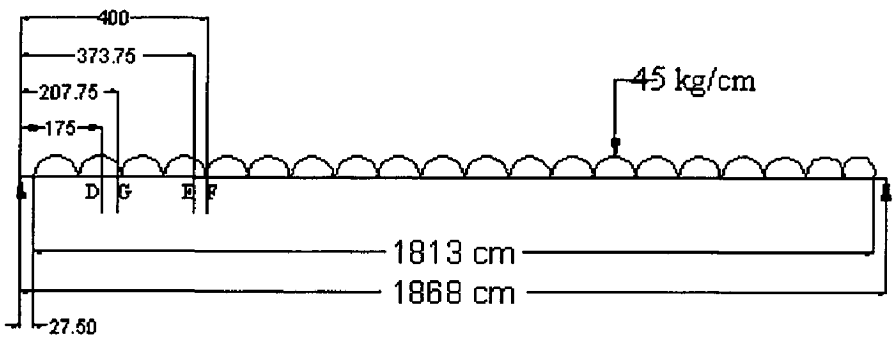


Figure: A.16 Loading diagram of top horizontal girder

R_A=R_B =45x1813/2 =40793 kg

B.M at the centre = 40793[(1868/2)-(1813/4)] =19611235 kg-cm

Shear stress at ends = 40793/95.5x1.0 =427 kg/cm^2

Shear force at 'E' = 40793-45(373.75-27.50) =25212 kg

Adopt the section shown in fig:24

Table: A.11 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		A(cm^2)	Y(cm)	A.Y	A.Y^2	I_{self}(cm^4)
		b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	(bh^3/12)
1	skin plate	300.0	0.8	240.0	0.4	96.0	38.4	12.8
2	web	1.2	235.0	282.0	118.3	33360.6	3946559.0	1297787.5
3	Flange	40.0	1.2	48.0	236.4	11347.2	2682478.1	5.8
				570.0		**44803.8**	**6629075.5**	**1297806.1**

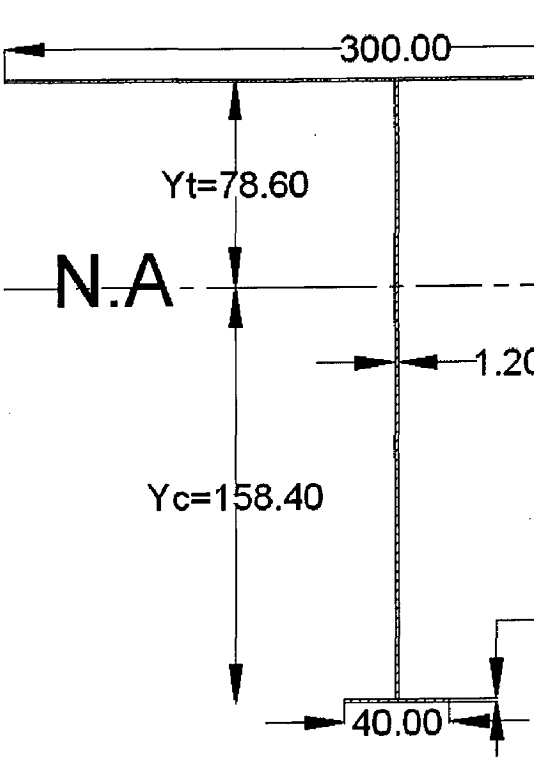


Figure: A.17 Section of top horizontal girder

Y_t=sum(AY)/sum(A) =	78.60	cm	$Y=h_1+h_2+h_3+h_4$=	237.0	cm
$Y_c=(Y-Y_t)$ =	158.40	cm			

I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})+plate(I_{zz})= 1806434 cm^4

$I_{N.A}=\mathbf{I_{yy}}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2$ = 4405161 cm^4

$Z_t=I_{yy}/Y_t$ = 56043.06 cm^3

$Z_c=I_{yy}/Y_c$= 27810.92 cm^3

Skin Plate Stress	$\sigma_t=M/Z_t$=	350	kg/cm^2	**ok**	< 1080	kg/cm^2
Flange Stress	$\sigma_c=M/Z_c$=	705	kg/cm^2	**ok**	< 1080	kg/cm^2

A.6.6 Combined stresses in horizontal girders:

The maximum stresses in skin plate due to skin bending and maximum stresses in skin plate due to girder bending act in the same direction. Therefore these stresses shall be algebraically added. These stresses developed due to vertical stiffener bending.

Each girder has got two sets of stiffeners, and two skin plate panels, symmetrically about centre line of web. For combining the stresses, the maximum stresses due to skin plate bending alone and minimum stresses in skin plate due to stiffener bending shall be considered in order to get the worst results.

The stresses shall be combined at critical location in each girder. The permissible combined stress is 1440 kg/cm^2.

Bottom Most Girder

Total stress in 'X' direction

Stress in Skin Plate due to skin plate bending $fx= \sigma_{3x\,(skin\ plate)}$ $=141.28\ kg/cm^2$

Total stress in 'Y' direction

Stress in skin plate due to beam bending $fy= \sigma_{t\,(beam)}+ \sigma_{3y(skin\ plate)}$ $= 926.74\ kg/cm^2$

Shear stress $fxy=0$

The combined stresses shall be calculated on the following basis.

Combined stress $fc= sqrt(fx^2 + fy^2 - fx.fy + 3fxy^2)$ $=864.80\ kg/cm^2$

Intermediate Girder

Total stress in 'X' direction

Stress in Skin Plate due to skin plate bending $fx= \sigma_{3x\,(skin\ plate)}$ $=531.48\ kg/cm^2$

Total stress in 'Y' direction

Stress in skin plate due to beam bending $fy= \sigma_{t\,(beam)}+ \sigma_{3y(skin\ plate)}$ $= 926.44\ kg/cm^2$

Shear stress $fxy=0$

The combined stresses shall be calculated on the following basis.

Combined stress $fc= sqrt(fx^2 + fy^2 - fx.fy + 3fxy^2)$ $=805.21\ kg/cm^2$

Top Most Girder

Total stress in 'X' direction

Stress in Skin Plate due to skin plate bending $fx = \sigma_{3x\,(skin\ plate)}$ $=468.34\ kg/cm^2$

Total stress in 'Y' direction

Stress in skin plate due to beam bending $fy = \sigma_{t\,(beam)} + \sigma_{3y(skin\ plate)}$ $= 449.40\ kg/cm^2$

Shear stress $fxy=0$

The combined stresses shall be calculated on the following basis.

Combined stress $fc = sqrt\ (fx^2 + fy^2 - fx.fy + 3fxy^2)$ $=459.16\ kg/cm^2$

A.6.7 DEFLECTION: (ref fig 6.1, 6.3, 6.6)

Deflection $= \dfrac{5}{384}\dfrac{WL^4}{EI}$

Bottom Most Girder $= \dfrac{5 \times 0.15435 \times 1868^4}{384 \times 2100 \times 8673632.59}$ $= 1.34$ cm

Intermediate Girder $= \dfrac{5 \times 0.15345 \times 1868^4}{384 \times 2100 \times 9701777.67}$ $= 1.19$ cm

Bottom Most Girder $= \dfrac{5 \times 0.045 \times 1868^4}{384 \times 2100 \times 4405161}$ $= 0.77$ cm

It will be seen that maximum deflection /span $= \dfrac{1.34}{1868}$ $= \dfrac{1}{1471}$

As against permissible value of $= \dfrac{1}{800}$

A.7.0 DESIGN OF WHEELS:

The gate has been designed in the three units. The wheels shall be kept symmetrically about C.G of water pressure diagram so that they carry equal loads. The webs of the horizontal girders were also kept at C.G of water pressure diagram thus the wheels shall also be symmetrical about centre line of webs of different horizontal girders.

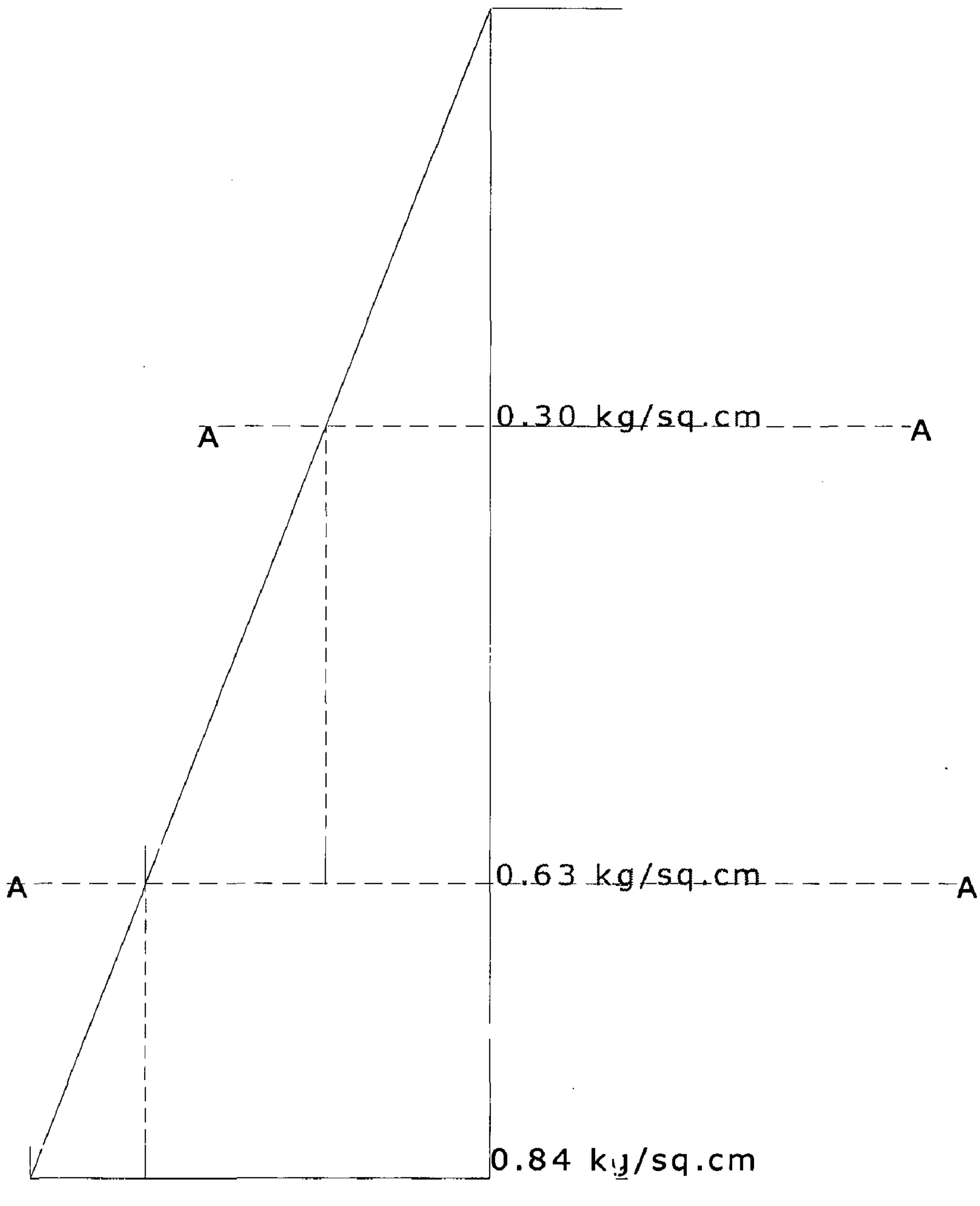


Figure: A.18 Loading diagram of wheels

TOP UNIT: - (refer Fig: A.18)

The C.G would obviously lie at H/3 i.e. 100 cm above base line.

INTERMEDIATE UNIT: - (refer Fig: A.18)

Considering A-A as the base line and taking moment about this line.

C.G = sum of moment ($\sum M$)/sum of area ($\sum A$)

$= \{0.3(330)^2/2+0.33(330)^2/6\}/ \{0.3(330)+0.33(330)/2\}$

$= (16335+5989.5)/ (99+54.45)$

$= 115.50$ cm

BOTOM UNIT: - (refer Fig: A.18)

Considering A-A as the base line and taking moment about this line.

C.G = sum of moment ($\sum M$)/sum of area ($\sum A$)

$= \{0.63(210)^2/2+0.21(210)^2/6\}/ \{0.63(210)+0.21(210)/2\}$

$= (13891.50+1543.50)/ (132.30+22.05)$

$= 100$ cm

A.7.1 Wheel Loads:

TOP UNIT: - (refer Fig: A.16)

Wheel loads $=R_A/2 = R_B/2 = 40793/2 = 20397$ kg

INTERMEDIATE UNIT: - (refer Fig: A.13)

$R_A = R_B = 153.45 \times 1813/2 = 139102$ kg

Wheel loads $=R_A/2 = R_B/2 = 139102/2 = 69551$ kg

BOTOM UNIT: - (refer Fig: A.10)

Wheel loads $=R_A/2 = R_B/2 = 139918/2 = 69959$ kg

Same wheels shall be provided for bottom unit and intermediate unit. The maximum load for which wheel is designed shall be 69959 kg.

Different wheels shall be provided for top unit. The wheel shall be designed for a load of 20397 kg.

A.7.2 Design of Wheels Bottom and Intermediate Units as Per IS: 4622

Maximum wheel load =69959 kg =69.959 t

Provide 550 mm ϕ wheel with 110 mm tread width contact.

Material:	Cast Steel Gr. IS: 1030 Grade 340 – 570 W				
	UTS	=	$570 MP_a$	= 5812 kg/cm^2	=5.812 t/ cm^2
	YP	=	$340 MP_a$	= 3467 kg/cm^2	=3.467 t/ cm^2

Allowable line contact stress = 1.6 UTS = 1.6 x 5.812 = 9.30 t/cm^2

Contact stress f_C = 0.418 x √ (P x E) / (r x l)

Where 'P' is the maximum wheel load = 69.956 t

'E' is modulus of elasticity =2100 t/cm^2

'R' is the radius of wheel =27.5 cm

'L' is the tread width =11 cm

Contact stress f_C = 0.418 x √ (P x E) / (r x l)

∴ f_C = 0.418 x √ (69.959 x 2100) / (27.5 x11.0)

= 9.20 t/cm^2 < 9.30 t/cm^2 hence safe

A.7.3 Design of Wheels Topmost Units As Per IS: 4622

Maximum wheel load =20397 kg =20.397 t

Provide 350 mm ϕ wheel with 70 mm tread width contact.

Contact stress f_C = 0.418 x √ (P x E) / (r x l)

∴ f_C = 0.418 x √ (20.397 x 2100) / (17.5 x7)

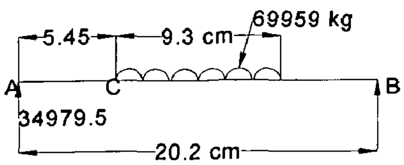
= 7.80 t/cm^2 < 9.30 t/cm^2 hence safe

A.7.4 Calculation for weight of Wheels

Weight of wheel	=	π x tread width (R^2-r^r) x density of steel	
Bottom and center unit (4 nos. wheel)	=	πx11x (27.5^2-6.5^2) x4x0.00785	=774.76 kg
Top unit (2 nos. wheel)	=	πx7x (17.5^2-4.5^2) x2x0.00785	=98.74 kg
			=873.50 kg

A.8.0 DESIGN OF PIN:

A.8.1 Design of Pin for Bottom and Intermediate Unit:



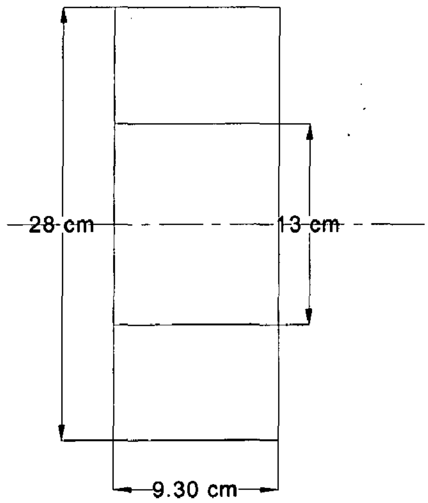


Figure: A.19 Loading diagram of pin **Figure: A.20 Bearing diagram of pin**

Same wheel pins shall be provided for bottom and intermediate units. The pin shall be designed for a maximum load of 69959 kg. Adopt bearing shown in above Fig. A.20.

Wheel load =69959 kg

R_A $=R_B$ =69959/2 =34979.5 kg

B.M at C=34979.5 x 5.45 =190638 kg cm

Max. B.M in centre =34979.5{(20.2/2)-(9.3/4)}

=271966 kg cm

Dia of Pin =13 cm

Z $=\pi\,(13)^3/32$ =215.689

Maximum stress =271966/215.689=1261 kg/cm^2

<u>Shear stress</u>

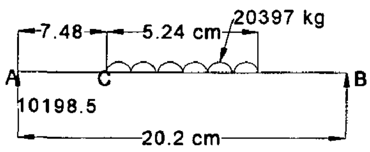
Dia of pin at support B = 115 mm

Therefore shear Area $=\pi(11.5)^2/4$ $=103.869\ cm^2$

Reaction at support B =34979.5 kg

Shear stress =34979.5/103.869=334 kg/cm^2

A.8.2 Design of Pin For Top Unit:



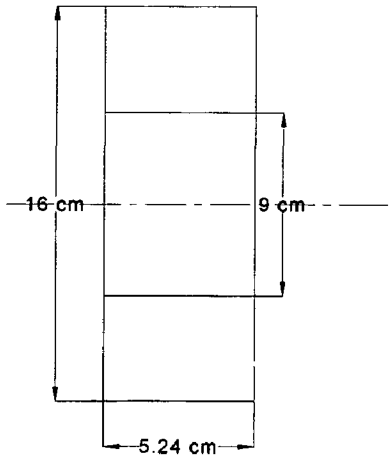


Figure: A.21 Loading diagram of pin **Figure: A.22 Bearing diagram of pin**

Wheel load =20397kg

R_A $=R_B$ =20397/2 =10198.50 kg

B.M at C=10198.50x7.48 =76285 kg cm

Max. B.M in centre =10198.50{(20.2/2)-(5.24/4)}

=89645 kg cm

Dia of Pin =9 cm

Z $=\pi (9)^3/32$ =71.569

Maximum stress =89645/71.569 =1253 kg/cm^2

<u>Shear stress</u>

Dia of pin at support B = 75 mm

Therefore shear Area $=\pi$ x 7.52/4 =44.179 cm^2

Reaction at support B =10198.50 kg

Shear stress =10198.50/44.179=231 kg/cm^2

A.9.0 DESIGN OF WHEEL TRACK:

Adopt the section shown in Fig. A.23

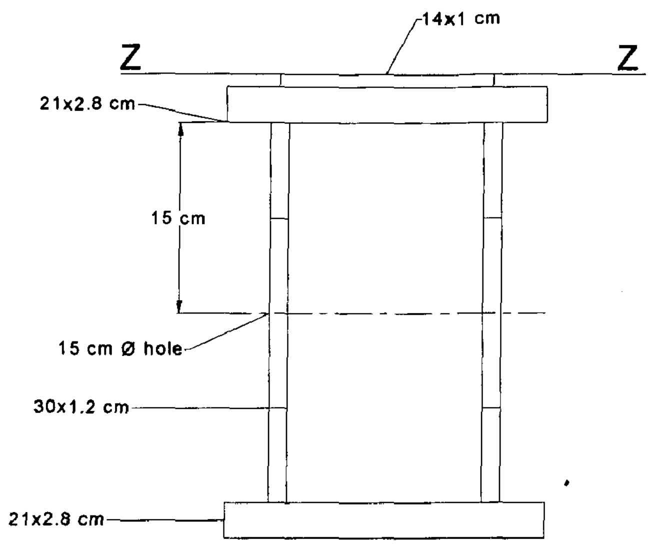


Figure: A.23 Section of track

Table: A.12 Calculation of sectional modulus and moment of inertia

	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
	b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	$(bh^3/12)$
	14.0	1.0	14.0	0.5	7.0	3.5	1.2
	21.0	2.8	58.8	2.4	141.1	338.7	38.4
2 nos.	1.2	30.0	72.0	18.8	1353.6	25447.7	5400.0
	21.0	2.5	52.5	35.1	1840.1	64496.4	27.3
(-)2 nos.	1.2	15.0	36.0	18.8	676.8	12723.8	675.0
			161		**2665.0**	**77562.4**	**4791.9**

d = 16.52 cm $Y=h_1+h_2+h_3+h_4=$ 36.3 cm

$Y_c=(Y-Y_t)=$ 19.78 cm

$I_{zz}=$ 4323.26 cm^4

$I_{N.A}=I_{yy}=$ $\sum AY^2+\sum I_{SELF}-(\sum A \times d^2)$ =38321.70 cm^4

$Z_t=I_{yy}/Y_t$ = 2319 cm^3

$Z_c=I_{yy}/Y_c=$ 1938 cm^3

Zmin = 1938 cm^3

The maximum stress in concrete and track will occurs,
Where wheel load is maximum i.e. when wheel load = 69959 kg.

Stress in concrete =0.2813 $P(Ec)^{1/3}/(EsxIxW^2)$

P=wheel load=69959 kg.
Ec=Modulus of elasticity of concrete
Es=Modulus of elasticity of steel
Ec/Es=1/13.33.......for M20 concrete
W=width of track in contact with concrete =21 cm
I=Moment of inertia of track=38321.70 cm^4

Therefore stress in concrete $=0.2813 \times 69959 \times (1/(13.33 \times 38321.70 \times 21^2))^{1/3}$

$=32.36\ kg/cm^2$

Bending stress in track $=0.4999\ P/Z\{(Es/Ec)x(1/W)\}^{1/3}$

$=0.4999 \times (69959/1938) \times (13.33 \times 38321.70/21)^{1/3}$

$=0.4999 \times (69959/1938) \times 28.97$

$=523\ kg/cm^2$

A.10.0 DESIGN OF END VERTICAL GIRDER:

The wheel shall be placed at a distance of 50 cm symmetrically about C.G. of water pressure or centre line of web. The bottom unit carries maximum load, therefore the design of this and vertical girder shall be critical.

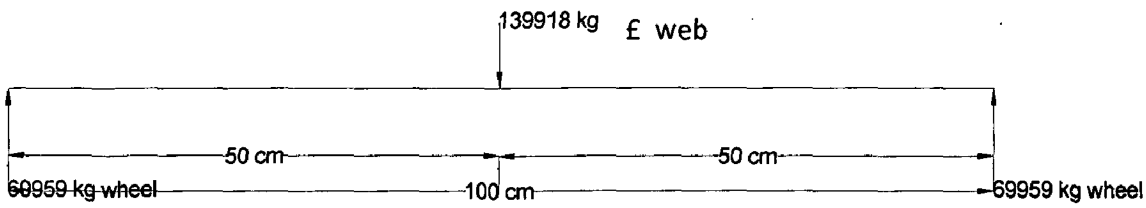


Figure: A.24 Loading diagram of end vertical girder

Maximum B.M in end vertical girder = WL/4 =139918 x 100/4

=3497950 kg cm

Adopt section shown in Fig.A.25

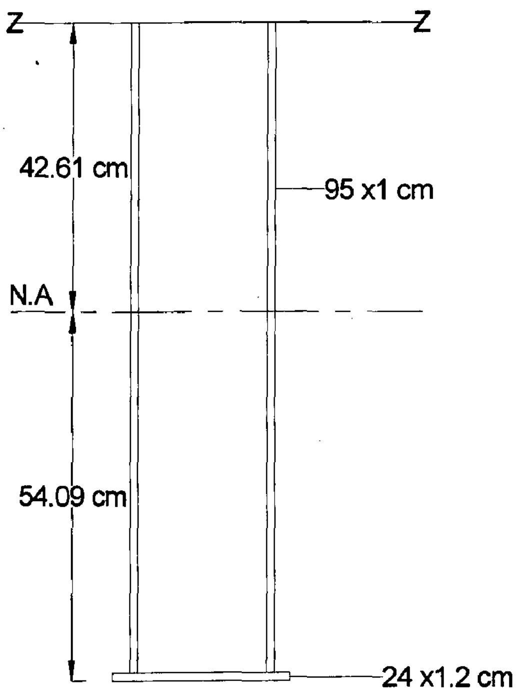


Figure: A.25 Section of end vertical girder

Table: A.13 Calculation of sectional modulus and moment of inertia

Item	Size		A(cm^2)	Y(cm)	A.Y	A.Y^2	I_{self}(cm^4)
	b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	($bh^3/12$)
24 x 1.2 PL	24.0	1.2	28.8	0.6	17.3	10.4	3.5
95.50 x 1.0 PL 2 nos.	1.0	95.5	191.0	49.0	9349.5	457655.6	145164.0
			219.8		**9366.7**	**457665.9**	**145167.4**

Y_t=sum(AY)/sum(A) = 42.61 cm $Y=h_1+h_2=$ 96.7 cm

$Y_c=(Y-Y_t)$= 54.09 cm

$I_{zz}=(1.2x24^3/12)+2 \times (95.5x\ 1^3/12)$ = 1398.32 cm^4

$I_{N.A}=I_{yy}$=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 203672.18 cm^4

$Z_t=I_{yy}/Y_t$ = 4779.38 cm^3

$Z_c=I_{yy}/Y_c$= 3765.76 cm^3

Zmin 3765.76

Max. Stress $\sigma_{max}=M/Z_{min}$ = 3497950/3765.76

=929 kg/cm^2 **ok** < 1080 kg/cm^2

$\sigma_{max}=M/Z_{min}$ = 3497950/4779.38

=732 kg/cm^2 **ok** < 1080 kg/cm^2

A.10.1 Calculation for weight of end vertical girder:

Weight of girder =Area of section (cm^2) x length/cm x height of gate (m) x density of steel (kg/cm^3)

=219.8x100x8.4x0.00785

=1449 kg   =1.449 t

OPTIMAL DESIGN OF UNDER SLUICE GATE OF BHIMGODA BARRAGE

The width of gate is 18m and height is 8.4m, symmetry between two supports is considers, then use the Excel program and done the 4-design sets hare after.

B.1.0 DESIGN SET-1: Design of under sluice gate of Bhimgoda Barrage (ref: appendix-A)

B.2.0 DESIGN SET-2:

Span of gate	=	1868	cm
Height of gate	=	840	cm
Thickness of skin plate	=	0.8	cm
Number of girder	=	4	
Total water pressure	=	8.4	t/m2
Total load =(1/2)x8.4x8.4	=	35.28	t/m
Load / beam=35.28/4	=	8.82	t/m
W	=	88.2	kg/cm

B.2.1 Design of Skin Plate:

The skin plate is supported on three Horizontal Girders and the Vertical Stiffeners placed @ 415 mm c/c Skin plate is designed as panel construction supported on all the four edges. (ref: IS 4622)

Design of Panel-A

b = 280 cm
a = 41.5 cm
Avg. p = 0.140 kg/cm^2 (Fig: B.1)
S =0.80 cm.
∴ b/a = 280 / 41.5 = 6.75

Maximum value of 'k' (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
6.75	25	7.5	50

Put above values in eqn. (1), we get

$$\sigma = \frac{k}{100} \times p \times \frac{a^2}{s^2} \quad \text{------------------------ (1)}$$

σ_{2x} = 94.19 kg/cm^2
σ_{2y} = 28.26 kg/cm^2
σ_{3x} = 188.37 kg/cm^2
σ_{3y} =0.3 σ_{3x}
= 56.51 kg/cm^2

Design of Panel-B

b = 230 cm
a = 41.5 cm
Avg. p = 0.395 kg/cm^2 (Fig: B.1)
S =0.80 cm.

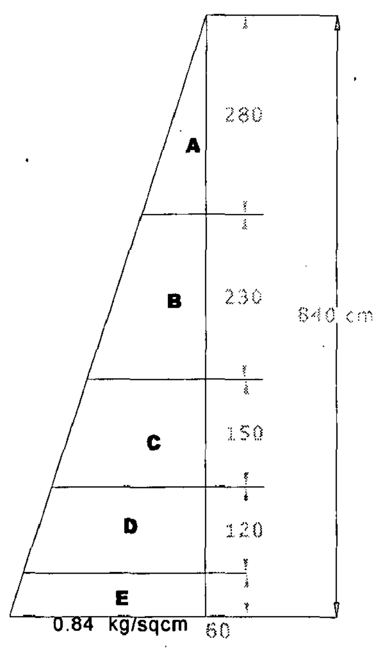


Figure: B.1 Pressure diagram

$\therefore$ b/a = 230 / 41.5 = 5.54

Maximum value of **'k'** (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
5.54	25	7.5	50

σ_{2x} = 265.74 kg/cm^2

σ_{2y} = 79.72 kg/cm^2

σ_{3x} = 531.48 kg/cm^2

σ_{3y} =0.3 σ_{3x}

= 159.44 kg/cm^2

Design of Panel-C

b = 150 cm

a = 41.5 cm

Avg. p = 0.585 kg/cm^2 (Fig: B.1)

S =0.80 cm.

$\therefore$ b/a = 150 / 41.5 = 3.61

Maximum value of **'k'** (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
3.61	25	7.5	50

σ_{2x} = 393.56 kg/cm^2

σ_{2y} = 118.07 kg/cm^2

σ_{3x} = 787.12 kg/cm^2

σ_{3y} =0.3 σ_{3x}

= 236.14 kg/cm

Design of Panel-D

b = 120 cm

a = 41.5 cm

Avg. p = 0.720 kg/cm^2 (Fig: B.1)

S =0.80 cm.

$\therefore$ b/a = 120 / 41.5 = 2.89

Maximum value of **'k'** (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
2.89	25	7.5	50

σ_{2x} = 484.38 kg/cm^2

σ_{2y} = 145.31 kg/cm^2

σ_{3x} = 968.77 kg/cm^2

σ_{3y} =0.3 σ_{3x}

= 209.62 kg/cm^2

Design of Panel-E

b = 60 cm

a = 41.5 cm

Avg. p = 0.81 kg/cm^2 (Fig: B.1)

S =0.80 cm.

$\therefore$ b/a = 60 / 41.5 = 1.45

Maximum value of **'k'** (from table 2 IS 4622)

b/a	σ_{2x}	σ_{2y}	σ_{3x}
1.45	22.1	12.2	45.5

σ_{2x} = 481.72 kg/cm^2

σ_{2y} = 265.93 kg/cm^2

σ_{3x} = 991.77 kg/cm^2

σ_{3y} =0.3 σ_{3x}

= 297.50 kg/cm^2

B.2.2 Design of vertical stiffener:

Table: B.1 Calculations of maximum bending moment and required modulus section:

Panels	Av.press	Spacing	Load(W)	Length(L)	B.M	Max.B.M	Zreq.
	kg/cm^2	cm	kg/cm	cm	kg-cm	kg-cm	cm^3
A	0.125	41.5	5.19	280	33892		
B	0.350	41.5	14.53	230	64031	64031	60.98
C	0.520	41.5	21.58	150	40463		
D	0.645	41.5	26.77	120	32121		
E	0.745	41.5	30.92	60	9275		

Table: B.2 Calculation of Neutral Axis and Modulus of section:

Item No	**Item**	**Size**		**A(cm^2)**	**Y(cm)**	**A.Y**	**A.Y^2**	**I_{self}(cm^4)**
		b(cm)	**h(cm)**	**(bxh)**	**dist. From X**	**(cm3)**	**(cm4)**	**(bh3/12)**
1	skin plate	16	0.8	12.8	0.4	5.12	2.048	0.682667
2	web	1.2	15.0	18	8.3	149.4	1240.02	337.5
				30.8		**154.52**	**1242.068**	**338.1827**

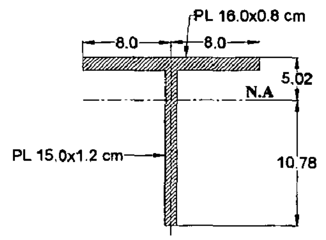


Figure: B.2 Section of vertical stiffener

Y_t=sum(AY)/sum(A) = 5.02 cm $\quad$ $Y=h_1+h_2$= 15.8 cm

Y_c=(Y-Y_t)= 10.78 cm $\quad$ M= 64031 kg-cm

I_{zz}=skin plate($hxb^3/12$)+web($hxb^3/12$)= 275.23 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 805.04 cm^4

$Z_t=I_{yy}/Y_t$ = 160.47 cm^3

$Z_c=I_{yy}/Y_c$= 74.66 cm^3 $>$ 60.98 cm^3 Zreq

Skin Plate Stress	$\sigma_t=M/Z_t$=	399.03	kg/cm^2	ok	< 1080	kg/cm^2
Stiffener Stress	$\sigma_c=M/Z_c$=	857.66	kg/cm^2	ok	< 1080	kg/cm^2

B.2.3 Design of horizontal girder:

	W =	88.2	kg/cm
	L =	1813	cm
$R_A = R_B$ =	$WL/2$=	79953.30	kg
B.M =	$WL^2/2$=	36238833	kg-cm
Zreq. =	B.M/σ=	34513.17	cm^3

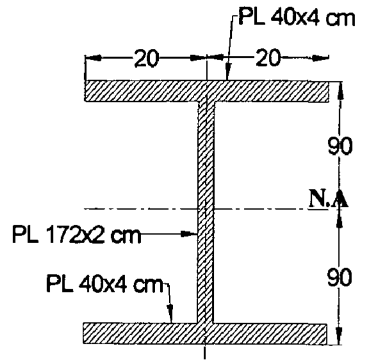


Figure: B.3 Section of horizontal girder

Table: B.3 Calculation of Neutral Axis and Modulus of section

Item No	Item	Size		A(cm²)	Y(cm)	A.Y	A.Y²	I_{self}(cm⁴)
		b(cm)	h(cm)	(bxh)	dist. From X	(cm³)	(cm⁴)	(bh³/12)
1	skin plate	40.0	4.0	160.0	2.0	320.0	640.0	213.3
2	web	2.0	172.0	344.0	90.0	30960.0	2786400.0	848074.7
3	Flange	40.0	4.0	160.0	178.0	28480.0	5069440.0	213.3
				664.0		**59760.0**	**7856480.0**	**848501.3**

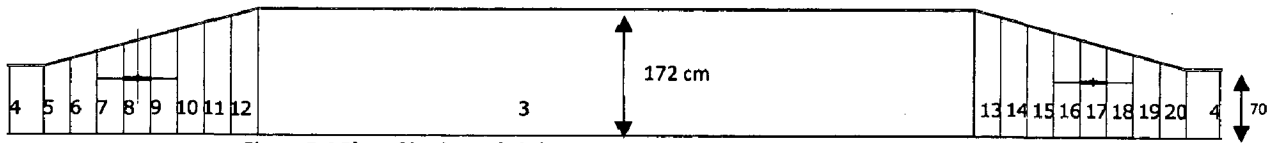


Figure B.4 Plan of horizontal girder

Weight of girder = 521 kg/m   Total weight for 4 girders =521x4x18.68=38929=38.929 t

Y_t=sum(AY)/sum(A)= 90.00 cm   Y = 180.0 cm

$Y_c=(Y-Y_t)$= 90.00 cm

I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})= 42781.33 cm^4

$I_{N.A}=I_{yy}$=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 3326581.33 cm^4

$Z_{min}=I_{yy}/Y_t$ = 36962.01 cm^3 > 34513.30 cm^3

$Z_{max}=I_{yy}/Y_c$= 36962.01 cm^3

Flange Stress	$\sigma_t=M/Z_t$=	980.43	kg/cm^2	**ok**	< 1080	kg/cm^2
Skin plate stress	$\sigma_c=M/Z_c$=	980.43	kg/cm^2	**ok**	< 1080	kg/cm^2

B.2.4 Design of end vertical girder:

The wheel shall be placed at a distance of 50 cm symmetrically about C.G. of water pressure or centre line of web. The bottom unit carries maximum load, therefore the design of this and vertical girder shall be critical.

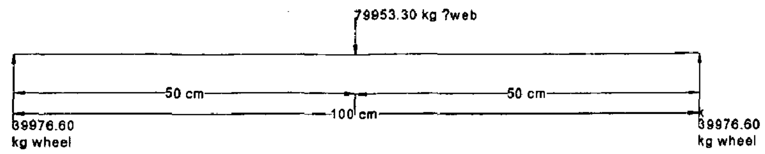


Figure: B.5 Loading diagram of end vertical girder

Load acting on each wheelR_F =WL/2 =88.2X1813/2 =79953.30 KG

Maximum B.M in end vertical girder = R_F L/4 =79953.30 x 100/4

=1998833 kg cm

Table: B.4 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		A(cm^2)	Y(cm)	A.Y	A.Y^2	I_{self}(cm^4)
		b(cm)	h(cm)	(bxh)	dist. From X	(cm3)	(cm4)	(bh3/12)
1	Flange	24	1.2	28.8	0.6	17.28	10.368	3.456
2	web	1	70.0	140	36.2	5068	183461.6	57166.67
				168.8		**5085.28**	**183472**	**57170.12**

Y_t=sum(AY)/sum(A) = 30.13 cm $Y=h_1+h_2$= 71.2 cm

$Y_c=(Y-Y_t)$= 41.07 cm   M= 1998833 kg-cm

I_{zz}=skin plate($hxb^3/12$)+web($hxb^3/12$)= 1388.23 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 87442.61 cm^4

$Z_t=I_{yy}/Y_t$ = 2902.56 cm^3

$Z_c=I_{yy}/Y_c$= 2128.91 cm^3

Skin Plate Stress	$\sigma_t=M/Z_t$=	688.65	kg/cm^2	**ok**	< 1080	kg/cm^2
Stiffener Stress	$\sigma_c=M/Z_c$=	938.90	kg/cm^2	**ok**	< 1080	kg/cm^2

B.2.5 Design of Wheel:

Maximum wheel load =39976 kg =39.976 t

Provide 450 mm ϕ wheel with 90 mm tread width contact.

Material: Cast Steel Gr. IS: 1030 Grade 340 – 570 W

UTS	=	570MP$_a$	= 5812 kg/cm^2	=5.812 t/ cm^2
YP	=	340MP$_a$	= 3467 kg/cm^2	=3.467 t/ cm^2

Allowable line contact stress = 1.6 UTS = 1.6 x 5.812 = 9.30 t/cm^2

Contact stress f_C = 0.418 x √ (P x E) / (r x l)

Where 'P' is the maximum wheel load = 39.976 t

'E' is modulus of elasticity =2100 t/cm^2

'R' is the radius of wheel =22.50 cm

'L' is the tread width =9 cm

Contact stress f_C = 0.418 x √ (P x E) / (r x l)

∴ f_C = 0.418 x √ (39.976 x 2100) / (22.50 x9)

= 8.51 t/cm^2 < 9.30 t/cm^2 hence safe

B.2.6 Design of Pin:

Same wheel pins shall be provided for bottom and intermediate and top units. The pin shall be designed for a maximum load of 39976 kg.

Wheel load =39976 kg

R_A =R_B =39976/2 =19988 kg

Max. B.M in centre =19988{(20.2/2)-(8/4)}

=161902 kg cm

Dia of Pin =12 cm

Z =π (12)^3/32 =169.64

Maximum stress =161902/169.64 =954.35 kg/cm^2

<u>Shear stress</u>

Dia of pin at support B = 115 mm

Therefore shear Area =π(10.5)^2/4 =86.59 cm^2

Reaction at support B =19988 kg

Shear stress =19988/86.59 =231 kg/cm^2

B.2.7 Combined stresses:

The stresses shall be combined in accordance with IS 4622.

The permissible combined stress is 1440 kg/cm^2.

Vertical stiffener:

Maximum stress occurring in panel 'c'

Total stress in 'X' direction

Stress in Skin Plate due to skin plate bending $fx = \sigma_{3x}$ =699.66 kg/cm^2

Total stress in 'Y' direction

Stress in skin plate due to stiffener bending $fy = \sigma_{t} + \sigma_{3y}$ = 209.89+857.66

=1067.55 kg/cm^2

Shear stress fxy=0

The combined stresses shall be calculated on the following basis.

Combined stress fc= $\text{sqrt}(fx^2 + fy^2 - fx.fy + 3fxy^2)$ =939.28 kg/cm^2

Horizontal girder:

Total stress in 'X' direction

Stress in Skin Plate due to skin plate bending $fx = \sigma_{3x\,(skin\ plate)}$ =699.66 kg/cm^2

Total stress in 'Y' direction

Stress in skin plate due to beam bending $fy = \sigma_{t\,(beam)} + \sigma_{3y(skin\ plate)}$ = 1040.82+209.89

=1250.71 kg/cm^2

Shear stress fxy=0

The combined stresses shall be calculated on the following basis.

Combined stress fc= $\text{sqrt}(fx^2 + fy^2 - fx.fy + 3fxy^2)$ =1085.69 kg/cm^2

B.2.8 Deflection

Deflection $= \dfrac{5}{384}\dfrac{WL^4}{EI}$

Bottom Most Girder $= \dfrac{5 \times 88.20 \times 1868^4}{384 \times 2.01 \times 10^6 \times 3326581.33}$ = 2.09 cm

Limiting deflection = L/800 =1868/800 =2.34 cm

B.2.9 Calculation for weight of the gate (deign set-2):

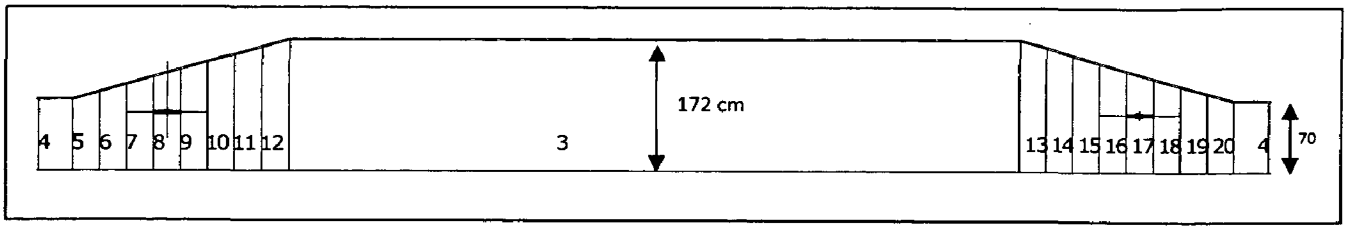


Figure: B.6 Plan of horizontal girder

Table: B.5 Calculation for weight of horizontal girder:

$A(cm^2)$	Unit length/m	Density	wt.(kg/m)	length(m)	total wt.	
664	100	0.00785	521.24	11.180	5827.463	
496	100	0.00785	389.36	0.519	404.156	
508	100	0.00785	398.78	0.415	330.987	
530	100	0.00785	416.05	0.415	345.322	
550	100	0.00785	431.75	0.415	358.353	
571	100	0.00785	448.235	0.415	372.035	
592	100	0.00785	464.72	0.415	385.718	
613	100	0.00785	481.205	0.415	399.400	
634	100	0.00785	497.69	0.415	413.083	
654	100	0.00785	513.39	0.415	426.114	
					9262.629	kg

Table: B.6 Calculation for total weight of the gate(design set-2)

S. No.	Component name	Weight in (kg)	Weight in (t)
1	Skin plate	(840x1868)x0.8x0.00785=9854	9.854
2	(a)Vertical stiffeners (b) stiffener at Top of the gate	(30.8x100x0.00785)x(8.4-0.09)x43=8639 (30.8x100x0.00785)x18.68=450 Total =8639+451=9089	9.089
3	End vertical girder	(168.8x100x0.00785)x8.4x2=2226	2.226
4	Horizontal girders (ref: Fig.2.5 & Table 2.5)	9262.629X4=37050.518	37.051
		Total	**58.22**
5	Wheels(8 wheels provided each side, left side as well as right side)	$[3.14x9x(22.50^2-6^2)]x0.00785x8=834.56$	0.834
		Total	**59.05**

B.3.0 DESIGN SET-3:

Span of gate	=	1868	cm
Height of gate	=	840	cm
Thickness of skin plate	=	0.8	cm
Number of girder	=	5	Nos.
Total water pressure	=	8.4	t/m2
Total load =(1/2)x8.4x8.4	=	35.28	t/m
Load / beam=35.28/5	=	7.056	t/m
W	=	70.56	kg/cm

B.3.1 Design of Vertical Stiffener:

Table: B.7 Calculations of maximum bending moment and required modulus section:

Panels	Av.press	Spacing	W	L	B.M	Max.B.M	Zreq.
	kg/cm^2	cm	kg/cm	cm	kg-cm	kg-cm	cm^3
A	0.125	41.5	5.19	170	12493		
B	0.350	41.5	14.53	200	48417	48417	46.11
C	0.520	41.5	21.58	150	40463		
D	0.645	41.5	26.77	140	43720		
E	0.745	41.5	30.92	110	31175		
F	0.815	41.5	33.82	70	13811		

Table: B.8 Calculation of Neutral Axis and Modulus of section:

Item No	**Item**	**Size**		**$A(cm^2)$**	**Y(cm)**	**A.Y**	**$A.Y^2$**	**$I_{self}(cm^4)$**
		b(cm)	**h(cm)**	**(bxh)**	**dist. From X**	**(cm3)**	**(cm4)**	**(bh3/12)**
1	skin plate	12	0.8	9.6	0.4	3.84	1.536	0.512
2	web	1.2	14.0	16.8	7.8	131.04	1022.112	274.4
				26.4		**134.88**	**1023.648**	**274.912**

Y_t=sum(AY)/sum(A) = 5.11 cm $Y=h_1+h_2$= 14.8 cm

$Y_c=(Y-Y_t)$= 9.69 cm M= 48417 kg-cm

I_{zz}=skin plate$(hxb^3/12)$+web$(hxb^3/12)$= 117.22 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 609.45 cm^4

$Z_t=I_{yy}/Y_t$ = 119.29 cm^3

$Z_c=I_{yy}/Y_c$= 62.89 cm^3 > 46.11 Zreq

Skin Plate Stress $\sigma_t=M/Z_t$= 405.89 kg/cm^2 **ok** < 1050 kg/cm^2

Stiffener Stress $\sigma_c=M/Z_c$= 769.88 kg/cm^2 **ok** < 1050 kg/cm^2

B.3.2 Design of Horizontal Girder:

	W =	70.56	kg/cm
	L =	1868	cm
$R_A = R_B$=	WL/2=	65903	kg
B.M =	$WL^2/8$=	30776720	kg-cm
Zreq. =	B.M/σ=	29311	cm^3

Table: B.9 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
		b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	$(bh^3/12)$
1	skin plate	40.0	4.0	160.0	2.0	320.0	640.0	213.3
2	web	2.0	152.0	304.0	80.0	24320.0	1945600.0	585301.3
3	Flange	40.0	4.0	160.0	158.0	25280.0	3994240.0	213.3
				624.0		**49920.0**	**5940480.0**	**585728.0**

Y_t=sum(AY)/sum(A)= 80.00 cm   Y = 160.0 cm

$Y_c=(Y-Y_t)$= 80.00 cm

I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})= 42768.00 cm^4

$I_{N.A}=I_{yy}$=sum(AY^2)+sum(I_{self})-sum(A)x$(Y_t)^2$ = 2532608.00 cm^4

$Z_{min}=I_{yy}/Y_t$ = 31657.60 cm^3 > Zreq 29311 cm^3

$Z_{max}=I_{yy}/Y_c$= 31657.60 cm^3

Flange Stress	σ_t=M/Z_t=	972.17	kg/cm^2	ok	< 1050	kg/cm^2
Skin plate stress	σ_c=M/Z_c=	972.17	kg/cm^2	ok	< 1050	kg/cm^2

B.3.4 Deflection:

Deflection $= \frac{5}{384}\frac{WL^4}{EI}$

Bottom Most Girder $= \frac{5 \times 70.56 \times 1868^4}{384 \times 2.01 \times 10^6 \times 2532608}$ = 2.19 cm

Limiting deflection = L/800 =1868/800 =2.34 cm

B.3.5 Design of end vertical girder:

Load acting on each wheel R_F =WL/2 =70.56X1813/2 =63962.64 kg

Maximum B.M in end vertical girder = R_F L/4 =63962.64 x 100/4

=1599066 kg cm

Table: B.10 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		A(cm^2)	Y(cm)	A.Y	A.Y^2	I_{self}(cm^4)
		b(cm)	h(cm)	(bxh)	dist. From X	(cm3)	(cm4)	(bh3/12)
1	Flange	24	1.2	28.8	0.6	17.28	10.368	3.456
2	web	1	60.0	120	31.2	3744	116812.8	36000
				148.8		**3761.28**	**116823.2**	**36003.46**

Weight = 116.808 kg/m total weight for 2no. stifeners = 981.1872 kg

say 0.9812 t

Y_t=sum(AY)/sum(A) = 25.28 cm Y=h_1+h_2= 61.2 cm

Y_c=(Y-Y_t)= 35.92 cm M= 1599066 kg-cm

I_{zz}=skin plate(hxb^3/12)+web(hxb^3/12)= 1387.40 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2 = 57751.17 cm^4

Z_t=I_{yy}/Y_t = 2284.69 cm^3

Z_c=I_{yy}/Y_c= 1607.66 cm^3 > 0.00 Zreq

Skin Plate Stress σ_t=M/Z_t= 699.90 kg/cm^2 **ok** < 1080 kg/cm^2

Stiffener Stress σ_c=M/Z_c= 994.66 kg/cm^2 **ok** < 1080 kg/cm^2

B.3.6 Design of Wheel:

Maximum wheel load =31981 kg =31.98 t

Provide 450 mm ϕ wheel with 90 mm tread width contact.

Material: Cast Steel Gr. IS: 1030 Grade 340 – 570 W

UTS	=	570MP$_a$	= 5812 kg/cm^2	=5.812 t/ cm^2
YP	=	340MP$_a$	= 3467 kg/cm^2	=3.467 t/ cm^2

Allowable line contact stress = 1.6 UTS = 1.6 x 5.812 = 9.30 t/cm^2

Contact stress f_C = 0.418 x √ (P x E) / (r x l)

Where 'P' is the maximum wheel load = 31.98 t

'E' is modulus of elasticity =2100 t/cm^2

'R' is the radius of wheel =22.50 cm

'L' is the tread width =9 cm

Contact stress f_C = 0.418 x √ (P x E) / (r x l)

∴ f_C = 0.418 x √ (31.98 x 2100) / (22.50 x9)

= 7.61 t/cm^2 < 9.30 t/cm^2 hence safe

B.3.7 Design of Pin:

Same wheel pins shall be provided for bottom and intermediate and top units. The pin shall be designed for a maximum load of 31981 kg.

Wheel load =31981 kg

R_A =R_B =39976/2 =15990 kg

Max. B.M in centre =15990{(20.2/2)-(8/4)}

=129523 kg cm

Dia of Pin =12 cm

Z =π (12)^3/32 =169.64

Maximum stress =129523/169.64 =763.51 kg/cm^2

<u>Shear stress</u>

Dia of pin at support B = 115 mm

Therefore shear Area =π(10.5)^2/4 =86.59 cm^2

Reaction at support B =19988 kg

Shear stress =15990/86.59 =184.66 kg/cm^2

B.3.8 Calculation for Weight of the Gate:

Table: B.11 Weight of horizontal girder:

A(cm^2)	Unit length/m	Density	wt.(kg/m)	length(m)	total wt.	
624	100	0.00785	489.84	11.180	5476.411	
496	100	0.00785	389.36	0.519	404.156	
508	100	0.00785	398.78	0.415	330.987	
530	100	0.00785	416.05	0.415	345.322	
550	100	0.00785	431.75	0.415	358.353	
571	100	0.00785	448.235	0.415	372.035	
592	100	0.00785	464.72	0.415	385.718	
613	100	0.00785	481.205	0.415	399.400	
634	100	0.00785	497.69	0.415	413.083	
654	100	0.00785	513.39	0.415	426.114	
					8911.577	kg

Table: B.12 Total weight of the gate

S. No.	Component name	Weight in (kg)	Weight in (t)
1	Skin plate	(840x1868)x0.8x0.00785=9854	9.854
2	Vertical stiffeners	(26.4x100x0.00785)x(8.4-0.11)x43=7387	7.387
3	End vertical girder	(148.8x100x0.00785)x8.4=981.18x2	1.962
4	Horizontal girders	8911.577x5=44557	44.557
		Total	**63.76**
5	Wheels(8 wheels provided each side, left side as well as right side)	$[3.14x9x(22.50^2-6^2)]x0.00785x10=1043.2$	1.0432
		Total	64.80

B.4.0 DESIGN SET-4:

Span of gate	=	1868	cm
Height of gate	=	840	cm
Thickness of skin plate	=	0.8	cm
Number of girder	=	6	Nos.
Total water pressure	=	8.4	t/m2
Total load =(1/2)x8.4x8.4	=	35.28	t/m
Load / beam=35.28/5	=	5.88	t/m
W =		58.8	kg/cm

B.4.1 Design of vertical stiffener:

Table: B.13 Calculations of maximum bending moment and required modulus section:

Panels	Av.press	Spacing	W	L	B.M	Max.B.M	Zreq.
	kg/cm^2	cm	kg/cm	cm	kg-cm	kg-cm	cm^3
A	0.110	41.5	4.57	220	18412		
B	0.320	41.5	13.28	200	44267	44266.67	42.16
C	0.480	41.5	19.92	120	23904		
D	0.590	41.5	24.49	100	20404		
E	0.680	41.5	28.22	80	15051		
F	0.760	41.5	31.54	80	16821		
G	0.820	41.5	34.03	40	4537		

Table: B.14 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		$A(cm^2)$	Y(cm)	A.Y	$A.Y^2$	$I_{self}(cm^4)$
		b(cm)	h(cm)	(bxh)	dist. From X	(cm3)	(cm4)	(bh3/12)
1	skin plate	10	0.8	8	0.4	3.2	1.28	0.426667
2	web	1.2	12.0	14.4	6.8	97.92	665.856	172.8
				22.4		**101.12**	**667.136**	**173.2267**

Y_t=sum(AY)/sum(A) = 4.51 cm Y=h_1+h_2= 12.8 cm

Y_c=(Y-Y_t)= 8.29 cm M= 44267 kg-cm

I_{zz}=skin plate(hxb^3/12)+web(hxb^3/12)= 68.39 cm^4

I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2 = 383.88 cm^4

Z_t=I_{yy}/Y_t = 85.04 cm^3

Z_c=I_{yy}/Y_c= 46.33 cm^3 > 42.16 Zreq

Skin Plate Stress σ_t=M/Z_t= 520.56 kg/cm^2 ok < 1050 kg/cm^2

Stiffener Stress σ_c=M/Z_c= 955.46 kg/cm^2 ok < 1050 kg/cm^2

B.4.2 Design of horizontal girder:

Table: B.15 Calculation of Neutral Axis and Modulus of section:

Item No	Item	Size		A(cm^2)	Y(cm)	A.Y	A.Y^2	I_{self}(cm^4)
		b(cm)	h(cm)	(bxh)	dist. From X	(cm^3)	(cm^4)	(bh^3/12)
1	skin plate	40.0	3.0	120.0	1.5	180.0	270.0	90.0
2	web	2.0	155.0	310.0	80.5	24955.0	2008877.5	620645.8
3	Flange	40.0	3.0	120.0	159.5	19140.0	3052830.0	90.0
				550.0		**44275.0**	**5061977.5**	**620825.8**

Y_t=sum(AY)/sum(A)= 80.50 cm Y = 161.0 cm

Y_c=(Y-Y_t)= 80.50 cm

I_{zz}=skin plate(I_{zz})+web(I_{zz})+flange(I_{zz})+plate(I_{zz})= 32103.33 cm^4

$I_{N.A}$=I_{yy}=sum(AY^2)+sum(I_{self})-sum(A)x(Y_t)^2 = 2118665.83 cm^4

Z_{min}=I_{yy}/Y_t = 26318.83 cm^3 > 24426 cm^3

Z_{max}=I_{yy}/Y_c= 26318.83 cm^3

Flange Stress σ_t=M/Z_t= 974.48 kg/cm^2 ok < 1050 kg/cm^2

Skin plate stress σ_c=M/Z_c= 974.48 kg/cm^2 ok < 1050 kg/cm^2

B.4.3 Deflection:

$$\text{Deflection} = \frac{5}{384}\frac{WL^4}{EI}$$

$$\text{Bottom Most Girder} = \frac{5 \times 58.8 \times 1868^4}{384 \times 2.01 \times 10^6 \times 2118666} = 2.19 \text{ cm}$$

Limiting deflection = L/800 =1868/800 =2.34 cm

B.4.4 Design of end vertical girder: Adopted same section calculated in (appendix-B, sec-3.5)

B.4.5 Calculation for weight of the gate:

Table: B.16 Calculation for weight of the gate:

S. No.	Component name	Weight in (kg)	Weight in (t)
1	Skin plate	(840x1868)x[illegible]x0.00785=9854	9.854
2	Vertical stiffeners	(22.4x100x0.00785)x(8.4-0.11)x43=6268	6.268
3	End vertical girder	(168.8x100x0.00785)x8.4x2=2226	2.226
4	Horizontal girders	(550x100x0.00785)x18.68x6=48390	48.390
		Total	66.738

B.5.0 CALCULATION OF WEIGHT FOR EACH DESIGN SET:

Table: B.17 Calculation of weight for each design set

Design Sets	Number of Horizontal Girder	Weight of Skin Plate (t)	Weight of Vertical Stiffeners (t)	Weight of End Vertical Girders (t)	Sum of [3+5+5]	Weight of Horizontal Girder (t)	Total Weight (t)
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
SET-1	3	12.854	10.8	2.898	26.55	35.01	61.562
SET-2	4	9.854	9.089	2.226	21.169	37.051	58.220
SET-3	5	9.854	7.387	1.962	19.467	44.557	63.760
SET-4	6	9.854	6.268	2.226	18.348	48.39	66.738