Structural Analysis of Gate Leaf of Automatic Outflow Regulating Gate System

Anushree Sunil Waikar[1] P. G. Mehar[2]
[1]P.G. Student [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1,2]K.D.K. College of Engineering, Nagpur, Maharashtra, India

Abstract— The main objective in the "Structural Analysis of gate leaf of Automatic outflow regulating gate system" is to achieve suitable design for Gate leaf proper. Finite element analysis of Gate leaf proper is taken for the study. Structural systems of Gate leaf can be easily analyzed using Finite Element techniques. So firstly a proper Finite Element Model is developed using Cad software Creo 1.0. Then static analysis is done to determine the Equivalent stresses, shear stress & total deformations etc in the present design for the given loading conditions in gate close position as well as gate open position using Finite Element Analysis Software ANSYS v 12. The analysis of gate leaf shows that stresses under both loading conditions are well below permissible limit.

Key words: Automatic Outflow Regulating Gate, Design Analysis, Ansys Workbench

I. INTRODUCTION

Automation in hydraulic gates is employed to regulate the flow of water through a reservoir or canal, without any human interference. This is normally done to satisfy one of the following two field requirements;

- To pass out excess discharge on downstream side, while maintaining the upstream water level.
- To pass out required discharge on downstream side.
- The automatic outflow regulating gate [1] is a water pressure operated gate, which does not need electricity for its operation. It is unique invention, which can decide by itself the timing as well as extent of opening & thus regulate the discharge flowing through it, by sensing water levels on Upstream &/or Downstream side.

The gate system [2] consists of 2 parts;

- Rotating gate leaf &
- A pair of supporting fulcrum assemblies & embedded parts fixed in supporting structures

The rotating gate leaf assembly consists of;

- Rotating gate leaf &
- A pair of supporting fulcrum assemblies & embedded parts fixed in supporting structures

The rotating gate leaf assembly consists of;

- Upstream skin plate
- Downstream skin plate
- Horizontal girders
- End girders
- Track plates
- Sealing system

(Gate leaf Proper: Upstream skin plate, Downstream skin plate, Horizontal girders; Rotating gate leaf assembly: Horizontal girders, End girders, Track plates, Sealing system)

The supporting fulcrum assemblies & embedded parts consists of rolling surfaces, link brackets, trunnion girder, seal anchors etc. The components of rotating gate leaf account for more than 60% of total weight of gate system. Hence if this portion is optimized, it will result in saving in weight as well as cost of Automatic outflow regulating gate system.

A. Operational behavior of automatic out flow regulating gates-

The Operational behavior [3] of the Automatic outflow regulating gate is as follows;

As long as reservoir water level in below F. R.L the gate remains in fully closed position (Fig-1)

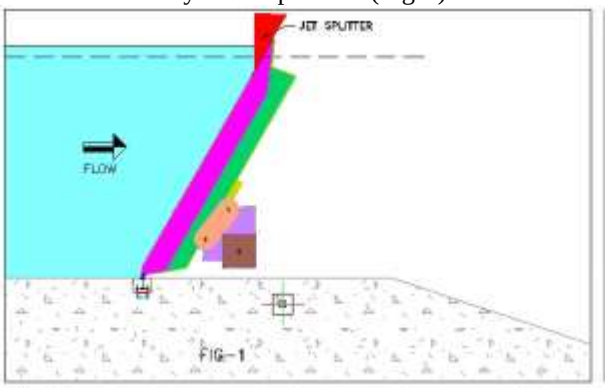


Fig. 1: Gate Remains In Fully Closed Position

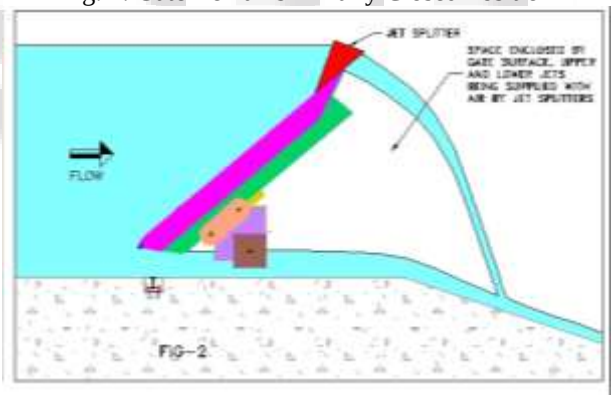


Fig. 2: Gate Stops to Move Further And Remains Stable In That Position

- As soon as the reservoir level tends to rise above F. R. L. (due to inflow into the reservoir) the gate slowly starts to open out. As soon as the outflow from the gate balances the inflow into the reservoir, the gate stops to move further and remains stable in that position (Fig-2).
- When the inflow into the reservoir increases, causing a further rise in reservoir water level, the gate automatically opens out further to the desired extent, so that the outflow matches the inflow again.
- With continuing rise in reservoir water level, the gate opens out more & more until it achieves its fully open position (Fig-3).

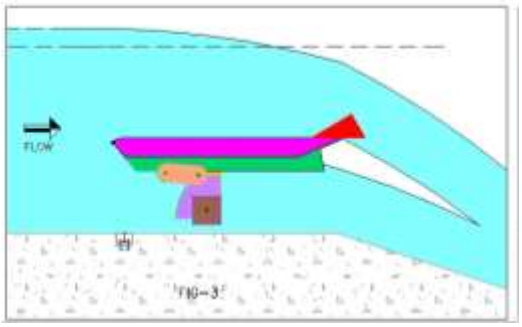


Fig. 3: Gate Opens Out More & More Until It Achieves Its Fully Open Position

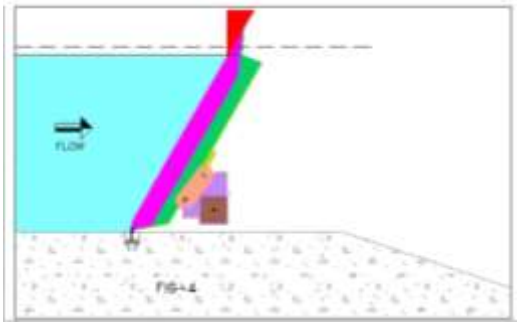


Fig. 4: The Gate Closes Completely

- By this time the reservoir water level shall have risen to about 10% of gate height above Full Reservoir Level. If the inflow increases further the gate remains stable in its fully open position until the reservoir level rises to fully designed Maximum Water Level
- As soon as the inflow starts to reduce, the reservoir level starts to fall where the reservoir level falls below Full Reservoir Level + 10% gate height, the gate starts to close back slowly so as to reduce the outflow to match with reduced inflow.

When the inflow reduces to zero, the reservoir level tends to fall below Full Reservoir Level and the gate closes completely (Fig-4)

II. CONSTRUCTION OF GATE LEAF PROPER OF AUTOMATIC OUTFLOW REGULATING GATE SYSTEM

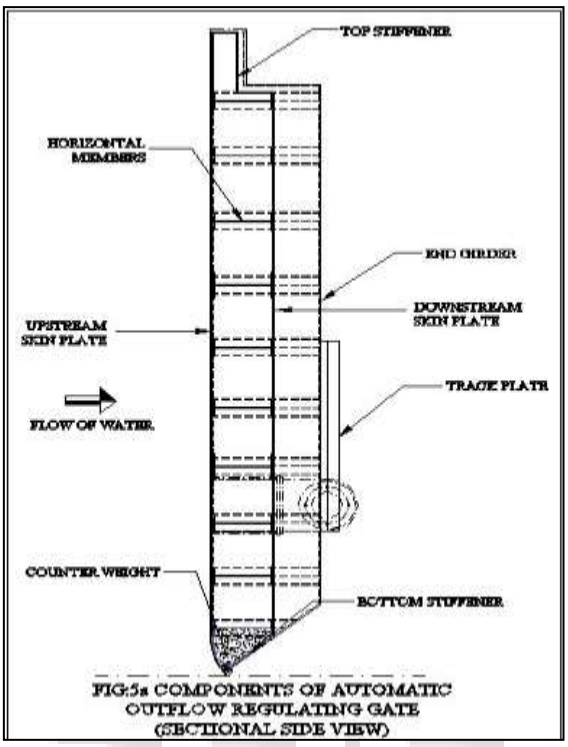


Fig. 5A: Construction Of Gate Leaf Proper Of Automatic Outflow Regulating Gate System

Sr. No.	Name of component	Number of components used in gate leaf assembly	Sections used for component	Material
1	Upstream Skin plate	1	12mm plate	Structural steel
2	Downstream Skin plate	1	12 mm plate	Structural steel
3	Horizontal members	10	ISMB 600	Structural steel
4	Bottom end angle	1	ISA 90 X 90 X 12	Structural steel
5	Top end channel	1	ISMC 250	Structural steel
6	Stiffeners for bottom portion of gate leaf	8	12 mm plate	Structural steel
7	Stiffeners for bottom portion of gate leaf	8	12 mm plate	Structural steel

Table 1: Component in gate leaf assembly

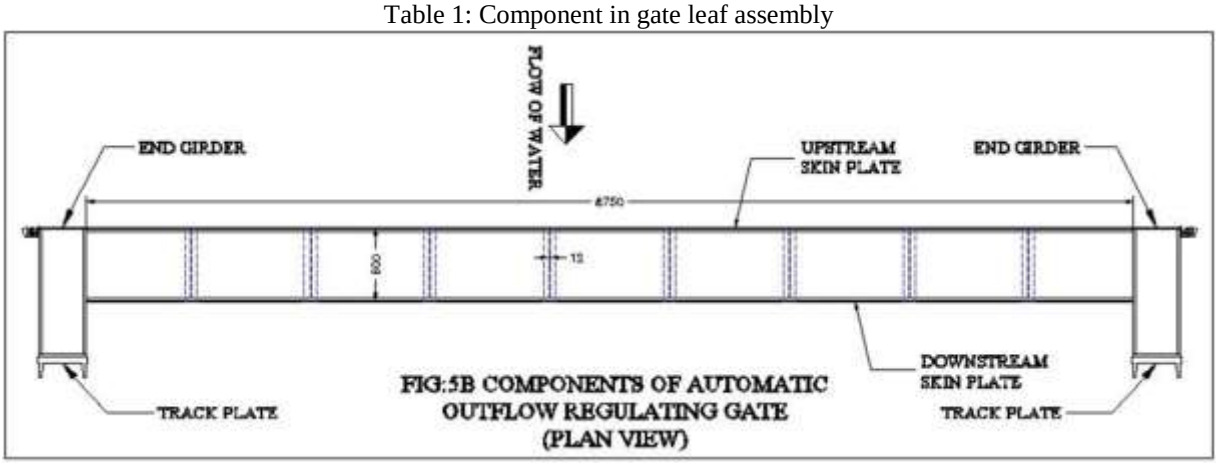


Fig- 5B: Component of Automatic Outflow Regulating Gate (Plan View)

III. OBJECTIVES

This research pertains to perform static structural analysis of the gate leaf part of Automatic outflow regulating gate system. By using analysis software for gate leaf structure we check the results for stresses & deformation to be under permissible limits. It is highly desirable to do this analysis for creating most economical gate leaf structure.

The working stress method which is presently used for computing stresses as described above is quite conservative. Today many computer based tools & methods of indeterminate structural analysis like FEM are available. It is therefore proposed to use these modern methods for design of components of rotating gate leaf for proposed structural analysis.

IV. PROBLEM FORMULATION

The gate leaf consists of upstream skin plate, downstream skin plate & horizontal members. The water load is transferred by upstream skin plate to the horizontal members, which subsequently transfer it to the end girders. Structurally, the upstream skin plate acts as a one-way slab spanning over horizontal members. The slab stresses in upstream skin plate in various panels are calculated from this consideration. The horizontal members and Upstream and Downstream skin plates co-act as a composite section. The effective width of co-acting flanges (Upstream & Downstream skin plates) for the intermediate composite sections is taken as 40*t + B, while that for top most & bottom most composite section is taken as 20t+b, where t=thickness of skin plate (after considering 1.5 mm corrosion allowance) and B=width of flange of horizontal member. The composite sections consisting of horizontal members along with co-acting skin plates are checked for bending stresses and shear stresses. The combined action of skin plates and horizontal members produces beam stresses in the skin plates, which act at right angles to the slab stresses. Hence the Upstream skin plate is also checked for combined stresses. The horizontal members transfer load to the end girder.

Normally, box sections are provided for End girders of gate leaf. Since the end girders are substantially rigid & stiff compared to horizontal members & skin plate (as shown in Fig 5B), it is presumed in this analysis that the horizontal members are rigidly fixed to the end girders on both sides.

As the Gate leaf part of the system i.e. Assembly of Horizontal members, upstream skin plate & downstream skin plate is in the range of 60% - 70% of weight of total Automatic outflow regulating gate system, we will concentrate on analyzing the gate leaf part only. The gate leaf part will be analyzed in gate close position where the loading is maximum in bottom portion of gate leaf & also in gate open position where top portion of gate will face maximum loading.

In this research, we are going to analyze the gate leaf of size 10.0m wide & 6.0 m height (nominal). As the gate is tilted 30 degrees in gate close position, to store water up to 6m of height we have to construct gate leaf of height [(1.155 X Height of water column to be stored) + free board of 0.5m] i.e. total height of gate is 7.48m. The width of gate is [(Width of clear span between two piers) – (2 X width of rubber seal) – (2 X width of seal seats) - (2 X width of End girders)] i.e total width of gate is 8.75 m. Thus the size of gate leaf which is to be analyzed is of size 8.75m wide & 7.48m height. For this gate leaf the two extreme loading conditions are as follows;

1) Gate fully closed and upstream water level up to top lip of gate, at 6.544m above gate sill
2) Gate fully open with upstream water level i.e., at 6.544 m above gate sill level. The height of water column is 3.32 m above the upstream skin plate in this condition. The spans & thicknesses of skin plates as well as section details of various Horizontal members are shown in Fig 5A (sectional side view) & 5B (plan view).

A. Permissible Stresses

The permissible stresses for different gate components are determined as per annexure B of IS: 4622-1992. The permissible stresses under "wet and accessible" conditions have been considered for all structural steel components of gate.

For structural steel corresponding to IS: 2062, minimum guaranteed yield point stress, Yp = 2550 kg/cm2. Hence after considering factor of safety we get permissible stresses as,

Permissible compressive/tensile stress in bending = 45% Y_p
= 0.45 * 2550 = 1145 kg/cm^2 = 112.5 Mpa
Permissible combined stress = 60% * Y_p
= 0.60 * 2550 = 1530 kg/cm^2 = 150 Mpa
Permissible shear stress = 35% * Y_p
= 0.35 * 2550 = 890 kg/cm^2 = 87.5 Mpa

Also, Maximum deflection of gate under normal condition of loading shall be limited to L/800 (L=length of gate leaf) of the span.

The load intensities at different points on gate leaf when gate is in closed position, for this loading condition are shown in fig: 6.

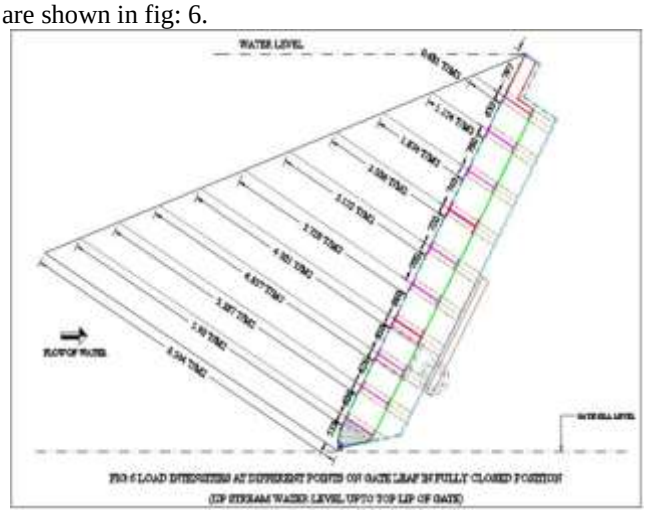


Fig. 6: Load Intensities on Gate Leaf In Gate Close Position

The load intensities at different points on gate leaf when gate is in open position, for this loading condition are shown in fig: 7.

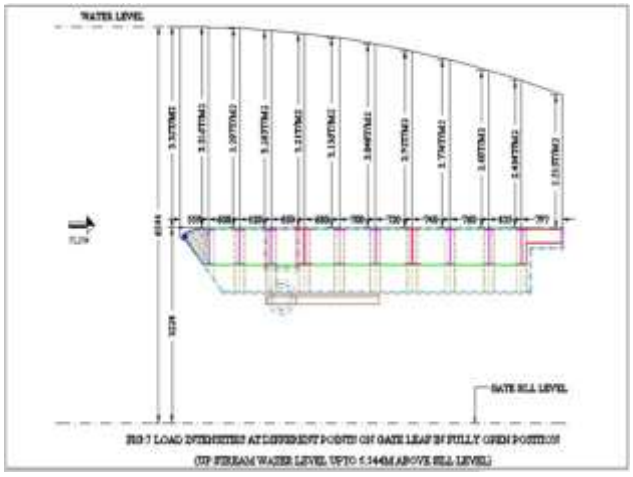


Fig. 7: Load Intensities on Gate Leaf In Gate Open Position

V. ANALYSIS & INTERPRETATION

This paper includes FEA analysis of Automatic outflow regulating gate system which is considered to give better results. Then the Finite Element Analysis method is applied on this design to get the more accurate results with the help of various Computer Aided Engineering tools and software.

The geometry of gate leaf is shown in fig:8. In this Fig cross section of gate leaf is shown. Every section shown in Fig: 8 is extruded 8750mm long to make gate leaf except that of Bottom & top portion stiffeners. The Stiffeners for bottom & top portion of gate leaf are arranged 1000mm centre to centre throughout the span of 8750mm of gate leaf.

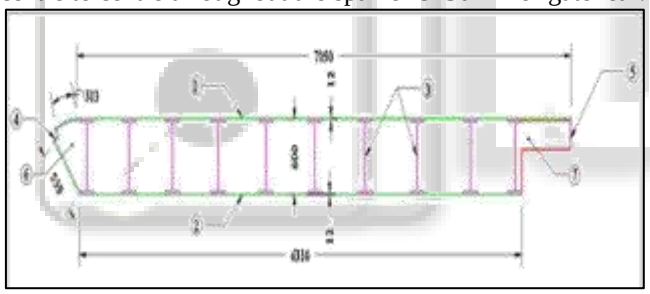


Fig. 8: Geometry of Gate Leaf

CAD Model of Gate leaf is made in Creo Parametric 1.0. This CAD model used for analysis is shown in fig 9.

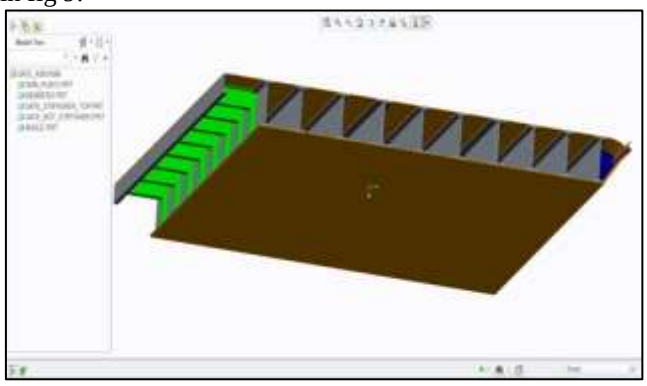


Fig. 9: Model Gate Leaf in CREO Parametric 1.0

After creating model in Creo, the next step is to export the model file in compatible extensions such as IGES or STP format. The required material is selected in "Engineering Data" section in Ansys as Structural steel. After selecting material, the next step in process is generating mesh for the model. The meshed model is shown in Fig: 10.

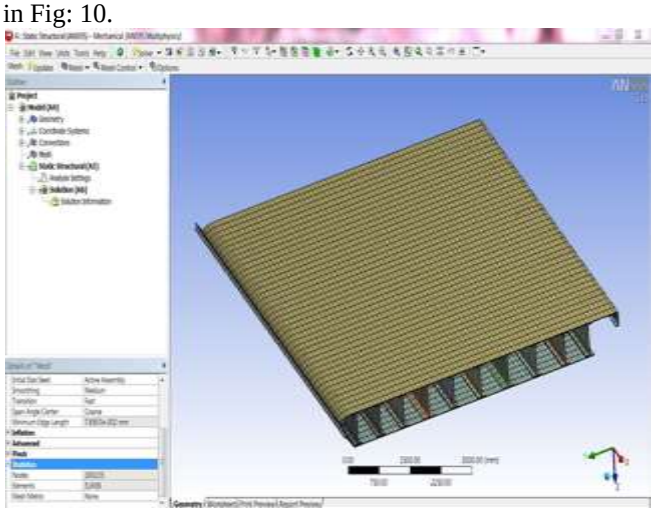


Fig. 10: Meshed Model of Gate Leaf

A. Constraints and Loading

After preparing the model ready for analysis, various constraints, supports and loads are applied, keeping in mind various boundary conditions. A Fixed Support is applied at both left & right ends of the gate leaf proper. Shown in Fig 11.

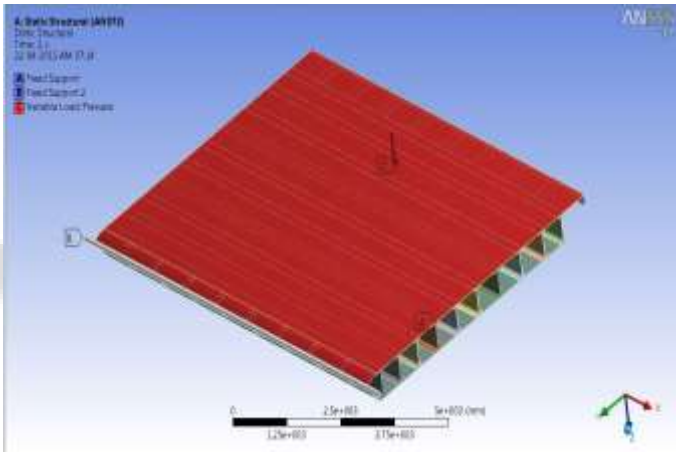
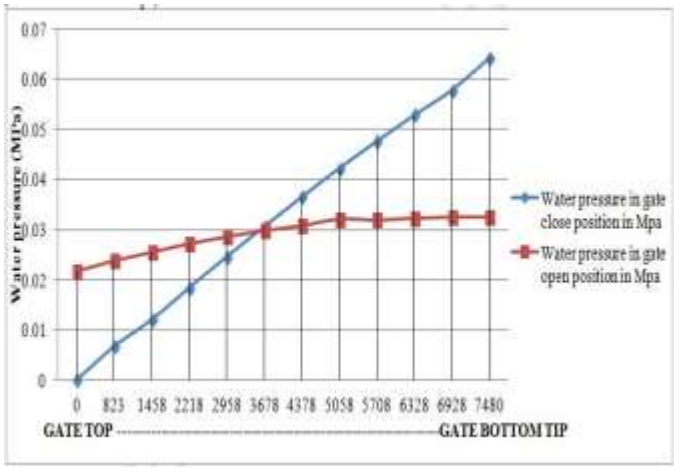


Fig. 11: Loading and Boundry Condition

The value of variable water pressure acting on gate leaf proper when Automatic outflow regulating gate system is in gate close position & open position considering gate top point as origin is as per following table 2;

X Co-ordinate (mm)	Water pressure in gate close position (Mpa)	Water pressure in gate open position (Mpa)
0	0	0.0217
823	0.0067	0.0238
1458	0.0120	0.0255
2218	0.0184	0.0272
2958	0.0246	0.0286
3678	0.0306	0.0298
4378	0.0365	0.0308
5058	0.0422	0.0326
5708	0.0476	0.0319
6328	0.0528	0.0323
6928	0.0578	0.0325
7480	0.0642	0.0325

Table 2: Gate Top Point



From above graph showing water pressure on gate leaf we can see that gate bottom is having maximum water pressure when gate is in close position & gate top is having maximum water pressure when gate is in open position. Thus, we have to analyze gate leaf proper in both the conditions i.e gate close & gate open condition.

B. Analysis for Water Pressure in Gate Close Position:

Fig 12 shows the variable pressure applied on upstream skin plate of gate leaf proper as per values shown in table above.

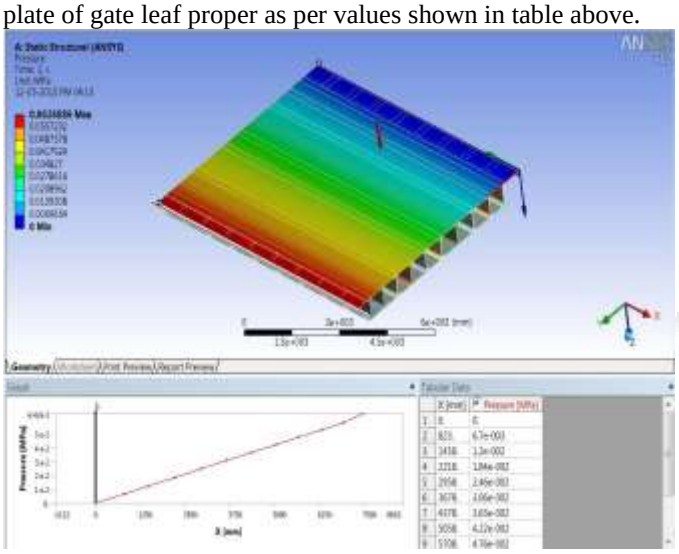


Fig. 12: Variable Water Pressure Applied On Gate Leaf Proper For Close Position

Fig 13 shows the equivalent stresses developed in gate leaf proper as a result of applied water pressure.

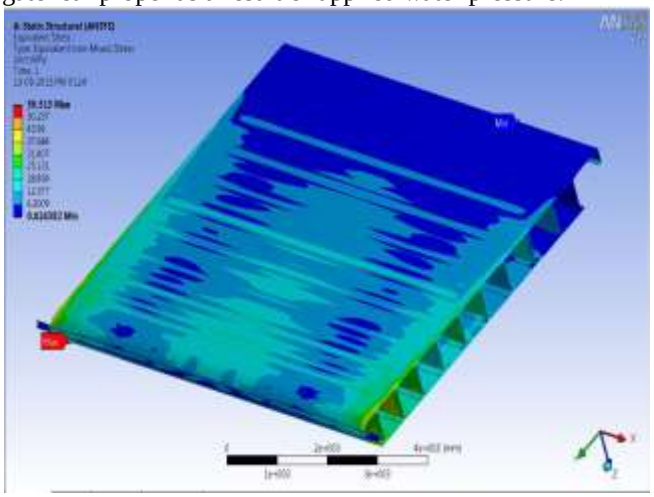


Fig. 13: Equivalent Stresses

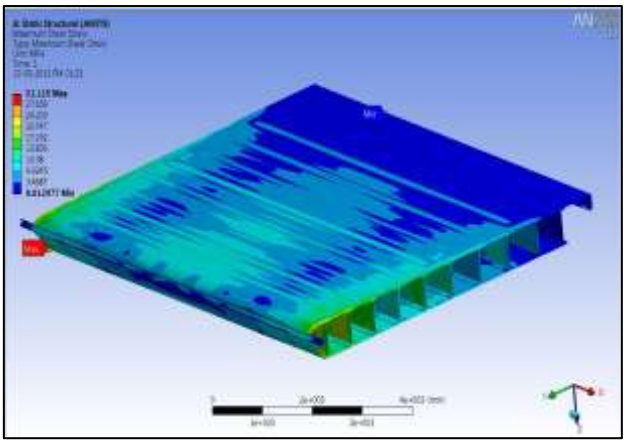


Fig. 14: Maximum shear stress

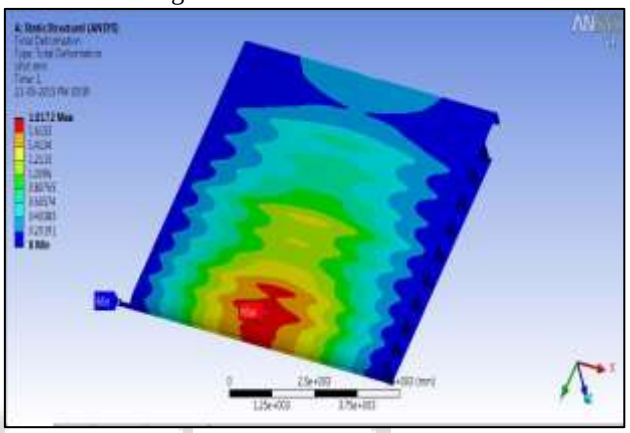


Fig. 15: Total Deformations Ansys results of gate leaf in close position loading condition

From above Fig 13 we can see that Maximum equivalent stress developed is 56.513Mpa in Skin plate which well below permissible value of combined stresses i.e. 150Mpa.

Fig 14 shows Maximum shear stress in Gate leaf which comes out to be 31.115Mpa in skin plate which is also below permissible value of Shear stresses i.e. 87.5Mpa.

Thus, we can say that stresses developed in the gate leaf proper are well below permissible in loading condition when gate is in close position.

C. Analysis for Water Pressure in Gate Open Position:

For analyzing gate leaf proper under water pressure in open position of gate variable pressure applied on upstream skin plate of gate leaf proper as per values shown in table above for gate open position. Fig 16 shows Ansys workbench inputs for above condition.

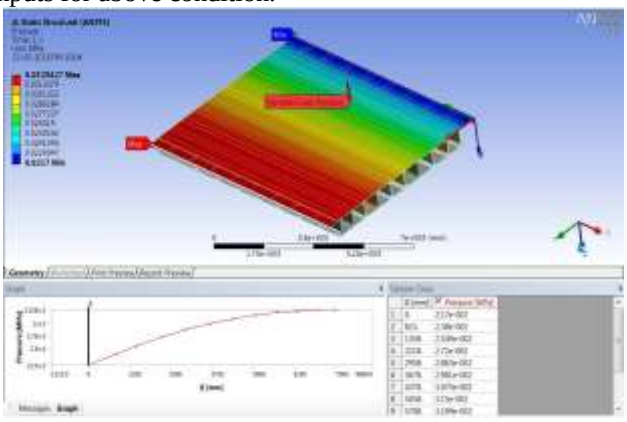


Fig. 16: Variable Pressure Applied For Gate Open Condition

Fig 17 shows Equivalent stresses developed in gate leaf proper when gate is in open position. Maximum equivalent stress is 36.417 Mpa which is less than permissible value of combined stress i.e. 150 Mpa.

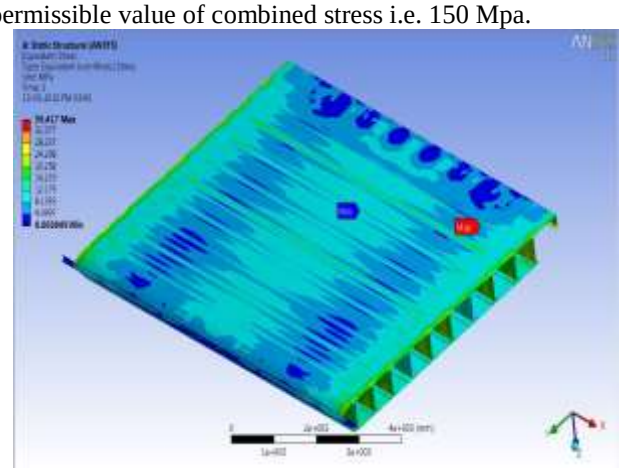


Fig. 17 EQUIVALENT STRESSES

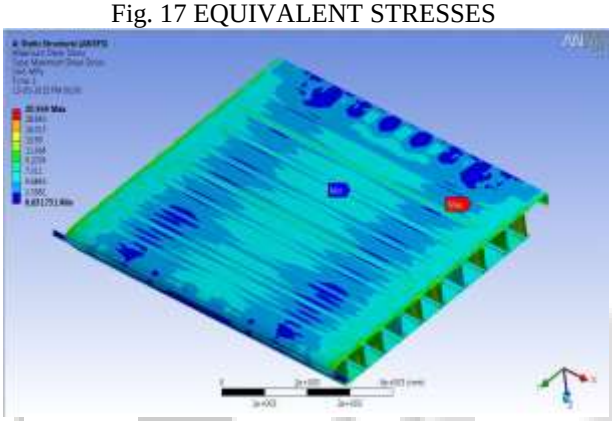


Fig. 18 Maximum shear stress

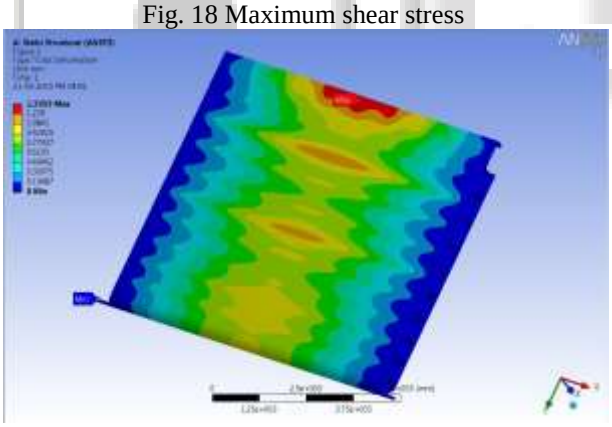


Fig. 19: Total Deformations Ansys Results Of Gate Leaf In Open Position Loading Condition

Fig 18 shows the maximum shear stress developed in the gate leaf. The maximum shear stress is 20.969 Mpa which is also well below permissible i.e 87.5 Mpa. The total weight of gate leaf proper comes out to be 24842 Kg.

VI. RESULTS OF ANALYSIS

Solution information	**Gate leaf proper of existing design**	
	Gate closed position	**Gate open position**
Equivalent Stress (Mpa)	56.513	36.417
Maximum Shear stress (Mpa)	31.115	20.969
Deformation (mm)	1.8172	1.3939
Weight of gate leaf proper (kg)	24842	

Table 3: Results

From above table we can see that all the stresses are below permissible (Permissible Equivalent stress = 150Mpa, Permissible shear stress = 87.5Mpa & Maximum deflection of L/800 (L=length of gate leaf) of the span = (8750/800) = 10.9375 mm as mentioned above).

VII. CONCLUSION

- The Stresses are found maximum on downstream skin plate & minimum on horizontal girders in both gate open as well as gate closed condition.
- The Deformation is found to be maximum on upstream skin plate & minimum on horizontal members in both gate open as well as gate closed condition.
- The Stresses are found to be much below permissible limit & hence future possibilities are there to optimize the existing design for economical design.

REFERENCES

[1] An Automatic outflow regulating gate – Prabhakar Damodar Godbole : Indian patent no. 183493
[2] The Godbole gate system – Information brochure for Automatic outflow regulating gate by Godbole gates Pvt Ltd, 2B Buty plots, Dharampeth, Nagpur 440010
[3] Operational behaviour of Automatic outflow regulating gate system - Information broacher for Automatic outflow regulating gate by Godbole gates Pvt Ltd, 2B Buty plots, Dharampeth, Nagpur 440010
[4] Godbole P.P., Dr. Ingle R.N., Dr. Porey P.D.; "The Automatic tilting gate – A powerful tool for development of water resources", The institute of Engineers 12th Indian engineering Congress, Nagpur, 9-13 January 1998, Page 176
[5] Godbole P.P., "Achieving automation in hydraulic gates without electricity by moving fulcrum type automatic gate", Seminar on Hydraulic gates & their control in water resources projects Nangal township, Punjab, Organised by Central board of irrigation & power, Bhakra Beas Management Board, 12-14 October, 1998, Page.93
[6] Litrico Xavier; Belaud Gilles; Baume Jean-Pierre; and Ribot-Bruno José, "Hydraulic Modeling of an Automatic Upstream Water-Level Control Gate" JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING © ASCE / MARCH/APRIL 2005
[7] Amir Khosrojerdi, "Hydraulic studies of pressure distribution around vertical lift gates" Indian Journal of Science and Technology Vol. 5 No. 3 (Mar 2012) ISSN: 0974- 6846, Page.2268
[8] Brett C. Commander, Jeff X. Schulz, George G. Goble, Bridge Diagnostics, Inc. Cameron P. Chasten, "Field Testing and Structural Analysis of Vertical Lift Lock Gates"
[9] Mahesh P. Sharma, Denish S. Mevawala, Harsh Joshi, Devendra A. Patel, "Static Analysis of Steering Knuckle and Its Shape Optimization". IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) E-ISSN: 2278-1684, P-ISSN: 2320-334X, Pg 34-38.

[10] Kuldeep B, Arun L.R, Mohammed Faheem, "Analysis and optimization of connecting rod using alfasic composites". International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 6, June 2013, ISSN: 2319-8753.
[11] Rehan H Zuberi, Dr. Long Kai, Prof. Zuo Zhengxing, "Design Optimization of EOT Crane Bridge". EngOpt 2008 - International Conference on Engineering Optimization Rio de Janeiro, Brazil, 01 - 05 June 2008.
[12] Hirak Patel, Khushbu C. Panchal, Chetan S. Jadav, « Structural Analysis of Truck Chassis Frame and Design Optimization for Weight Reduction". International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-4, April 2013, Pg 665-668.
[13] F. Faluyi, C. Arum, "Design Optimization of Plate Girder Using Generalized Reduced Gradient and Constrained Artificial Bee Colony Algorithms". International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 2, Issue 7, July 2012, Pg 304-312
[14] Indian Standard "RECOMMENDATIONS FOR STRUCTURAL DESIGN OF FIXED-WHEEL GATES" (Third Revision) Bureau of Indian Standards, Manak bhavan, 9 Bahadur shah zafar marg, New Delhi.

