International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

Design analysis of water control gate for diversion dams

Mewael Gebrehiwot Hailu and Ashish Thakur*

School of Mechanical and Industrial Engineering, Mekelle University, Mekelle, Ethiopia
Solid Mechanics and Design Chair, Ethiopian Institute of Technology, Ethiopia

Received 10 April 2018, Accepted 12 June 2018, Available online 16 June 2018, **Vol.8, No.3 (May/June 2018)**

Abstract

This paper summarizes the development of sliding gate in tigray region, mekelle, Ethiopia. Research work deals design and develop of new gate mechanism for diversion dams that alleviate the operational and structural failure problems. Systematic product development was followed to manage the different phases, from collecting and compiling information about the target market and users; to idea generation and realisation of concepts. The basic criteria used for generating concepts are ease ofopening mechanism, assembly and maintainability. Detail analysis was done by calculation and CFD and ANSYS. The developed gate has new features which makes it superior over the existing mechanism.

Keywords: *Dam, gate, gate plate, cost, pressure distribution, ANSYS, CFD, GAMBIT, FLUENT*

1. Introduction

To ensure food security and generate foreign currency from agriculture in developing countries like Ethiopia, irrigation plays irreplaceable role. Knowing this, the government has given an emphasis on construction of large irrigation dams, development of off stream diversions from small rivers and small catchments to irrigation fields. Off stream diversions from small rivers and small catchments are designed to have temporary gates, blocks and allow water flow, which is assembled and disassembled seasonally.

Opening and closing gates and water level regulating structures in irrigation networks establish unsteady flow in channels that adversely impacts the efficiency of these structures. The temporal and local variations in discharge along with the flow depth change produce a complex hydraulic condition in irrigation networks. Without using numerical models, accurate evaluation of flow pattern and behavior is very difficult. The water delivery irrigation channels must provide a sustainable and appropriate amount of flow to specific locations at suitable times. For any channel, this process is affected by the methods used to operate and control the channel and by rate of change in discharge. In order to shorten response time, limit water level fluctuation, and maintain the stability and performance of automatic control channel systems, appropriate automatic channel control methods should be adopted (Reddy*et al*, 1990; Blesa*et al*, 2010; Fleiu*et al*, 2007].

Different types of gates that can be accessed in diversion technology that are selected according to the type of the dams, head of the water, fish passage and so on. Type of gates can be slide/sluice, open channel, bulk head, roller, weir, flap, stop logs and other mechanisms which are developed according to the working environment. The off stream diversion dam which is available around is designed and built to be suitable to the land arrangement and built in low cost. Since the erosion in the upper stream of the diversion dam is high, it is designed 35-50% of the dam to be slotted along the length of the dam in order to allow flood and silt to flow freely in rainy season. Therefore, half of the dam length is constructed by the sliding gate as shown in the figure below. Diversion gate built by Relief Society of Tigray (REST), found in Bel-a-t is shown in Fig. 1 given below.

Figure 1: Diversion gate built by REST, found in Bel-a-tS

*Corresponding author's Email: thakurashish1@gmail.com
ORCID ID: 0000-0001-9287-700X
DOI: https://doi.org/10.14741/ijcet/v.8.3.26

Sliding gate that is assembled in most of all diversion dams in Ethiopia are introduced by the help of REST through training and experience sharing. Mostly the sliding gates are used in distribution of water in open channels in irrigation field and sluice channels with additional structure attached over the head of the leaf.
The sliding gate mechanism is just attaching a screw on upper leaf plate attached on a fixed structure with a length extended at least equal to the length of the leaf. In order to have this mechanism either the dam height must be doubled or additional mechanism should be incorporated on the recent design of the dam. Building such structure on the available design of the diversion dam will make it costly and difficult to access easily. Commercially available sliding gate is shown in Fig. 2 given below.

Figure 2: Commercially available sliding gate

Since, the current dam structure doesn't entertain such kind of mechanism, it has been tried to modify the arrangement of the sliding mechanism as shown in the Fig. 3 given below.

Figure 3: Current gate mechanism

Number of failures occurs in the diversion dams' such as structural failures, mechanism failures, corrosion failures, maintainability, leakage, operation failures etc. which cause fail of their gates. Failed diversion dam (WeredaHintaloWejerat, Tabia-Shahshahta) is shown in Fig. 4 given below.

The objective of the work was to reduce failure of diversion dams by developing new gate mechanism which is appropriate to the current diversion system. To achieve those objectives, study the causes of failure of current mechanism, select concepts that suit the problems, appropriate gate size determined by simulating through application software, designing the mechanical equipments, manufacturing the product, test the product analytically and physically were carried out.

Watching customers using an existing product or perform a task for which a new product is intended can reveal important details about customer needs [Fleiu*et al*, 2007].[Pahl, G, Beitz*et al*2006; [Monö, R*et al*1997]have proposed an engineering design for product understanding of the gate and its mechanism as well. The problems of the gate were observed in the field area and during manufacturing. The parts that face problems and the operation difficulty were clearly shown by the following photographs Fig. 3.1 and 3.2 given below. Failure of the gate plate is shown in Fig. 3.3 given below.

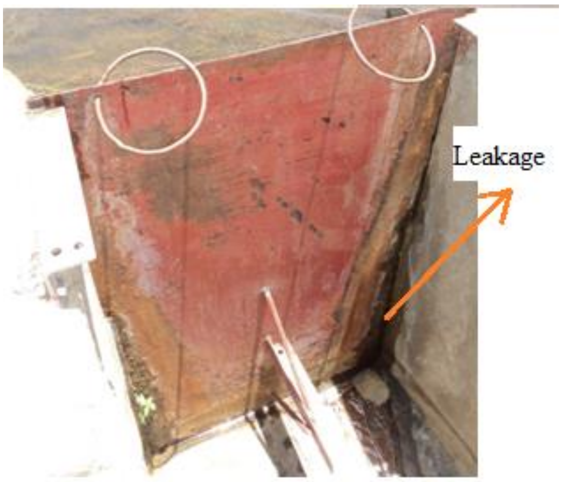

Figure 3.1: Mostly fail part

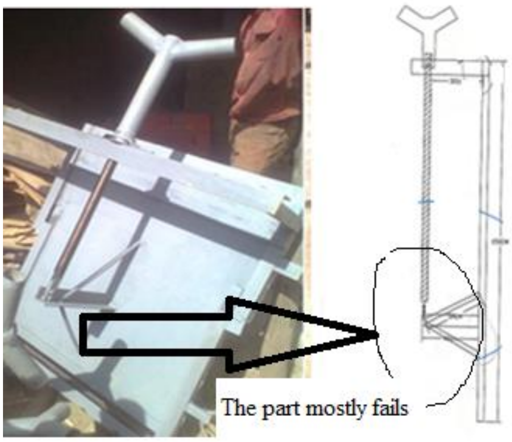

Figure 3.2: Leakage along the sides

Figure 3.3: Failure of gate plate

Figure 4: Failed diversion dame (WeredaHintaloWejerat, Tabia-Shahshahta)

2. Materials and methods

The product is prototyped virtually by CATIA software and developed in Mekelle University work shop.The pressure distribution and flow characteristics test was conducted using fluent, GAMBIT of CFD software and the structural stability and detail design studied using ANSYS software. Ordinary equations are used to define one dimensional unsteady non-uniform flow in open channels.

2.1. The study area

The study was conducted at the Bel-a-t, located in the Mekelle province of Tigray, Ethiopia. Main channel is from Relief Society of Tigray (REST) diversion dam to WeredaHintaloWejeratlocation. Failed diversion dam is WeredaHintaloWejerat andTabia-Shahshahta. There are about 5 diversions and check dams constructed and 2 under construction which costs from 200,000 – 1.2Milion Birr (Ethiopian local currency unit) each depending on the size of the dam. As per the information gathered from Water, Mines and Energy Resource and Development office of Tigray, a number of gates have been constructed.

2.2. Concept generation and selection

Concept generation was done to solve the customer needs and followed steps:

- Preliminary layout of the product with estimations of dimension.
- Preliminary estimation of the cost.
- Describing the technical solution in text, sketches, physical models, etc.
- Argument for the chosen solution.
- A compilation of rough calculation, analysis, results.

Concept containing all the points listed above is taken to manufacture a proper prototype that has got the functional specifications specified [Johannesson, H *et al*2004]. Concept selection was done with the help of product design concept elements such as scoring, screening or by developing decision matrices [Ulrich, KT *et al,* 2004]. In order to evaluate/ select a concept, basically following facts were considered such as

- Focus groups
- Decision matrices
- Testing- building of prototype
- Institution, feeling, "experience"

The advantage of virtual model is the possibility to examine the three dimensional models from different angles without having actual physical model [Monö, R *et al,*1997].

The customer statements were translated by the authors into interpreted needs. [Ulrich and Eppinger*et* *al,* 2008] introduce five guidelines for interpreting customer statements into needs. [Crilly, N *et al*, 2004] studies consumer response to the visual domain in product design for concept was conceived.

Ergonomic design concept for people work for gate design was conceived before estimation of the gate development [N.Somadeepti Chengalur*et al*, 2004].

2.3. Idea generation

The overall function of the gate is divided into three sub functions. In order to arrive at an overall solution the sub functions have to be combined. By dividing the problem, new solutions and combinations are discovered. The sub functions are:

- Handle Opening mechanism
- Assembly
- Gate plate arrangement

Different brainstorming sessions were held, where the author worked together with students and professionals with that area. Discussions with employees' at Mesfin Industrial Engineering, Mekelle, Tigray, Ethiopia and faculty staffs at Mekelle University concerning the sub functions are also carried out. The best and most realistic solutions to each problem area are selected from the brainstorming. Concept was made on the basis of ease of operation, ease of manufacturing, complexity and cost of production, structural stability, ease for maintenance and interchangeability of parts and intensive brainstorming session with concept screening. Concept implemented of gate drawing is shown in Fig. 5 given below.

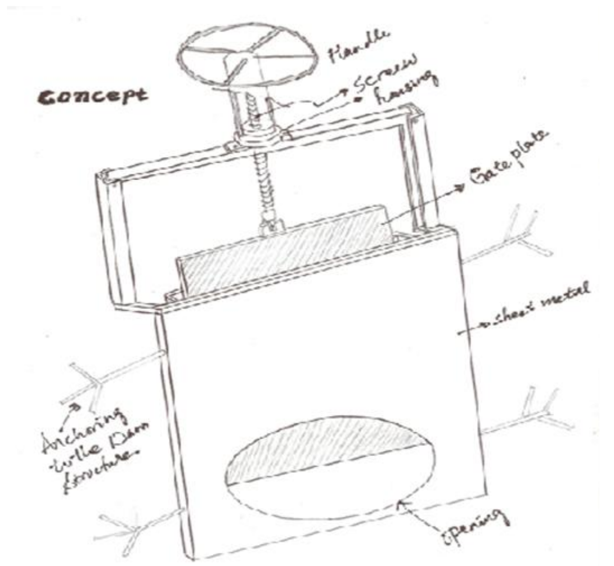

Figure 5: Schematic drawing for gate concept selection

2.4. Testing

The developed prototype is tested by application software and thereafter mounted in actual diversion dam. The pressure distribution and flow characteristics tested by CFD software that is by FLUENT and GAMBIT and the structural stability and detail design by ANSYS software.

2.5. Gate design

The gate which is expected to be manufactured should have a dimension that fit the predesign opening sizes. Gate design concept was adopted from the previous studies [Charles R.Mischke*et al*, 2001]. Structure-selected design guidelines for gate were adopted [Alberta transportation; Water Resources Department].

A numerical model based upon a second-order upwind cell-center finite volume method on unstructured triangular grids is developed for solving shallow water equations. To alleviate the problems associated with numerical instabilities due to small water depths near a wet/dry boundary, the friction source terms are treated in a fully implicit way [M. Aliparast*et al*, 2009].

Dams are constructed to impound water within a reservoir. The basic element in any sustainable dam project is safety, which includes the following safety elements: ① structural safety, ② dam safety monitoring, ③ operational safety and maintenance, and ④ emergency planning. Design requirements including stability, seismic loading, strength, and durability, pore pressure and instrumentation, sedimentation and water tightness [Malcolm J. Brandt *et al*, 2017].

All the constructed diversion and check dams do have the same opening width, but depending on catchment area characteristics the height varies from 0.8 to 1.5 meter. Geometrical design, structural design, material selection, simulation of fluid flow was developed using CFD and ANSYS. Detail size dimension of diversion dam is shown in Fig. 6 given below.

Figure 6: Size of diversion dam

During survey in at least 10 diversion and check dams, the average height of the dam is 1.2 meter. Therefore, an average gate height of 1.2 and width 1 meter is selected for further design analysis. Opening model of dam is shown in Fig. 7 given below.

Velocity of the fluid flow at opening found at height *h* below surface of water exposed to atmosphere is calculated as,

$$V = C_v\sqrt{2gh} \quad (1)$$

C_v= coefficient of velocity usually range from 0.97-0.99.

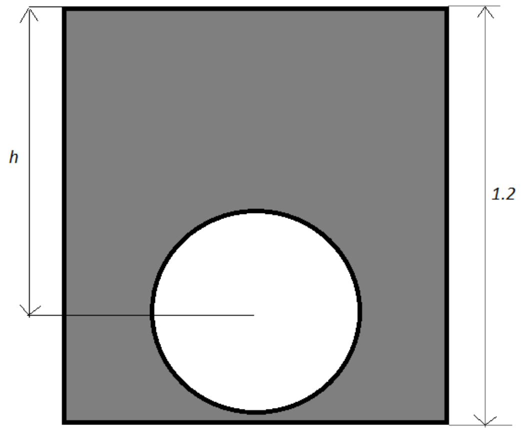

Figure 7: Opening model of dam

For example the velocity of water at h=0.8 meter

V=0.98*$\sqrt{2 * 9.81 * 0.8}$ = 3.8m/s

The size of the opening area is dependent on the flow rate in the upper stream, number of gates in a dam, the depth and position of opening. In order to discharge water at higher rate the opening is better to position at lower part of the opening. In addition to this, the opening area should allow the flow to be laminar in order not to affect the gate by inducing force during circulation and turbulence.

2.6. Gate forces

Hydrostatic and hydrodynamic forces were experienced by the gate. The amount of head flowing over the sections of the gate is determined from hydraulic studies and operational criteria for the structure [P. Novak *et al*, 2007]. The maximum hydrostatic pressure is at the bottom of the gate. Assuming the operating pressure is the pressure at the bottom of the gate, the pressure distribution at the dam and sliding gate can be evaluated. The operating pressure is,

P= σgh (2)

= 1000kg/m^3*9.81*1.2= 11772Pa.

The hydrodynamic pressure distribution can be calculated by the following formula.

$$-\frac{\tilde{a}dy}{dn} - \frac{\partial p}{\partial n} = \breve{n}\frac{V^2}{R} \quad (3)$$

2.7. Modeling and simulation of flow

To determine the static and dynamic pressure distribution in the sliding gate, the dam is modeled in GAMBIT. The two dimensional geometry of the dam is modeled, meshed and the constraints are defined as shown in the Fig. 8 given below. Since the important portion of the flow is at gate opening side the mesh size of the water body far from the opening is given less concentration. Iteration data obtained using FLUENT is shown in Fig. 9 given below.

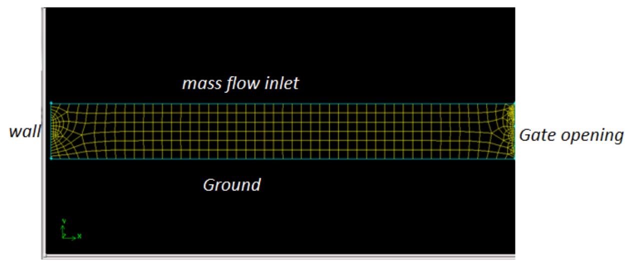

Figure 8: Dam model by GAMBIT

After the dam and the sliding gate geometry is modeled, meshed and the boundary conditions are stated, it is exported to FLUENT. The following assumptions were considered during simulation by FLUENT.

1) The fluid in the dam is pure water that means the density of water is 1000Kg/m^3.
2) The velocity profile in the opening is constant which is equal to 4m/s.
3) Operating pressure is maximum pressure in the ground position which is 11772Pa.

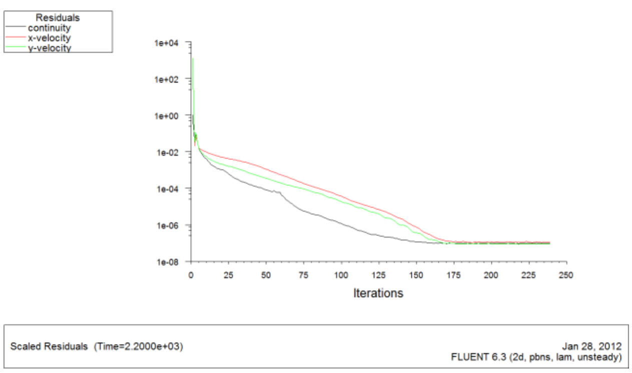

Figure 9: Iteration

The residuals have dropped by 6 to 7 orders of magnitude and have leveled out. This means that the solution has converged. Hydrostatic pressure distribution of the water is shown in Fig. 10 given below.

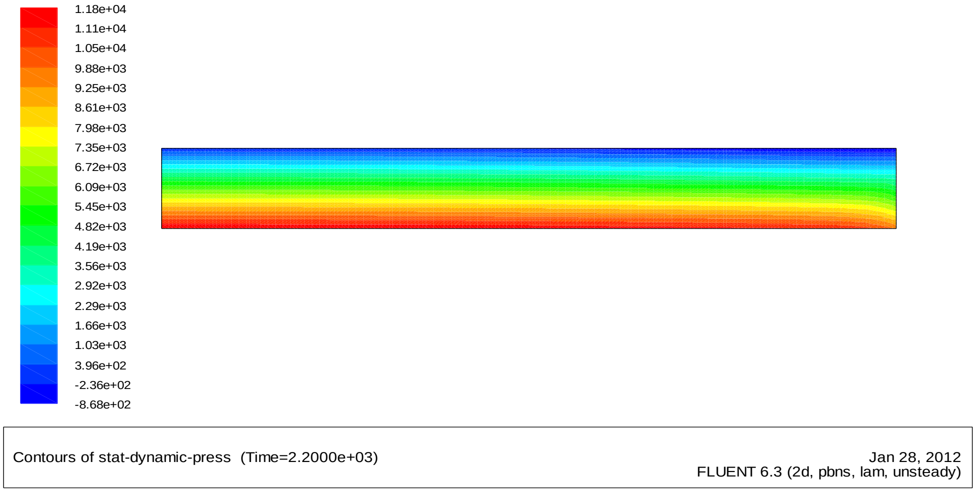

Figure 10: Hydrostatic pressure distribution of the water

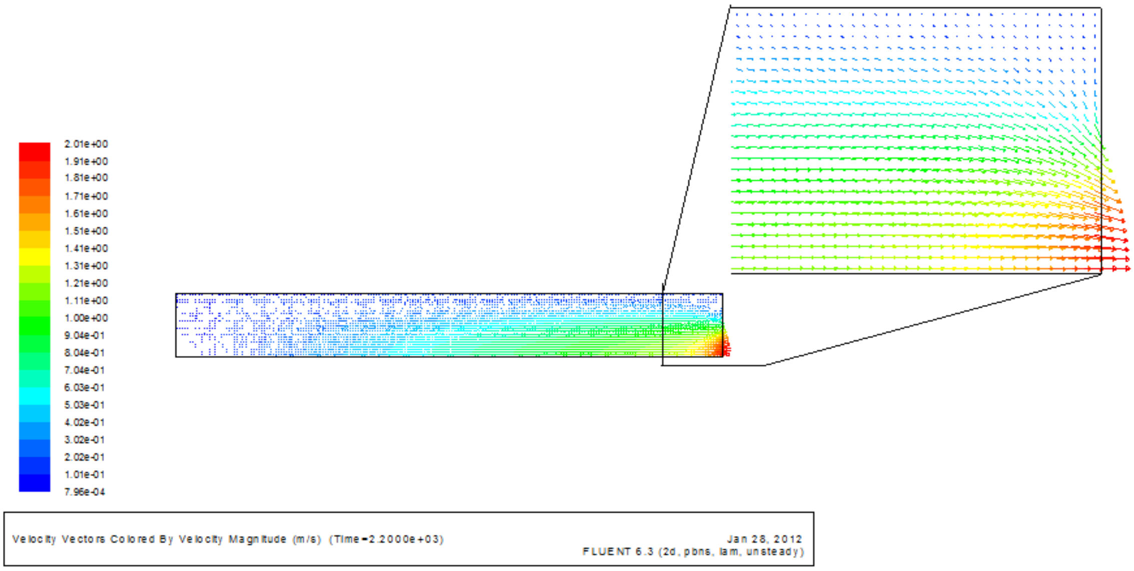

Figure 11: Velocity vector when the gate fully opened

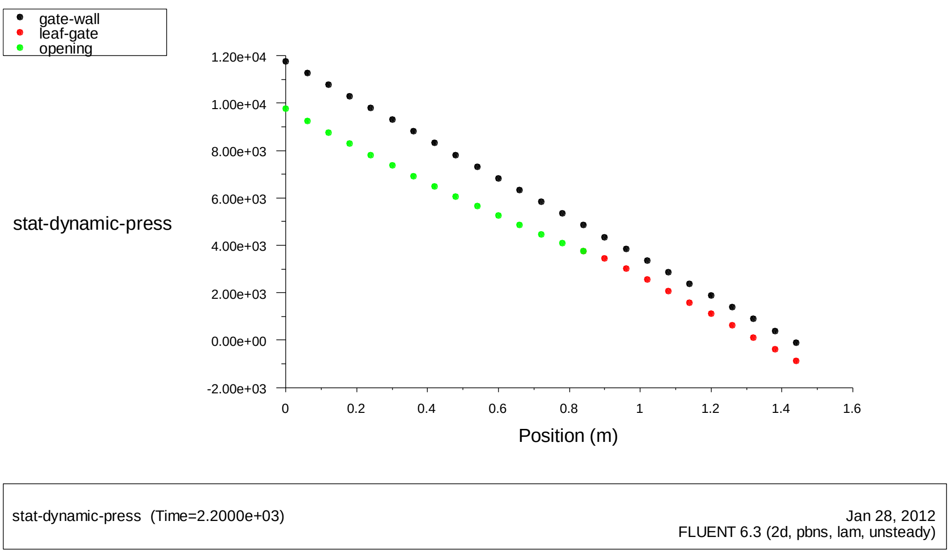

Figure 12: Static and dynamic pressure distribution in the gate

The above contour shows hydrostatic pressure distribution on the gate and the walls of the dam. As it is expected the pick pressure is at the bottom of the sliding gate. The maximum pressure, which is assumed as working pressure, is 11800 Pa. Velocity vector of the fully open gate model is shown in Fig. 11 given below.

The contour in the above Fig. 11 shows the velocity of water when the gate is fully opened. Though the velocity magnitude has a slight variation with the theoretical one, the profile of laminar flow as desired. This shows the opening size of the sliding gate is optimum. Slight variation of opening area has negative effect. If the area is below the optimum area i.e. 0.3 m^2 the flow profile changes to steady flow. Hence the recirculation of the fluid induces force to the gate plate. Likewise, if opening area is greater than the optimum area, the structural stability and strength of the gate plate will be affected. Static and dynamic pressure distribution experienced in the open gate is shown in Fig. 12 given above.

Static and dynamic pressure distribution are exerted along the gate opening, gate plate and left wall of the gate. Gate plate dimension is shown in Fig. 13 given below.

The analytical solution for pressure along the vertical line of the gate is derived from

$$-\frac{\tilde{a}dy}{dn}-\frac{\partial p}{\partial n}=\check{n}\frac{V^2}{R} \quad (4)$$

Where σ = 1000 Kg/m^3 density of a fluid, P_1 = 11772Pa pressure at the ground

Substituting, the geometry condition of the gate and by integrating it yields,

$$P = P_1 - \sigma g y - \sigma v^2 ln\left[\frac{6}{6-y}\right] \quad (5)$$

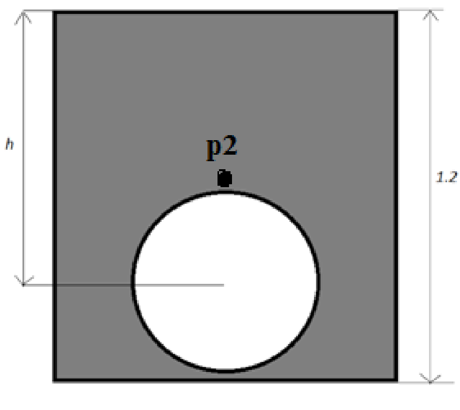

Figure 13: Gate plate

The pressure distribution in the gate opening at different heights from the ground is shown below.

- At a height of 0.7 meter from the ground, P_2= 5.4KPa.
- At a height of 0.2 meter from the ground P_3=9.6KPa.

As per the pressure distribution predicted by fluent shown in the above Fig.8,

- P_2= 5.2KPa.
- P_3=9.45KPa

The results from analytical and simulation vary with a margin of 3.2% and 1.5% respectively, which is acceptable.

2.8. Open shape selection

The area of the opening is already determined by iterating in the fluent software. The opening area allows the water to flow without turbulence. If the fluid flow is not laminar, there will be pressure loss that will be induced to the gate structure. In addition to the size of the opening area, the shape of the opening also has an effect on the force distribution and deformation on the gate.

Three openings with the same cross sectional area are presented as shown in the Fig. 14, 15 and 16 and Table1 given below.

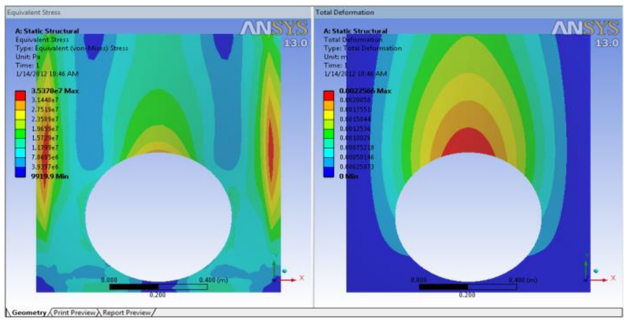

Figure 14: Stress distribution and deformation in circular opening

As it is shown in the above Fig. 14, the maximum stress is at the fixed ends of the gate leaf whereas; the maximum deformation is at the center of the leaf and at the upper tip of the opening.

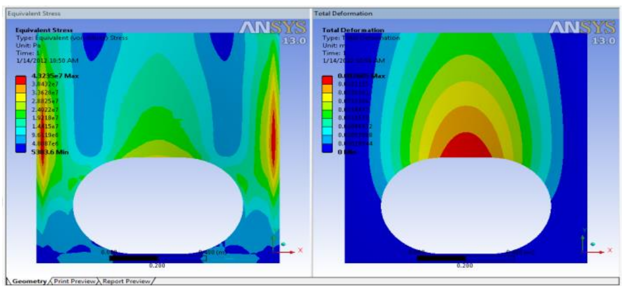

Figure15: Stress distribution and deformation in elliptical opening

Likewise, the circular opening, the maximum stress is at the fixed ends of the gate leaf whereas; the maximum deformation is at the center of the leaf and at the upper tip of the opening. Hence unlike the circular opening the magnitude of stress is higher and the zone of deformation is large in magnitude and areal distribution.

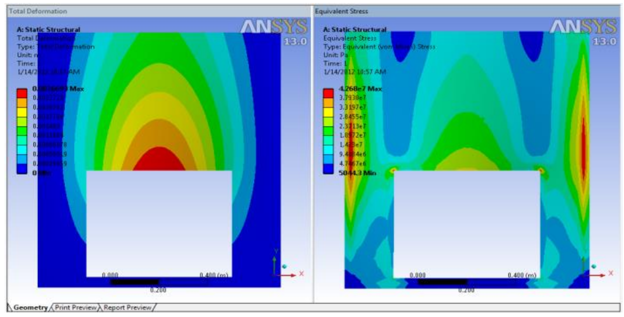

Figure 16: Stress distribution and deformation in rectangular opening

The same to the circular and elliptical openings, the maximum stress is at the fixed ends of the gate leaf whereas; the maximum deformation is at the center of the leaf and at the upper tip of the opening. Hence, unlike to the two openings discussed above, there are local stress concentrations in the corners of the opening. Maximum stress and deformation in openings is shown in Table 1 given below. Since circular shape opening has less stress and less deformation depicted in Table 1, it confirms that this might be preferred over the other openings.

Table 1: Maximum stress and deformation in openings

S/No	Shape opening	Max. Stress(MPa.)	Max. deformation(mm)
1	Rectangular	42.7	2.8
2	Circular	35.4	2.2
3	Elliptical	43.2	2.6

Therefore, depending on the following criterion circular opening has been selected.

a. Relatively small zone of deformation.
b. Relatively small magnitude of gate leaf deformation.
c. Relatively smaller maximum stress distribution and
d. Absence of local stress concentrations.

2.8.1. Gate leaf design

After the geometrical modeling of leaf gate in ANSYS has been done, the constraints were defined. The constraints are fixed supports anchored to the wall of the dam A, B, C and standard earth gravity D, and variable hydro static pressure E. Constraints and meshing of leaf gate is depicted in Fig. 17 given below.

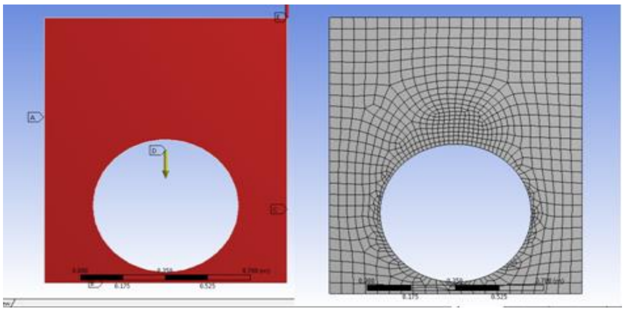

Figure 17: Constraints and meshing of leaf gate

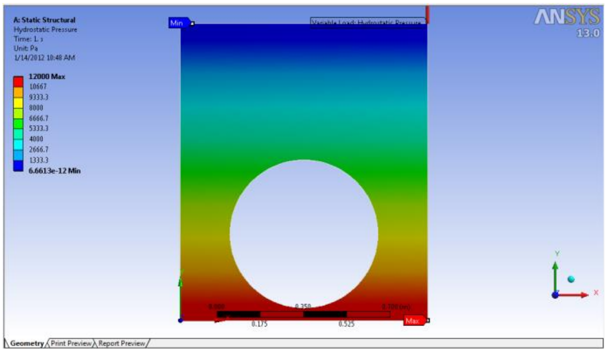

Figure 18: Pressure distribution along the leaf gate

The leaf gate is exposed to hydro static and hydrodynamic forces. The hydro static force varies from 11772Pa. to 0 linearly along the length of gate leaf. Pressure distribution along the leaf gate is depicted in Fig. 18 given above. Stress distribution of leaf gate is shown in Fig. 19 given below.

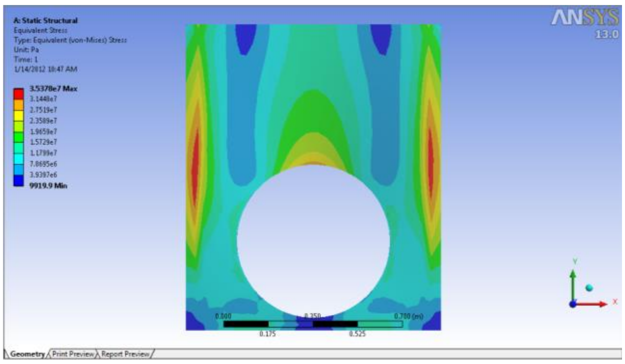

Figure 19: Stress distribution in leaf gate

Assuming, full area of the gate is exposed to hydrostatic force, the average concentrated force exerted at 1/3 of the height can be calculated as

Average pressure = $\gamma * h/2$ (6)
=1000*9.81*1.2*0.5= 6000Pa.

Force on the wall can be calculated as,
F = p*A
(7)= 6000*1.2*1=7200N
This force will be divided to both fixed ends of the leaf gate. That means 3600N each.

By taking a structural steel with yield strength of 250MPa and thickness of 6mm, the equivalent (Von-Mises) Stress varies from minimum 9920 Pa to a maximum of 35.4MPa.

The factor of safety will be,

$$n=\frac{\text{yeild strength}}{\text{Actual stress}}=\frac{250\text{MPa}}{35.4\text{MPa}}= 7 \qquad (8)$$

Since, these gates will be continuously exposed to water and wet environment, large safety factor is necessary.

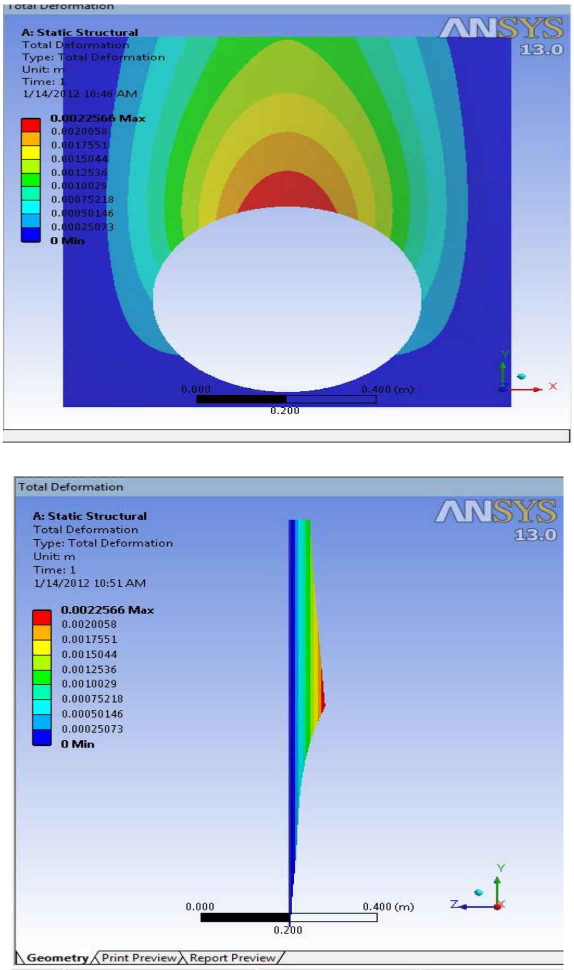

Figure 20: Deformation of leaf gate

The maximum deformation is at the tip of the opening and magnitude of deformation is 2.2mm. The value of deformation is acceptable when we compare with other opening shapes. Deformation of leaf gate is shown in Fig. 20 given above.

2.9. Design of opening plate

Since the operating condition and the constraints in the opening are similar to the leaf gate, the design procedure is similar with designing leaf gate. Pressure distribution experienced in the opening gate is shown in Fig. 21 given above.

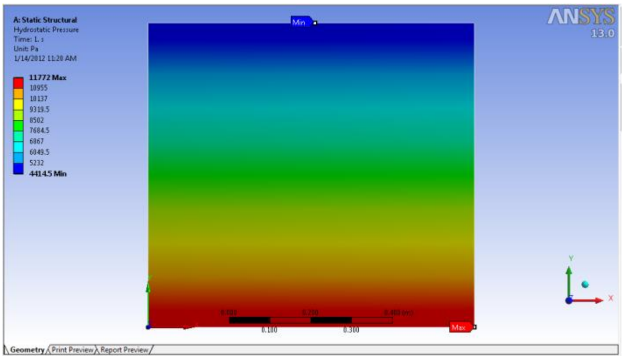

Figure 21: Pressure distribution in the opening gate

Since opening gate is submerged in the water, the gauge pressure distribution varies from a minimum of 4414.5Pa to a maximum of 11772Pa.

The resultant force due to the distributed pressure, on the opening gate submerged at a depth of h1, as shown below can be calculated as,

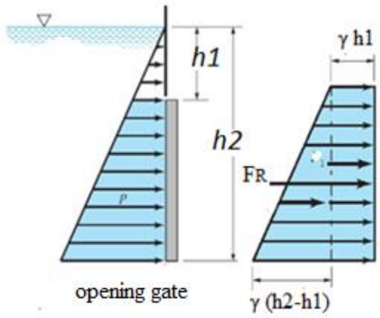

Figure 22: Resultant force on opening gate

$$F_R = (\gamma h1)A + 0.5[\gamma(h2 - h1)]A \qquad (9)$$

When the opening gate with area of 0.5m^2 is fully closed, and submerged h1=0.6meter below the water surface and h2=1.2meter, the reaction force will be

F_R=4500N

This average reaction force will be distributed in both ends of the opening gate. Resultant force on opening gateis shown in Fig. 22 given above. Von-Mises stress in the opening gate shown in Fig. 23 given below.

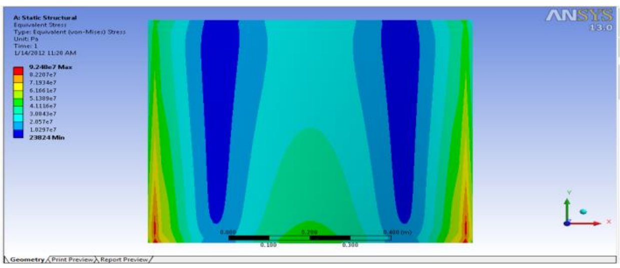

Figure 23: Von-Mises stress in the opening gate

By taking a structural steel with yield strength of 250Mpa and thickness of 6mm, the Equivalent (von-

Mises) Stress varies from minimum 23824 Pa to a maximum of 92.5MPa.

The factor of safety will be,

$n = \frac{250\text{MPa}}{92.4\text{MPa}} = 2.7$

Since there gate will be continuously exposed to water and wet environment, this much safety factor is reasonable.

2.10. Designing opening handle

The opening screw is expected to raise a load or pressure distributed at the opening gate. As it already discussed above, the summation force concentrated at gate is F_R=4500N and pulling height to be 600mm. Since the force is applied to the gate perpendicularly, it can be taken as normal force. By assuming maximum sliding frictional coefficient between the opening gate and guide, i.e. one the normal force is taken as frictional force.

2.10.1. Design of the screw

Considered a mild steel screw for which the tensile and shear strengths may be taken to be approximately 448MPa and 224 MPa respectively. Assuming a very high factor of safety due to the nature of the application and considering the axial tensile, the core diameter of the screw d_c is calculated.

$$d_c = \sqrt{\frac{4500}{\frac{\pi}{4}\left(\frac{448*10^6}{10}\right)}} = 12mm \quad (10)$$

From normal series square threads the nearest standard nominal diameter of 30 mm with pitch p=10 mm is chosen. Therefore, core diameter d_c = 20 mm, Major diameter d_{maj}= 30mm, Mean diameter d_m= 25 mm, Nominal diameter d_n = 30mm.

The torque required to raise the load is given by

$$T = \frac{Fdm}{2}\left(\frac{\text{l}+\mu\pi\text{dm}}{\pi\text{dm}-\mu\text{l}}\right) \quad (11)$$

Where l = np, n being the number of starts. Here we have a single start screw and hence
l = p =10mm, d_m= 25mm, F = 4500N.

Taking a safe value of μ for this purpose to be 0.26 and substituting the values we get

T = 140 Nm.

By assuming average human being can apply a force of 200N, the diameter of the handle can be determined.

T=force *radius (12)
140Nm=200*r

The radius of the handle that can raise the load is, r=0.70m.

2.10.2. Check for combined stress

In the screw there are combined tensile $\sigma_t$and torsional shear stress τ. The tensile direct stress is calculated as follows,

$$\sigma t = \frac{4F}{\pi\, dc^2} = 14.5MPa \quad (13)$$

And the tensional sheer stress also calculated as,

$$\tau = \frac{16T}{\pi\, dc^3} = 89MPa \quad (14)$$

The principal stress,

$\sigma_{1,2} = \frac{14.5}{2} \pm \sqrt{\left(\frac{14.5}{2}\right)^2 + (89)^2}$ = 96.55MPa and -82MPa
The factor of safety in tensile $=\frac{448}{96{,}55}$ = 5, therefore the screw dimensions are safe.

2.10.3. Design of the nut

A suitable material for the nut is phosphor bronze which is a Cu-Zn alloy and the yield stresses may be taken as

- Yield stress in tension σ_{ty}= 125MPa
- Yield stress in compression σ_{cy} = 150MPa
- Yield stress in shear τ_y = 105MPa
- Safe bearing pressure P_b = 15MPa.

Considering that the load is shared equally by all threads bearing failure may be avoided if

$$F = \frac{\pi}{4}\left(\text{d}_{\text{maj}}^2 - \text{d}_{\text{c}}^2\right)P_n\text{n} \quad (15)$$

Where n is the number of threads in contact. Substituting values n = 1. Let n=4.
Therefore, H = np = 4X10 = 40mm.

The nut threads are also subjected to crushing and shear. Considering crushing failure we have

$$F = \frac{\pi}{4}n\left(\text{d}_{\text{maj}}^2 - \text{d}_{\text{c}}^2\right)\sigma_c \quad (16)$$

This gives σ_t = 14.5 MPa which is adequately safe since σ_{ty} = 125 MPa and therefore crushing is not expected. To avoid shearing of the threads on the nut we may write F = πd_{maj} t n/ τ where t is the thread thickness which for the square thread is p2 i.e. 5. This gives τ =8.9 MPa and since τ_y= 105MPa shear failure of teeth is not expected.

3.1. Welding design

The opening gate slides on the angle iron welded on the leaf gate. The weld between the angle iron and leaf gate is fillet type.

3.1.1. Input Data

- Applied force on the opening gate, F = 4500 N
- Total length of the weld L = 750mm+750mm+800 mm= 2300 mm
- Design stress of the filler material Pw = 195.65 N/mm^2, with steel grade S275 and electrode classification 35 from Table 2 given below.

Table 2: Design Strength p_w of fillet welds

	Electrode classification		
	35	43	50
Steel Grade	N/mm^2	N/mm^2	N/mm^2
S275	195.65	195.65	195.65
S355	195.65	250	250
S460	195.65	250	280

3.1.2. Determining Welding Size

Assume throat thickness for the weld as t.
The total weld area A, which is resisting the force F, can be calculated as:

$$A = L*t = 2300*t\ mm^2 \quad (17)$$

Developed shear stress (T) in the weld can be calculated as:

$$T = F/A = 4500/(2300*t)\ N/mm^2$$

In order to sustain the welding design T should be at least equal to P_w. T =P_w that is

4500 / (2300*t) = 195.65, i.e. t = 0.01 mm for S275 (25, 43 and 50)
4500/ (2300*t) =250.00, i.e. t = 0.0078 mm for S355 (43 and 50) and for S 460(43)
4500/ (2300*t) =280.00, i.e. t = 0.0069 mm for S460 (43 and 50) and for S 460(50)

Since this weld thickness is very small, and then it is taken 0.2 mm weld thickness.

Leg length (s) of the weld can be calculated from the following equation:

$$s = 1.414 * t \quad (18)$$
$$= 1.414 * 0.2\ mm$$
$$= 0.2828\ mm$$, equivalent to 0.3 mm approximately.

Conclusion

The design analysis has been done by application software and manually for verification of the results. The results obtained from analysis are reasonable and in acceptable range and do not affect the opening mechanism and assembly. When the gate is opened and it is exposed for hydrostatic and hydrodynamic force, the gate plate and the leaf gate deform. The leaf gate deforms only 2.2 mm and hence the gate plate slides normally. By integrating the pressure on the gate plate area the force needed open is calculated. The torque needed to raise the load is 140Nm and by assuming average person can apply 200N, the diameter of the opening wheel was determined. Therefore, the key problem of the product in use is solved.

Acknowledgement

The authors wish to express their gratitude to the Mekelle University, Ethiopia, for their financial support.

References

Reddy JM (1990), Evaluation of optimal constant-volume control for irrigation channels.*Appl Math Model*, 14(9), pp 450–8.

Blesa J, Puig V, Bolea Y(2010), Fault detection using interval LPV models in an open-flow channel. *Control Eng Practice*, 18(5), pp 460–70.

Fleiu-Battle V, Rivas Perez R, Sanchez Rodriguez L (2007). Fractional robust control of main irrigation channels with variable dynamic parameters, *Control Eng Practice*, 15(6), pp 673–86.

Johannesson, H, Persson, JG, PetterssonD (2004), Produktutveckling: effektiva metoder för konstruktion och design, Liber, Stockholm, Sweden.

Ulrich, KT, Eppinger, SD (2004), Product Design and Development.*McGraw-Hill*, New York, USA.

Crilly, N, Moultrie, J & Clarkson, JP (2004), seeing things: consumer response to the visual domain in product design. *Elsevier*, Great Britain.

Pahl, G, Beitz, W, Feldhusen, J (2006), Engineering Design: a systematic approach. *Springer*, Berlin, Germany, 2006.

Monö, R (1997), Design for product understanding: the aesthetics of design from a semiotic approach. Liber, Stockholm, Sweden.

N.SomadeeptiChengalur, Suzanne H.Rrodgers, Thomas E.Bernad (2004), KODAK'S Ergonomic Design for people at work second edition, *John Wiley and Sons*, Inc.

Charles R.Mischke, Joseph Edward Shigley (2001), Mechanical Design Engineering, 6/E with student Resources, *McGraw-Hill Higher Education*.

P.Novak,A.I.B.Moffat, C.Nalluri and R.Narayanan (2007), Hydraulic Structures, 4th edition ,*TaylerFransis*.

Alberta transportation (2004), water control structure-selected design guide lines for gate.

Water Resources Department, <http://mahayantriki.gov.in/activities/radial_gate.htm>

M. Aliparast (2009), Two-dimensional finite volume method for dam-break flow simulation, *International Journal of Sediment Research*, 24(1), pp 99-107.

Malcolm J. Brandt, K. Michael Johnson, Andrew J. Elphinston, Don D. Ratnayaka (2017), Dams and Reservoirs, *Twort's Water Supply (Seventh Edition)*, Chapter 5, pp 159-204.