Optimization of Gate Leaf of Automatic Outflow Regulating Gate System

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Abstract

The main objective in the "Optimization 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. The new designed & optimized gate leaf is also analyzed to determine the von Misses stress, shear stress etc. Compared to existing design of gate leaf, new designed gate leaf has 30.38% less in weight while satisfying the permissible stress condition.
Keywords: Automatic Outflow Regulating Gate, Design Analysis, Optimization, 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.

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;

- Upstream skin plate
- Downstream skin plate Gate leaf Proper
- Horizontal girders Rotating gate
- End girders leaf assembly (Shown in Fig-1)
- 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.

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

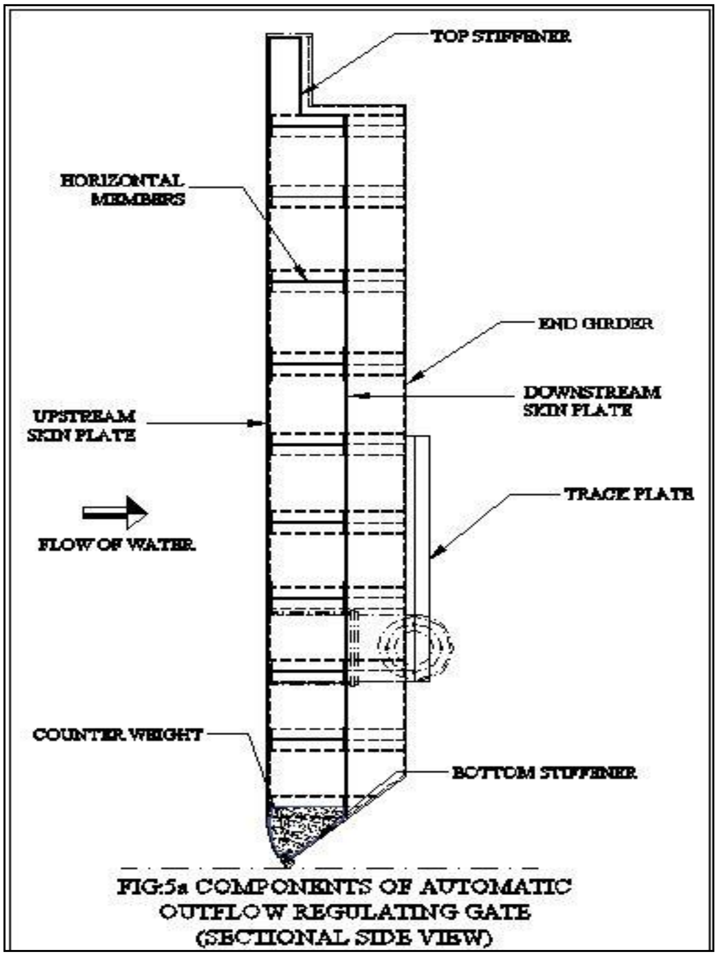

Fig. 1: Construction

Table - 1

Sr. No.	*Name of component*	*Number of components used in gate leaf assembly*	*Sections used*	*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*

III. OBJECTIVES

This research pertains to optimize the gate leaf part of Automatic outflow regulating gate system. By using analysis software for gate leaf structure we check the results for minimum weight with respect to height of the gate. It is highly desirable to do this analysis and optimization 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 optimization work.

The optimization of Gate leaf can result in reduction of weight of gate leaf & hence cost reduction. Hence, the need of proposed work.

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-2), 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;

- Gate fully closed and upstream water level up to top lip of gate, at 6.544m above gate sill
- 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% Yp
= 0.45 * 2550 = 1145 kg/cm2 = 112.5 Mpa
Permissible combined stress = 60% * Yp
= 0.60 * 2550 = 1530 kg/cm2 = 150 Mpa
Permissible shear stress = 35% * Yp
= 0.35 * 2550 = 890 kg/cm2 = 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. 3.

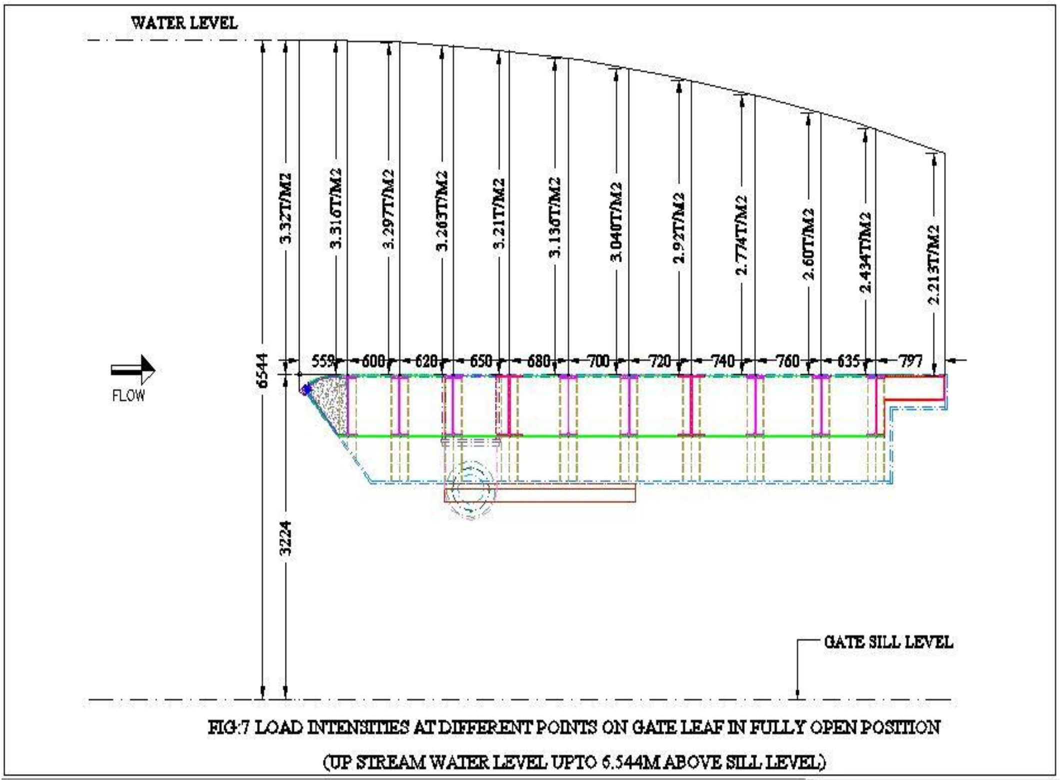

Fig. 3: Load Intensities On Gate Leaf In Gate Close Position

The load intensities at different points on gate leaf when gate is in open position, for this loading condition are shown in Fig. 4.

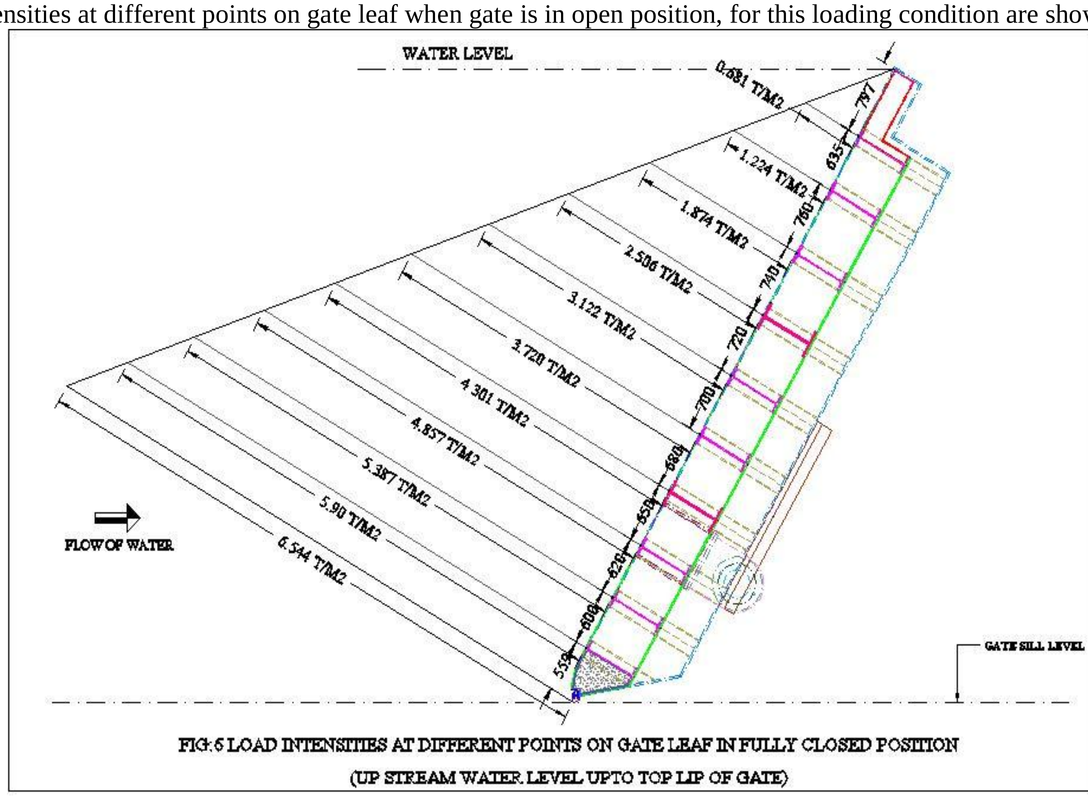

Fig. 4: Load Intensities On Gate Leaf In Gate Open Position

V. ANALYSIS & INTERPRETATION

The model of existing design of gate leaf shown in Fig. 1 was created in Creo parametric 1.0 & analyzed for gate close & gate open loading condition in Ansys Workbench [3] giving the results as follows in Table-2;

Table - 2

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*	

From above table we can see that all the stresses well 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).

The Stresses are found to be much below permissible limit & hence possibilities are there to optimize the existing design for economical design.

VI. OPTIMIZATION

Optimization is defined as a maximization of wanted properties and minimization of unwanted properties. In case of structural optimization the gate leaf; Desired Properties are: Strength, Stiffness & Deflection etc & Undesired Properties are Material, Cost, and Weight etc.

In the case of gate leaf we can reduce the weight by reducing thickness of skin plate, but it will increase the deflection as well as the shear stress. Also we can reduce depth of horizontal members etc. Some of the design combinations are analyzed below to get optimized weight of gate leaf with all the desired properties within permissible limits.

The cases considered for optimization are as follows;

Table - 3

Parameters	*Existing*	*CASE I*	*CASE II*	*CASE III*
Skin plate thickness	*12mm*	*10mm*	*8mm*	*8mm*
Depth of ISMB Girder	*600mm*	*550mm*	*550mm*	*500mm*
No. of bottom & top stiffeners	*8*	*6*	*6*	*6*

B. Static structural Analysis of CASE-I (Gate close loading condition)

The above model for Case I is prepared in the Creo parametric & analyzed giving the results as follows;

Applying the water pressure for gate close position on new model of gate leaf, we get the following results of Equivalent stress is shown in figure 5.

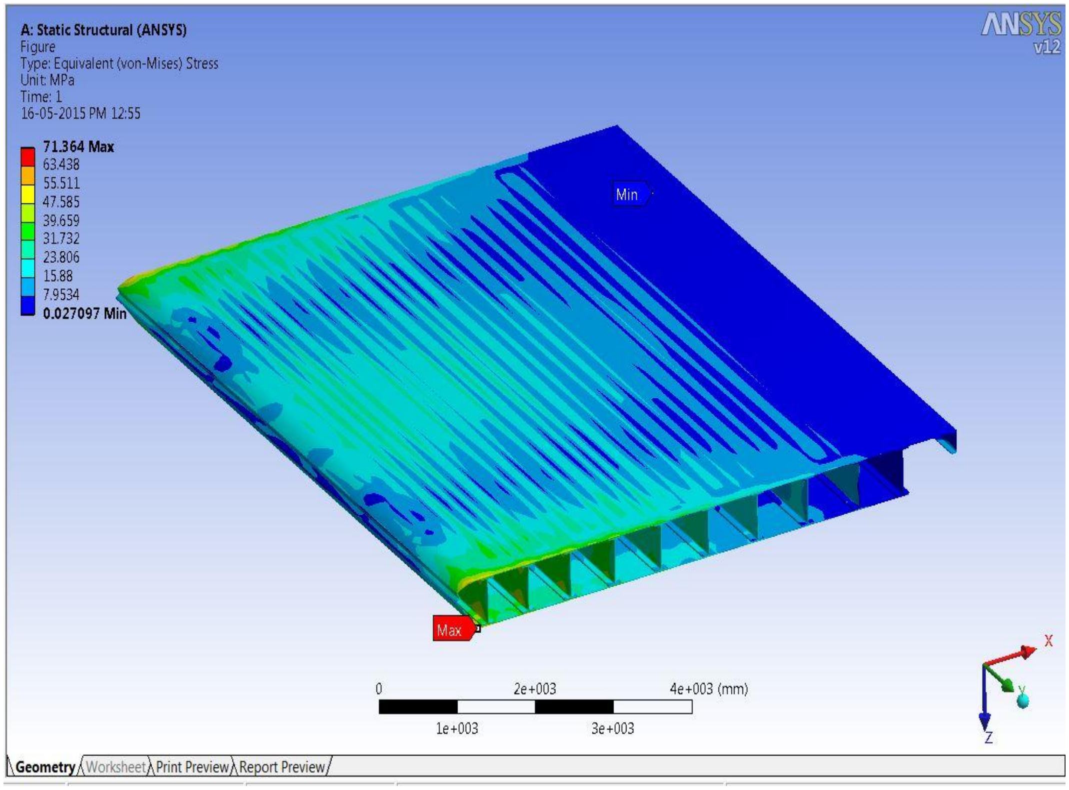

Fig. 5: Equivalent Stresses

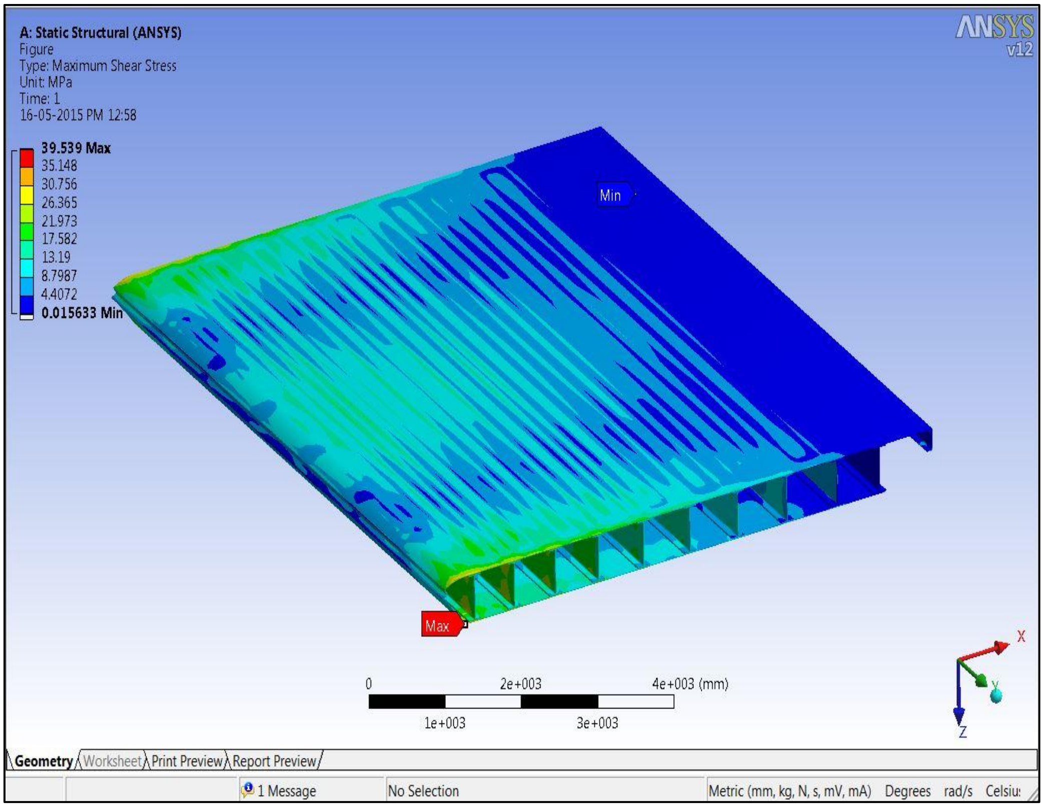

Fig. 6: Maximum shear stress

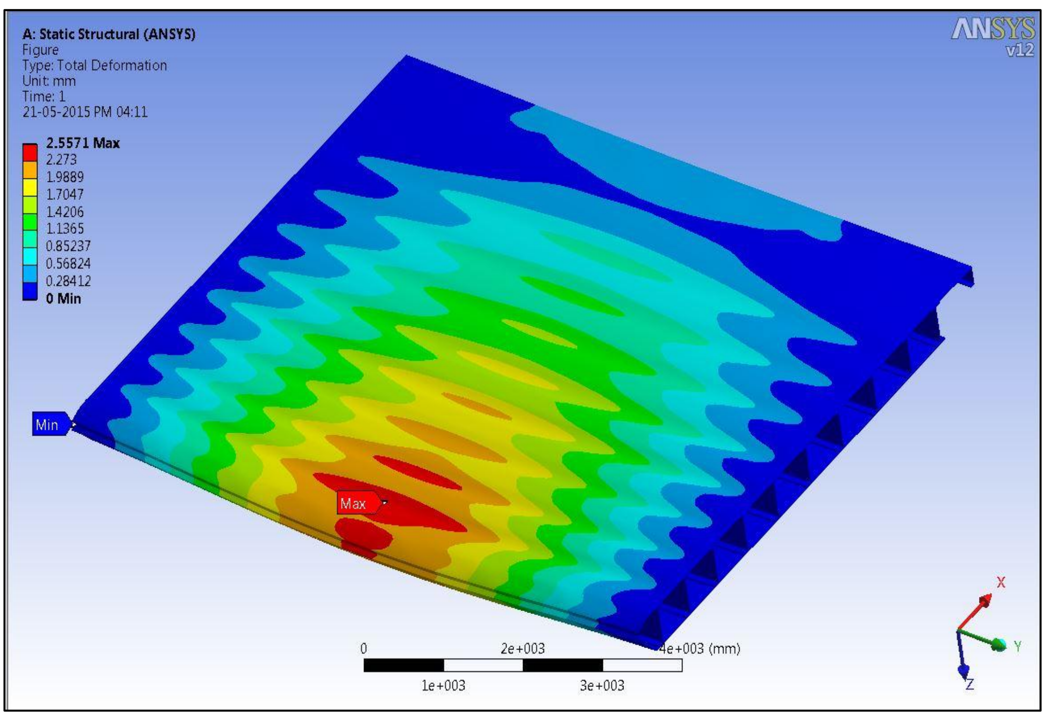

Fig. 7: Total Deformations

The maximum equivalent stress comes out to be 71.364 Mpa. The maximum Shear stress is shown in figure 6. The Maximum shear stress comes out to be 39.539Mpa which is less than permissible stress. The weight of the new designed gate leaf comes out to be 19552 Kg.

C. Static structural analysis of CASE-I (Gate open loading condition)

Applying the water pressure for gate open position on new model of gate leaf, we get the following results of Equivalent stress is shown in figure 8.

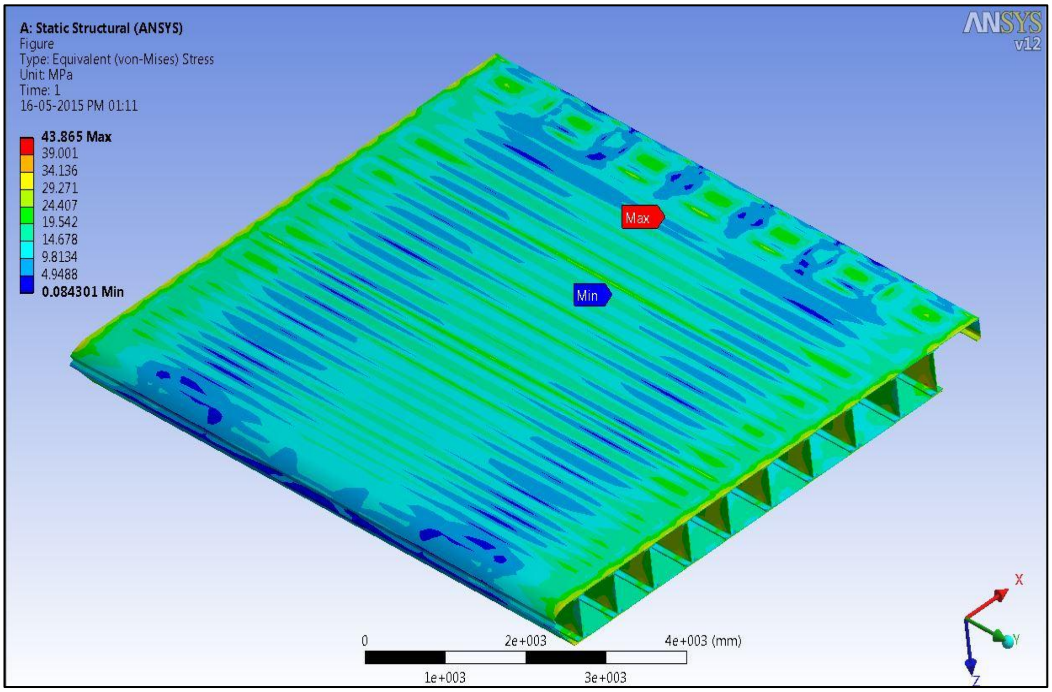

Fig. 8: Equivalent Stresses

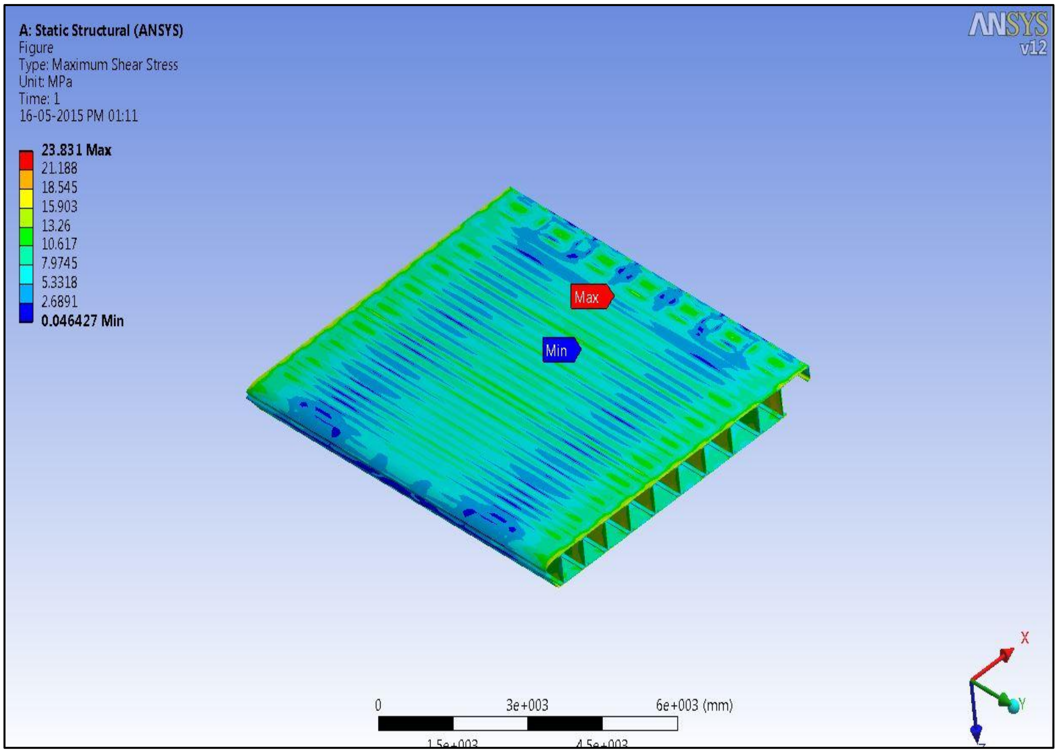

Fig. 9: Maximum shear stress

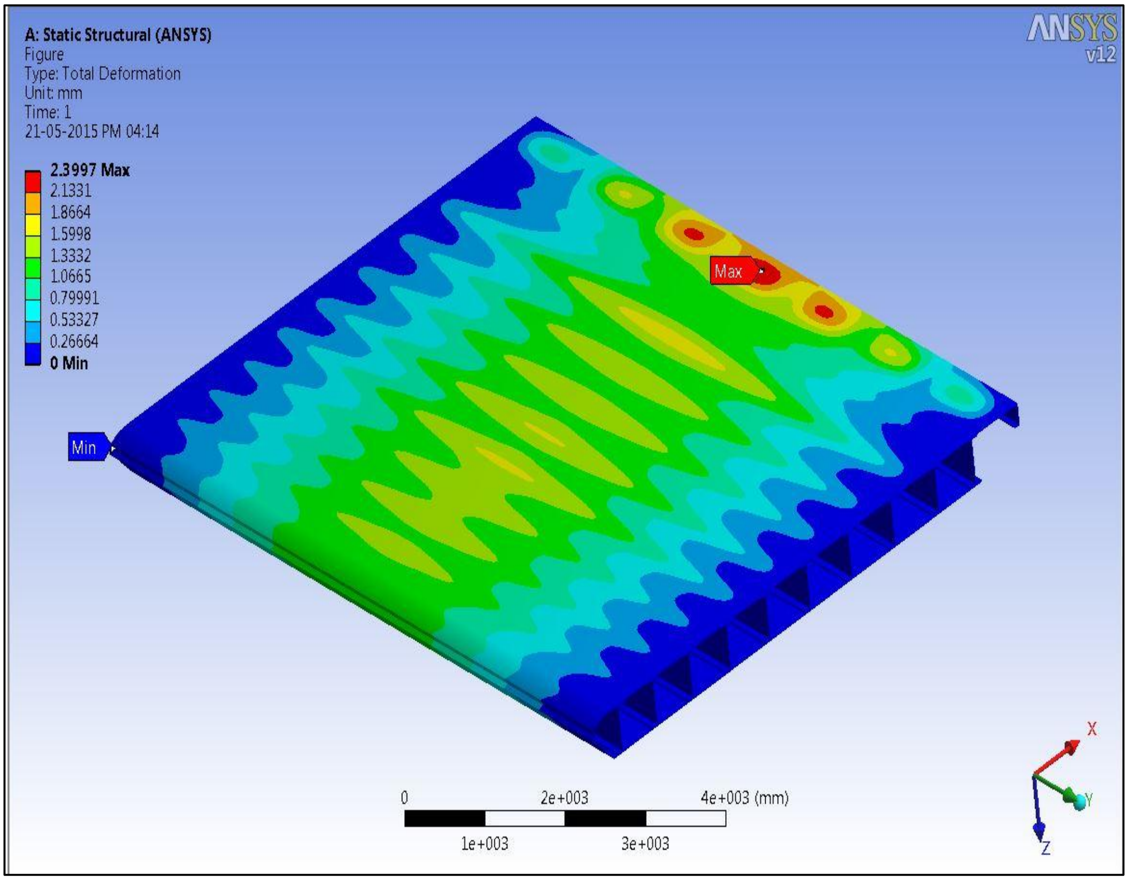

Fig. 10: total Deformations

The Maximum Equivalent stress developed in gate when gate is in open position is 43.865Mpa i.e well below permissible stresses. Now in Figure 9 Maximum shear stress in gate is 23.831 Mpa.

Similarly Case-II & Case-III are analyzed in Ansys workbench. Stresses & deformation comes out to be in permissible limits. The results of all the three cases

VII. RESULTS OF ANALYSIS

The results of analysis for all the 3 cases are tabulated in following table 4

Table – 4
Results of analysis

Solution Information	*CASE-I*		*CASE-II*		*CASE-III*	
	Water loading condition – (a) Gate closed position & (b) Gate open position					
	a	*b*	*a*	*b*	*a*	*b*
Equivalent Stress (Map)	*71.36*	*43.86*	*80.73*	*49.37*	*94.69*	*58.42*
Maximum Shear Stress (Mpa)	*39.54*	*23.83*	*44.87*	*25.86*	*52.67*	*31.88*
Total Deformation (mm)	*2.557*	*2.399*	*3.095*	*3.086*	*3.808*	*3.546*
Weight of gate leaf proper (kg)	*19552*		*17547*		*16052*	

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).

Also, we can see that there is difference of 8790 Kg (24842 – 16052) in existing designed gate leaf (TABLE-2) & optimized gate leaf (TABLE-4 & CASE-III). The existing design of gate leaf is optimized by 30.38% in terms of weight of gate leaf & hence cost.

VIII. CONCLUSION

– It was found that the components of gate leaf proper with modification in thickness of plates & depth of horizontal member gives sufficient reduction in the existing weight of gate without exceeding in permissible stresses.

- The Stresses are found maximum on downstream skin plate & minimum on horizontal girders in all the cases.
- The Deformation is found to be maximum on upstream skin plate & minimum on Horizontal members in all the cases.
- The weight of gate leaf proper was reduced to 16052 Kg from 24842 Kg i.e by 30.38% which is significant.
- Optimization was performed by changing sections of various components also by reducing number of stiffeners of top & bottom.

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