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COMPARATIVE STUDY OF DESIGN OF FLAT AND CURVE GATE USED IN HYDROPOWER PLANTS

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Abstract

This paper is based on the basic steps for analyzing two different hydro mechanical Gates of hydropower plants for an effective and safe design point of view. In an analysis, we found effective and safer results. We used the ANSYS Workbench software to determine these gates' deformation, stress, strength, and reliability for analysis. These gates are also known as sluice gates. In this study, we modeled one using the usual flat-shape geometry. In contrast, the other, as a specific curve-shaped geometry, performed the virtual finite element analysis for better results. An analysis found that the peak stresses induced on the flat gate and curved gate are different, respectively, while the deformation occurred due to peak stresses being less and more, respectively; from these results, It is concluded that the curved gate is a better one.

Keywords: *Sluice gate, Stress-Strain Analysis, Hydropower plant.*

1. Introduction

A sluice gate is a hydromechanical equipment used to control and regulate water flow in dams, channels, micro irrigation pump houses, and rivers. It operates and lifts in the up and down directions by the mechanisms of the hoist system, wire-rope hoist, lifting beam, screw hoist system, and drum rope system. The primary function of a sluice gate is to control the water level to ensure the water's distribution to agriculture with the help of a micro-irrigation pump house. The vertical gate is also used in dams to prevent flooding during heavy rains [5]. Hydrostatic pressure is essential in acting as uniformly variable pressure on the gates by measuring the water head from the sill to the full supply level (FSL).

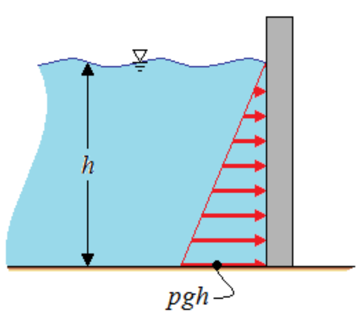

Fig.1. Hydrostatic pressure (courtesy- EngArc) [5]

The hydrostatic pressure is nothing but a uniformly variable load, i.e., in some conditions, the water head is the same as the gate height, which is a triangular load acting on it, and in some conditions, the water head is greater than the height of the gate, in which case the trapezoidal pressure is acting on it. When the hydrostatic pressure is acting on the gate, the maximum pressure is L/3 of the height of the gate. That means the maximum pressure is acting on. So, the maximum pressure experienced by the gate is at the sill level or lower part of the gate [1].

Total load on the gate $= \mathrm{L \times B \times (H - \frac{L}{2}) \times 9.81}$ **[2]**

L = Length of the gate
B = Breath of the gate
H = Water Head

1.1. Classification of Hydromechanical gates

The Hydromechanical gates may be classified based on the water head above the sill level as follows:

i. **High head gate** — Gates operating at 30m and above height.
ii. **Medium head gate** — Gates operating at a head of 15 meters and above but not exceeding 30 meters.
iii. **Low head gate** — Gate which operates with a height less than 15 m [1].

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1.2. Typical types of gates utilized in Dam and Barrage structures in India

i. Vertical Lifting Gates IS: 5620 [13]
ii. Vertical Lifting fixed wheel gate IS: 4622
iii. Vertical Lift Slide gate
iv. Radial Gates IS: 4623

1.3. Vertical Lift Gate IS: 5620

The vertical lift gate is usually rectangular in shape and size and consists of a horizontal channel ISMC or ISMB BEAM and a skin plate on the upstream side. The guide frame slides vertically, and a musical rubber seal prevents water leakage. It operates vertically by the mechanism of a hoist system, a lifting beam system, or a wire-rope drum hoist system [13].

Components of gate

i. Skin plate
ii. Horizontal girder/channel
iii. Vertical stiffener plates
iv. Vertical end plates
v. Lifting shaft/pulleys
vi. Guide angles
vii. Guide bars
viii. Musical note rubber seal

Fig.2. Vertical lift slide gates (courtesy- Walchand Institute of Technology, Solapur) [4].

1.4. Fixed Wheel Vertical gate IS: 4622

A vertical lift gate is usually rectangular in shape and size but has a fixed roller on both sides. The roller is used when operating in the guide frame, and it runs on a track plate on the opposite side of the rubber seal. They also consist of an upstream horizontal channel ISMC or ISMB BEAM and a skid plate [13].

Components of gate,

i. Skin plate
ii. Horizontal girder/channel
iii. Vertical stiffener plates
iv. Vertical end plates
v. Lifting shaft/pulleys
vi. Rollers
vii. Roller track
viii. Musical note rubber seal

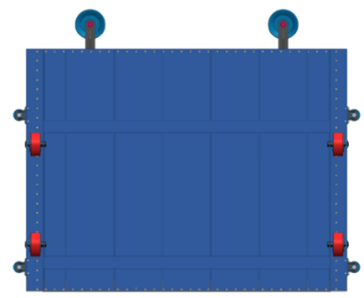

Fig.3. A typical representation of a vertical fixed wheel gate Designed and modeled with SolidWorks. (Back View)

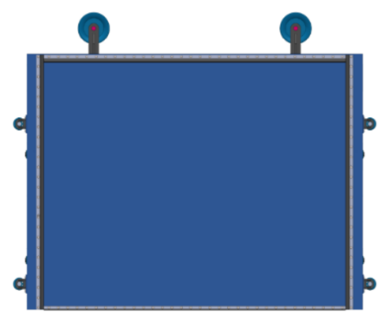

Fig.4. A typical representation of a vertical fixed wheel gate Designed and modeled with SolidWorks. (Front View).

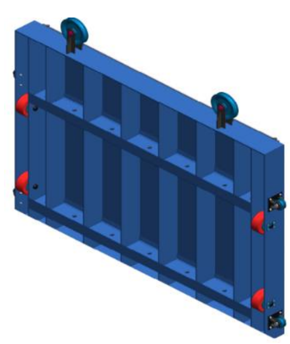

Fig.5. A typical representation of a vertical fixed wheel gate Designed and modeled with SolidWorks (Isometric 3D-View)

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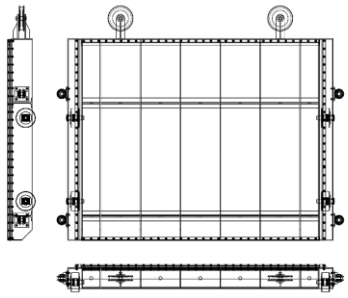

Fig.6. A typical representation of a vertical fixed wheel gate in a wireframe modelled with SolidWorks

2. Design and Implementation

2.1. Curved Shaped Model

We have taken the concept of the curved-shaped gate from the Hoover Dam. When the hydrostatic pressure acts on the sluice gate's plane plate skin, one side of the pressure acting becomes compressed, and the other becomes tense. When the hydrostatic pressure is applied from the curved side of the sluice gate, the compression becomes on both sides across the neutral axis area. Our concept behind the curved gate is to find the minimum deflection on the gate, so we used two gates of similar materials but with different geometry.

2.2. Water Pressure Release Valve

The water pressure release valve, which we introduced in the sluice gate, helps release the water pressure in emergencies. They auto-lock with the help of water pressure, and the valve is opened with the help of a lifting wire system.

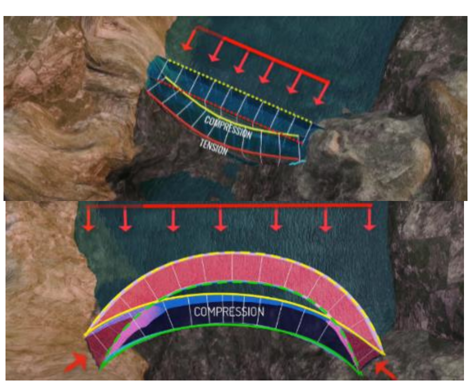

Fig.7. Bureau of Reclamation, Hoover Dam. (Courtesy-Hoover Dam) [2]

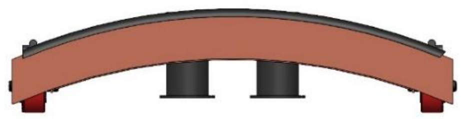

Fig.8. Typical representative of a curved gate Designed and modeled with SolidWorks (Top view).

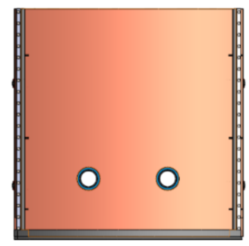

Fig.9. Typical representative of a curved gate designed and modeled with SolidWorks (Front view).

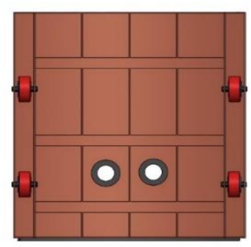

Fig.10. Typical representative of a curved gate Designed and modeled with SolidWorks (Back view).

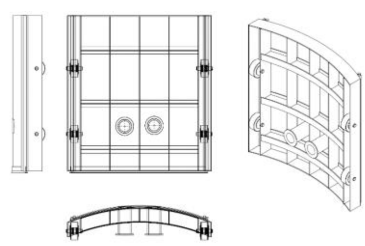

Fig.11. A typical representation of a curved gate in a wireframe modeled with SolidWorks

The hydrostatic fluid pressure acting on a gate results from the pressure exerted by a fluid by variable conditions. The maximum pressure acts on the bottom level/sill level, and the minimum pressure at the top level of the gate.

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The point load maximum pressure acts on,

$$\frac{\text{Total height of the Gate (L)}}{3}$$

3. Methodology

Table 1 The design calculation of the sluice gate is given below

Design Standard	IS: 4622
Type of gate	Vertical Lift, Fixed Wheel Gate
Gate size	2M X2M
Design head	5.5M
Materials	**IS-2062 Structural Steel**
C/C of side seals	1900 mm C/C
Sill to top seal Centre	2000 mm C/C
C/C of wheel tracks	1900mm C/C

The total load on the gate =LxBx $(H-\frac{L}{2})$ x9.81 [3]

L = Length of the gate
B = Breath of the gate
H = Water Head
= 176.58 KN

Table 2 Materials properties and BOQ (Build of Quantities) [3]

Design standard	Qty.	Size/material
Skin plate	01	2M X 2M - IS: 2062 Arc Length -2064mm LG.
Horizontal Girder	03	ISMB-200 – IS: 2062 1891mm LG.
Vertical stiffener plate	03	5.5M – IS: 2062 200mm x 2000mm LG.
End box plate	02	IS-2062 Structural Steel 200mm x 2000mm LG.
Roller	04	Ø240x100THK – IS: 2062, Structure steel
Sill beam	01	ISMB-200 2.5M LG.
Roller track	02	100mm x 10 THK
Musical note rubber seal	04	IS: 11855
Bearing	04	22208E SKF/NTN
Axle shaft	04	Ø50x200mm LG.

Table 3 Permissible stresses: as per is: 4622 [1]

Structure steel IS:2062		The 0 - ≤ 20 Yield point : 2550Kg/ cm^2 Ultimate tensile strength : 4180 Kg/ cm^2
Direct compression and Compression in bending	0.40 YP	1020 Kg/cm^2
Direct tension and tension in bending	0.40 YP	1020 Kg/cm^2
Shear stress	0.30 YP	765 Kg/cm^2
Combine stress	0.50 YP	1275 Kg/cm^2
Bearing stress	0.45 YP	1147 Kg/cm^2

3.1. Design Calculation of Both Gates

We are using two different models to achieve different results in simulations.

- Flat Gate
- Curved Gate

In 3D modeling of a sluice gate, we use the same materials but with different geometry. The dimensions of both gates are 2000mm x 2000mm in size, with the same material properties (IS: 2062).

Table 4 Technical design data & Size [3].

Descriptions	Details
Water head	5.5M.
Gate size	2M X 2M
Load on the gate	176.58 KN
Load in kg.	18 TON
Load in pressure	0.044145 Mpa

4. Analysis and Results

The analysis processes are now quietly transforming into digital analysis with the help of simulation software like ANSYS, which helps them surpass human efforts and time and produce easy and precise results.

Finite Element Analysis: The best way to analyze a problem and, with the help of ANSYS

WORKBENCH, achieve different results and make the structure safe.

4.1. Finite Elements Analysis (FEA) – Static Structure Analysis

Finite Element Analysis (FEA) is a process for studying the behavior of hydromechanical gates under static loading conditions. In static analysis, the applied hydrostatic pressure is variable or changes very slowly over time, and the aim is to determine the stress, strain, and deformation of a hydromechanical gate at a specific point in time without considering dynamic effects or time-dependent behavior. The hydrostatic pressure acting on gates is static, while the gates are closed or at sill or bottom level.

4.2. Meshing

The tetrahedral meshing method is one of the most widely used in finite element analysis. The density of the mesh is directly related to the element's size. That's why we used the tetrahedron method in meshing and changed the element size from 50mm to 10mm in both gates (curved and flat) to provide more accurate results.

Flat rate meshing size 50mm.

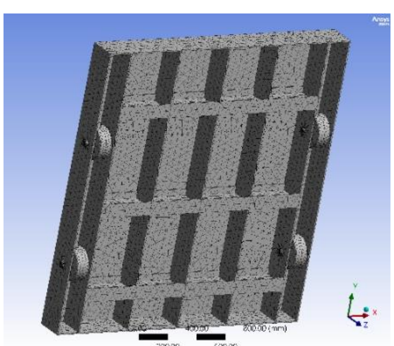

Fig.12. Meshing of a flat gate with a 50mm element size using Finite Element Analysis (FEA)

Table 5 Results of Fig. 12

Descriptions	Results
Nodes	68300
Elements	35187
Element size	50mm

Flat Gate Meshing Size 10mm.

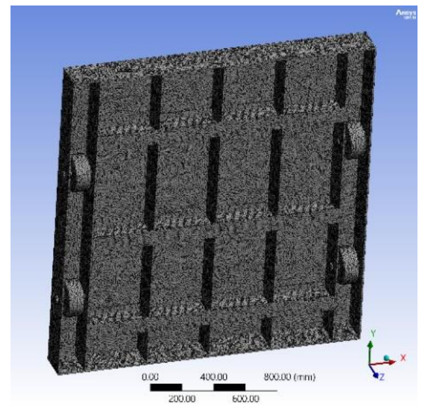

Fig.13. Meshing of a flat gate with a 10mm element size using Finite Element Analysis (FEA)

Table 6 Results of Fig. 13

Descriptions	Results
Nodes	1759136
Elements	1003889
Element size	10mm.

Curved gate Meshing 50mm.

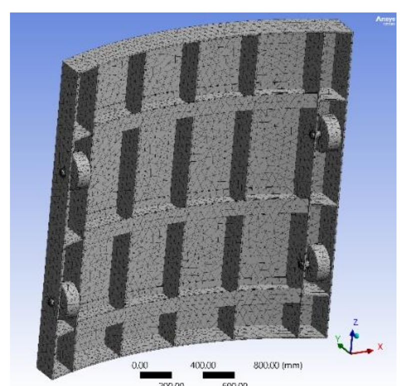

Fig.14. Meshing of a Curve gate with a 50mm element size using Finite Element Analysis (FEA)

Table 7 Results of Fig. 14

Descriptions	Results
Nodes	74153
Elements	38183
Element size	50mm.

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Curved gate Meshing 10mm.

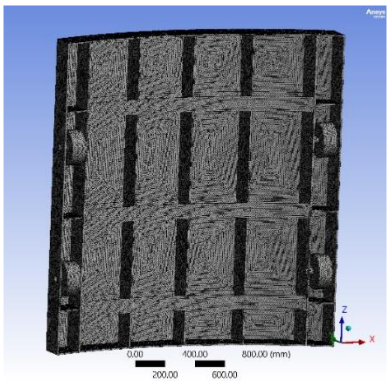

Fig.15. Meshing of a Curve gate with a 10mm element size using Finite Element Analysis (FEA)

Table 8 Results of Fig. 15

Descriptions	Results
Nodes	1753033
Elements	977709
Element size	10mm.

4.3. Loading Conditions

The hydrostatic pressure is applied to both gates and fixed to the rollers and end box plates. The same water head of 5.5 meters is used on both gates, so we get different results.

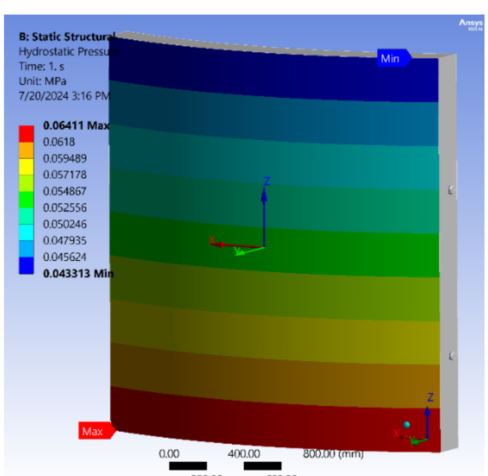

Fig.16. Hydrostatic pressure acting on a curved gate analyzed using Finite Element Analysis (FEA).

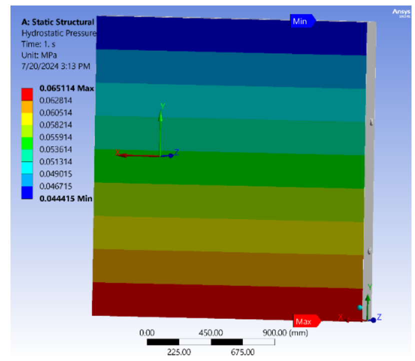

Fig.17. Hydrostatic pressure acting on a Flat gate analyzed using Finite Element Analysis (FEA).

5. Results and Discussion

The two sets of different results are obtained under similar conditions and assumptions. Consistency in geometry is variable, but material properties, boundary conditions, and applied hydrostatic water head pressure are the same.

The given formula is used to determine the gate's total load.

Total load on the gate $= \mathrm{L} \times \mathrm{B} \times (\mathrm{H} - \frac{\mathrm{L}}{2}) \times 9.81$ **[1]**

Table 9 Results

Descriptions	Results
Water head	5.5M.
Gate size	2M X 2M
Load on the gate	176.58 KN
Load in kg.	18 TON
Load in pressure	0.044145 Mpa

Comparatively Deformation and Stresses in Flat Gate Sizing Element 50mm & 10mm

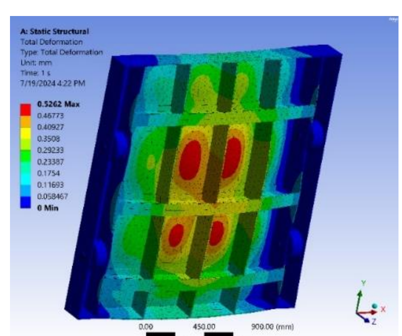

Fig.18. Total deformation of a flat gate with 50mm tetrahedron meshing using Finite Element Analysis (FEA)

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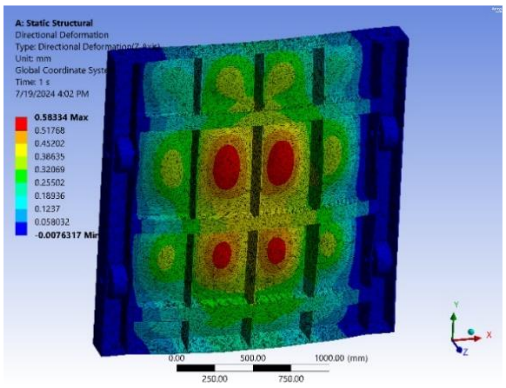

Fig.19. Total deformation of a flat gate with 10mm tetrahedron meshing using Finite Element Analysis (FEA)

Comparatively Maximum Principal Stress & Shear in Flat Gate of Sizing Element 10mm

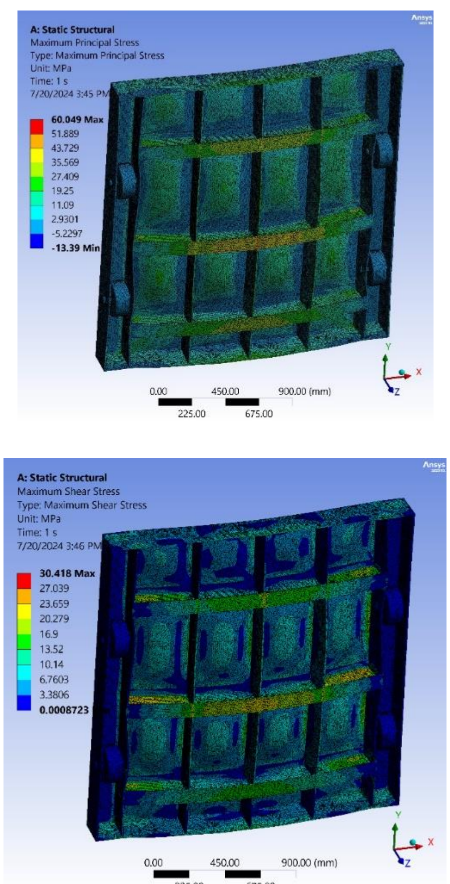

Fig.20. Maximum principal and shear stress in a flat gate with 10mm tetrahedron meshing.

Comparatively Maximum Principal Stress & Shear in Flat Gate of Sizing Element 50mm

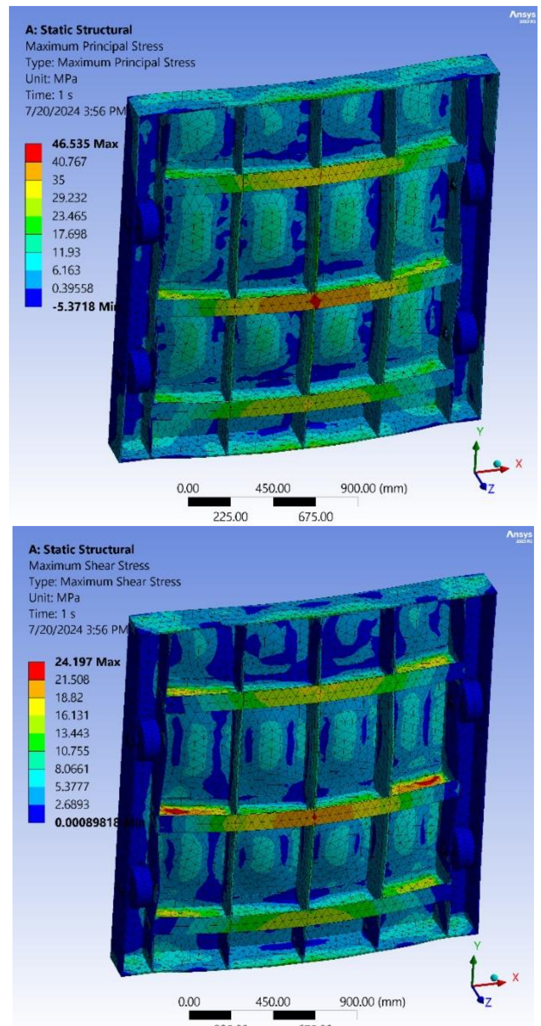

Fig.21. Maximum principal and shear stress in a flat gate with 50mm tetrahedron meshing.

Deformation, Stress & Shear Stress in Flat Gate Results

Table 10 Results of Fig. 17

50mm Meshing Size in Flat Gate	Results
Deformation	0.5262mm
Maximum principal Stress	46.535 Mpa.
Maximum Shear Stress	24.197 Mpa.

Table 11 Results of Fig. 18

10mm Meshing Size in Flat Gate	Results
Deformation	0.58335mm
Maximum principal Stress	60.049 Mpa.
Maximum Shear Stress	30.418

Comparatively, Deformation in Curved Gate of Sizing Element 50mm

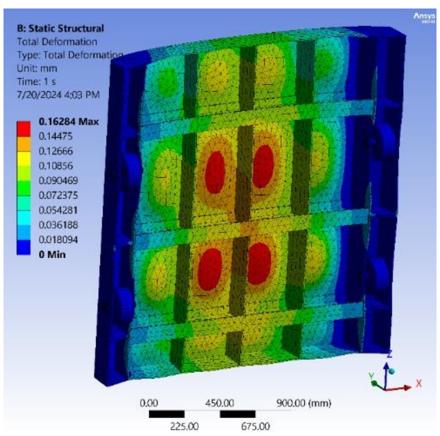

Fig.22. Total deformation of a Curve gate with 50mm tetrahedron meshing using Finite Element Analysis (FEA)

Comparatively Deformation in Curved Gate of Sizing Element 10mm

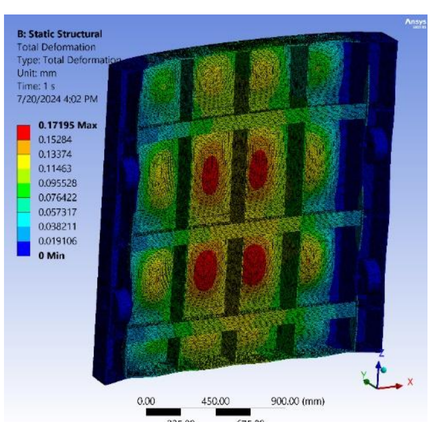

Fig.23. Total deformation of a Curve gate with 10mm tetrahedron meshing using Finite Element Analysis (FEA)

Comparatively Maximum Principal Stress & Shear in Curved Gate of Sizing Element 50mm

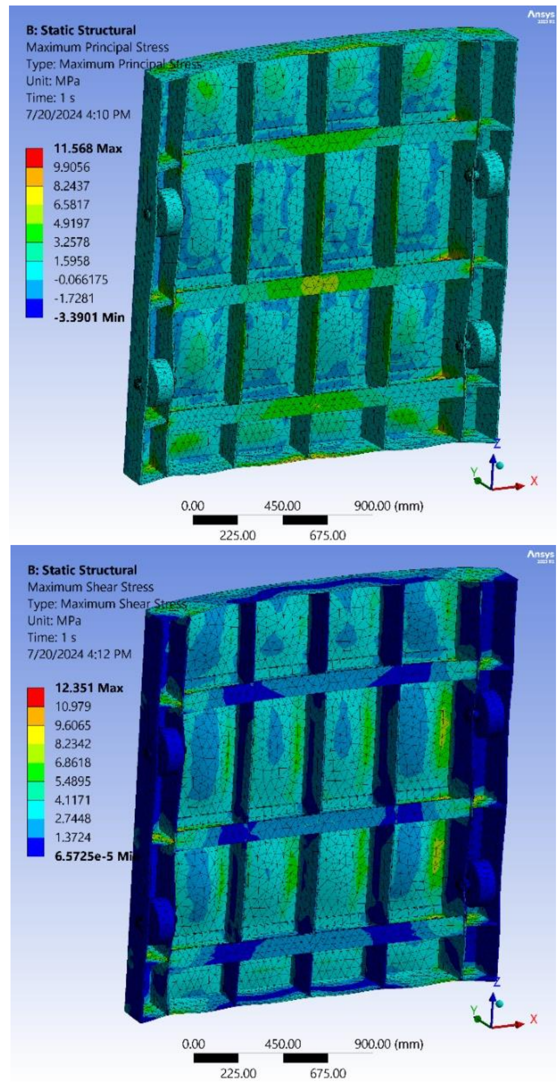

Fig.24. Maximum principal and shear stress in a Curve gate with 50mm tetrahedron meshing.

Table 12 Results of Fig. 22

50mm Meshing Size in Curved Gate	Results
Deformation	0.1628mm
Maximum principal Stress	11.58 Mpa
Maximum Shear Stress	12.35 Mpa.

Table 13 Results of Fig. 23

10mm Meshing Size in Curved Gate	Results
Deformation	0.1719mm
Maximum principal Stress	25.013 Mpa
Maximum Shear Stress	18.13 Mpa.

Comparatively Maximum Principal Stress & Shear in Curved Gate of Sizing Element 10mm

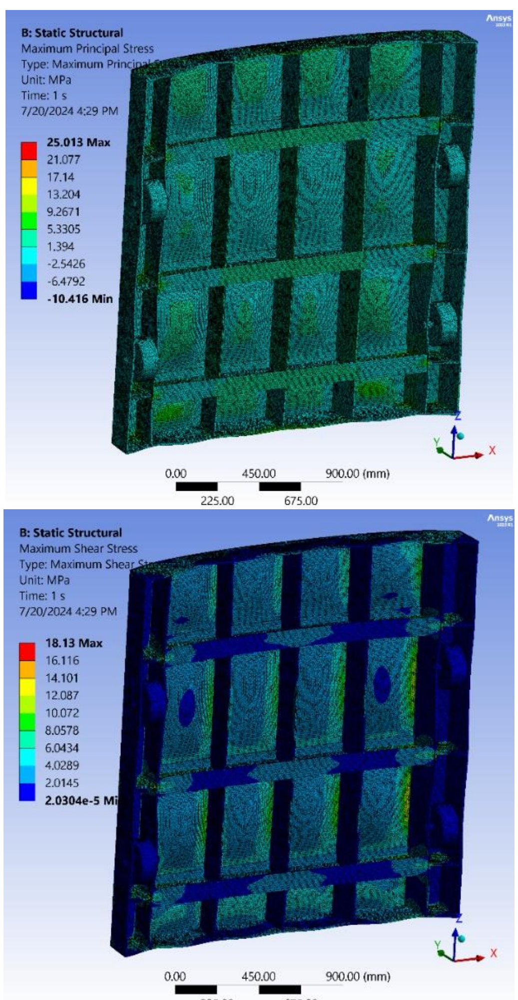

Fig.25. Maximum principal and shear stress in a Curve gate with 10mm tetrahedron meshing.

Hence, above the results of both the flat gate & Curved gate, we consider only curved gate values as below,

Permissible deflection

$= \frac{L}{800}$ [1].

= 2.5mm > 0.1719 (In figure 23)

Permissible stress

Bending stress = 11250 N/cm^2 [1]

= 112.5 Mpa > 25.013 Mpa (In Fig. 24)

Shear stress = 8750 N/cm^2 [1]

= 87.5 Mpa > 18.13 Mpa (In Fig. 24)

6. Conclusion

In conclusion, the safety factor of sluice gates can be improved by implementing minor design changes in shape geometry. We analyzed both gates (2m x 2m). First, the usual bureau of Indian standard (IS 4622): fixed wheel flat gate and fixed wheel curved gate, shaped geometry with the same materials but of different shape geometry.

In presented research, it is found that the obtained results of deformations, bending stress, and shear stress are found to be less as compared to the flat gate shape geometry and this are (Deformation-0.1719mm, Bending Stress-25.013 Mpa, Shear stress-18.13Mpa) respectively, as compared to (Deformation-0.58335mm, Bending stress-60.049 mpa, Shear stress-30.418 mpa) of flat sluice gate. By incorporating these measures, the safety factor of sluice gates can be increased to much more of a curve-shaped sluice gate, making them a safer and more efficient part of hydropower plants.

References

1. *Bureau of Indian Standards, "IS-4622:2003 recommendations for structural design of fixed-wheel gates.".*
2. *Bureau of Reclamation, "Hoover Dam."*
3. *Narmada Valley Development Authority, India, "Design data book of junction structure at RD 9775 M of RBC Omkareshwar Canal."*
4. *D. G. Kim, "Numerical analysis of free flow past a sluice gate," Mokpo National University, Korea, 2007, pp. 127-132.*
5. *Walchand Institute of Technology, Solapur, "Dept of Civil Engineering."*
6. *E. Kubrak, "Flow measurements using a sluice gate; analysis of applicability," Warsaw University of Life Sciences-SGGW, Poland, 2020, p. 819.*

7. *F. Trebuna, "Methods for verification of safety of the sluice gates in water power plants," Technical University of Košice, Slovakia, 2009.*

8. *H. Poornakanta, "Optimization of sluice gate under fatigue life subjected to forced vibration by fluid flow," B.V. Bhoomaraddi College of Engineering, Karnataka, India, 2018, pp. 129-142.*

9. *Hydraulic Structures for Flow Diversion and Storage, "Gates and valves for flow control," Version 2 CE IIT Kharagpur, India.*

10. *J. Bocko, "Analysis of sluice gates of hydroelectric power stations," Technical University of Košice, Slovakia, 2013, pp. 324-328.*

11. *M. D. A. Wahab, "Stress analysis on fixed wheel vertical lift gate," Indian Institute of Technology Roorkee, India, 2005.*

12. *M. Pástor, "Experimental and numerical analysis of 60-year-old sluice gate affected by long-term operation," Technical University of Košice, Slovakia, 2020, p. 5201.*

13. *S. Natsheh, "Design of stainless-steel and aluminum slide gates based on a combined analytical and finite element approach," The University of Akron, 2018.*