GROUP No.: 33

DEVELOPMENT OF A COMPUTATIONAL FRAMEWORK FOR DESIGNING DAM SPILLWAY RADIAL GATE SUSTAINING FLOOD-INDUCED FORCES.

190281T	Jeyasathan.P
190524T	Ravinath.S
190598V	Sivakanthan.S

Advised by

Dr.KKNP Samaraweera
Department of Mechanical Engineering
University of Moratuwa

Dr.DSPA Baragamage
Department of Mechanical Engineering
University of Moratuwa

Report submitted in partial fulfilment of the requirements for the degree of Bachelor of Science in Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

May 2024

Group No.:33

Declaration Page

We, the undersigned, hereby declare our commitment to the project titled “Development of a computational framework for designing dam spillway radial gate sustaining flood induced forces." as described below:

We declare that this is our own work, and this report does not incorporate without acknowledgement any material previously submitted for a degree or Diploma in any other University or institute of higher learning and to the best of my knowledge Group No: 33 and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. Also, we hereby grant the University of Moratuwa the non-exclusive right to reproduce and distribute our report, in whole or in part in print, electronic or other medium.

The above candidates have carried out the research included in this research under my supervision.

Dr. KKNP Samaraweera Department of Mechanical Engineering, University of Moratuwa

Signature ____________ Date __________

Dr. DSPA Baragamage Department of Mechanical Engineering, University of Moratuwa

Signature Dilshan Date 14/05/2024

Abstract

Our project aims to investigate the flow across spillways through numerical modeling. Utilizing the capabilities of Ansys Fluent, we will predict fluid dynamic forces and pressure fluctuations associated with vortex induced vibrations at Kilinochchi Iranamadu Dam. Specifically, our focus lies in simulating vortex induced vibrations and determining the natural frequencies of the radial gate structure using Ansys Fluent for fluid dynamics and ANSYS structural analysis for structural integrity assessment.

Acknowledgements

We extend our sincere gratitude to all those who contributed to the successful completion of this project, “Development of a computational framework for designing dam spillway radial gate sustaining flood induced forces" undertaken by three undergraduate students from the University of Moratuwa, with the guidance of two dedicated supervisors.

We are deeply thankful to Dr.KKNP Samaraweera, Department of Mechanical Engineering, University of Moratuwa, Dr.D.S.P.A.Baragamage, Department of Mechanical Engineering, University of Moratuwa, our project supervisors, for their invaluable guidance, mentorship, and unwavering support throughout the duration of this project. Their expertise and encouragement have been instrumental in shaping our research direction and ensuring its quality.

We would like to express our deepest appreciation to the engineers, staff, and authorities of Kilinochchi Iranamadu Dam for their invaluable assistance and cooperation. Without their support, access to essential data and resources would not have been possible. Their expertise and collaboration were instrumental in guiding our research and ensuring its relevance and accuracy.

Additionally, we acknowledge the engineers from the Irrigation Department Hydraulic Laboratory, whose insights and knowledge greatly contributed to our understanding of dam structures, spillway dynamics, manufacturing processes, and the intricate details of dam construction. Their willingness to share their expertise enriched our project and paved the way for a more comprehensive analysis. Furthermore, we are grateful to our colleagues and peers for their insightful discussions, feedback, and moral support, which enriched our understanding and helped us overcome challenges encountered during the course of this project.

Thank you.

Ravinath S

Jeyasathan P

Sivakanthan S

Table of Contents

Table of Figures

List of Tables

1. Introduction

Sri Lanka, being primarily an agricultural nation, places immense value on its irrigation systems. The country boasts many dams and reservoirs. Dams play a crucial role in conserving water and regulating its flow, particularly during periods of heavy rainfall. Within these dams, the spillway gate assumes a pivotal role, facilitating the safe discharge of excess water downstream. Various types of spillway gates, including slide gates, radial gates, section gates, and roller gates, find application. Among these, the radial gate prevails due to its operational efficiency during opening and closure. Effective management of irrigation systems holds paramount importance, not only for the security of the dam itself but also for the surrounding environment. Constructing a robust and secure dam spillway gate is of utmost significance.

During the construction of such gates, a comprehensive analysis of multiple influencing criteria is imperative. These factors encompass the flow rate, the reservoir's head, and the hydrostatic and hydrodynamic loads the spillway gate will encounter. A subsequent in-depth structural analysis of the gate's design is necessary to ensure its viability and integrity. In Sri Lanka, the prevailing approach to designing spillway radial gates is to replicate existing designs. When embarking on new projects, the practice involves directly duplicating the design for installing radial gates.

furthermore, the Irrigation Department currently lacks a computational framework for calculating hydrodynamic and hydrostatic forces. Additionally, they lack the necessary framework to analyse how the gate would respond to these forces. Solving hydrodynamic and hydrostatic equations through analytical means can prove to be challenging. However, the utilization of computational tools simplifies this process. Failing to conduct a structural analysis to assess its capacity for handling various loads can be hazardous. Without a clear understanding of how the structure would perform under extreme conditions, we cannot determine its ability to withstand such situations.

2. Aim and Objectives

2.1 Aim

Develop a computational framework to design a dam spillway radial gate.

2.2 Objectives

1. Identify design criteria to construct dam spillway radial gate.
2. Develop computational framework to calculate hydrodynamic and hydrostatic loads acting on structure.
3. Develop validated computational framework to find out the structural response of gate based on hydrodynamic and hydrostatics loads.

3. Literature Review

3.1 Dam Spillway gates Introduction.

A spillway is one of most important features of a dam, it is like a safety valve [1]. When water exceeds a limited level, it helps to pass water downstream. Appropriate design of spillway prevents the potential risk of failure and dam over topping. For a controlled flow we use a gate system. Gate design should be strong enough to withstand the hydraulic forces.

A discharge coefficient (C) is a quantitative variable that measures the spillway's efficiency at moving floodwaters [1]

$$Q = C_g DL(2gH)^{\frac{1}{2}}$$

where, C_g = discharge gated coefficient, D = gate opening in meter, L = net length of the spillway crest. g = gravity acceleration, H = vertical distance between the total upstream head and the centre of the gate opening.

3.1.1 Spillway gate Types

Some of the spillway gate types are flat, flap segment, cylinder, and roller gates.

3.1.1.1 Flap gates

Figure 1 Flat gate in Parid River, Indonesia [6].

This gate type has surface of straight or curved, pivoted on a fixed axis at the sill. While in fully opened position flap gate makes angle in range of 60 to 70 degrees horizontally and while fully lowered skin plate forms a continuous surface with the weir bottom presenting no obstacle to water flow [2]. Like the drum and sector gates, the water flows over the flap gate when it is open. Seals are provided at the lower edge and the sides of the gate leaf. The lower seal may be made with a rubber strip bolted to the sill and the skin plate.

3.1.1.2 Flat gate

Figure 2 Flat gate in Columbia River, Gorge [6]

This figure shows a flat gate application in Columbia, flat gates one of the types widely used spillway gates.

3.1.1.3 Segment gate.

Figure 3 Upper Kotmale damp spillway [7].

In simple terms, a segment gate is like a curved metal plate shaped like a slice of a cylinder. It is held in place by arms that spread out from the centre and can move around a horizontal axis, like a rod going through the centre of a wheel. This axis usually lines up with the Centre of the curved plate. Because of this setup, when water pushes against the gate, it does not naturally want to open or close the gate on its own. Sometimes, the curved plate's centre is positioned above the axis, creating a lifting force that helps when you use a winch to open the gate. This lifting force needs to be less than the weight of the gate to make sure it can close properly. In some cases, the gates are balanced with weights on the arms' other side, so they can be operated with very little effort.

The segment gate is the least expensive and the most adequate type of gate for passage of large floods, due to its simplicity of operation and maintenance [1] (easy access to bearings and gate leaf framing), light weight and because it requires low-capacity hoists. Hoists designed to overcome the dead weight of the movable parts and the friction forces on the bearings and side seals operate these gates. For greater safety of the equipment, the hoist is usually provided with a manual device to permit the gate lifting in case of power failure.

The absence of slots in the piers simplifies the design and favours the hydraulic flow conditions near the walls; this makes the segment gate suitable for operation in partial openings. Once the spillway maximum flow has been determined, the width of the bays should be selected to minimize the spillway length and therefore, its overall cost [2].

Gate bearings should be located at least 1 m above the water nappe flowing over the spillway crest under maximum flood discharge [2] bearing position affects the direction of the resultant of the water thrust acting on the gate. For reasons of spillway stability, it is desirable to have the direction of the resultant thrust approximately horizontal or directed downward, to reduce the overturning moment [2]**.** Location of the bearings at a third of the gate height above the sill, causes the resultant to have a horizontal direction, while its positioning below that point directs it downwards [2]. The skin plate curvature radius inversely affects the gate weight, that is, the smaller the radius, the heavier the gate. the larger the radius and the higher the bearings, the higher will be the lifting required for passage of the maximum discharge.

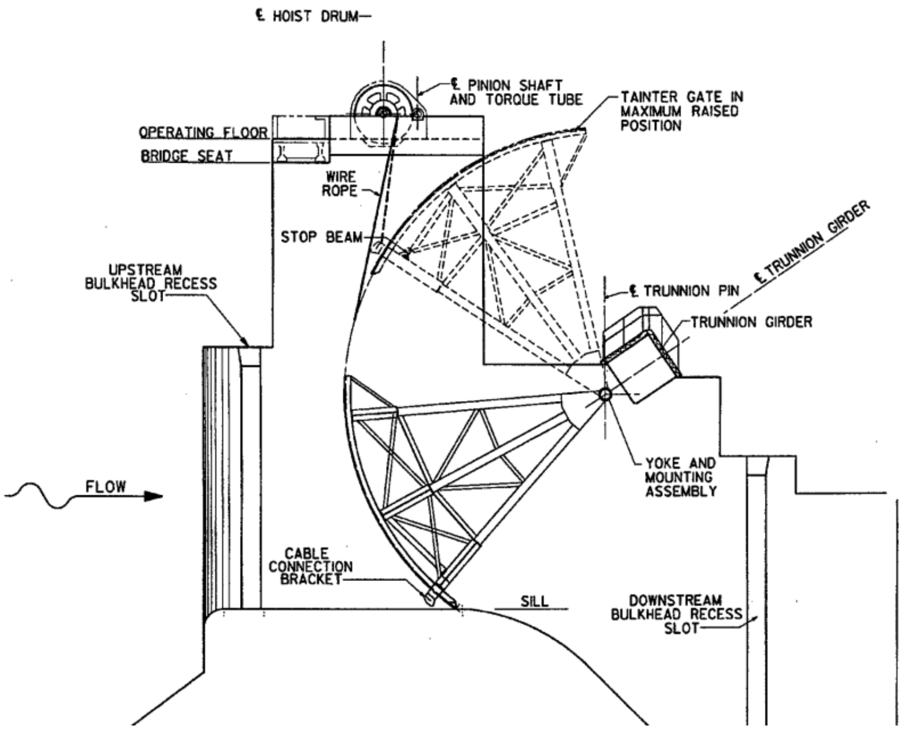


Figure 4 Gate with sill position

The choice of the sill position should be carefully made since it affects the gate height, the bearing location, the minimum lifting height, and the crest pressures. If the sill placed upstream of the crest axis, the jet ejecting from under the gate will get detached from the concrete surface, resulting in low pressures and possible cavitation damage to the crest. The U.S. Army Corps of Engineers recommends “that the sill should be placed between 1.5 m and 3 m downstream of the crest axis” [3]

"In small gates, a common design features arms parallel to the pier face, connected to the ends of the horizontal beams." The arms are usually fastened to the main girders with bolts and designed as columns subjected to axial loads and the bending moment due to bearing friction. In the axial direction, the arms are subjected to the water thrust and to the lifting force exerted by the hoists. The arms have a radial direction and are fastened to the trunnion hubs by welding or bolts. The hub is a hollow cylinder manufactured from cast or forged steel.

3.1.2 Structural Design

Primary gate components of the radial gate are skin plate, horizontal grides, end frames and trunnions. The skin plate assembly are a cylindrical surface consisting of stiff skin plates and supported by curved vertical ribs and horizontal girders. Downstream side of radial gate each rib is attached to the upstream flange of horizontal girders.

The horizontal girders are supported by the end frames. End frames consist of radial struts or strut arms and bracing members that converge at the trunnion which is anchored to the pier through the trunnion girder. The end frames may be parallel to the face of the pier (support the horizontal girders at the ends) or inclined to the face of the pier (support the horizontal girders at some distance from the end with cantilever portions at each end). The trunnion is the hinge upon which the gate rotates.

3.1.2.1 Load cases.

- Normal case- considers the most unfavourable values and combinations of the hydrostatic loads at normal water levels (including the influence of waves), hydrodynamic effects, friction forces, dead weight, buoyancy, transit loads and driving forces.
- Occasional case – wind loads, temperature effects,

- ❖ Exceptional case - hydrodynamic effects and overloads due to the driving forces in the event of lining or penstock failure, seismic effects.

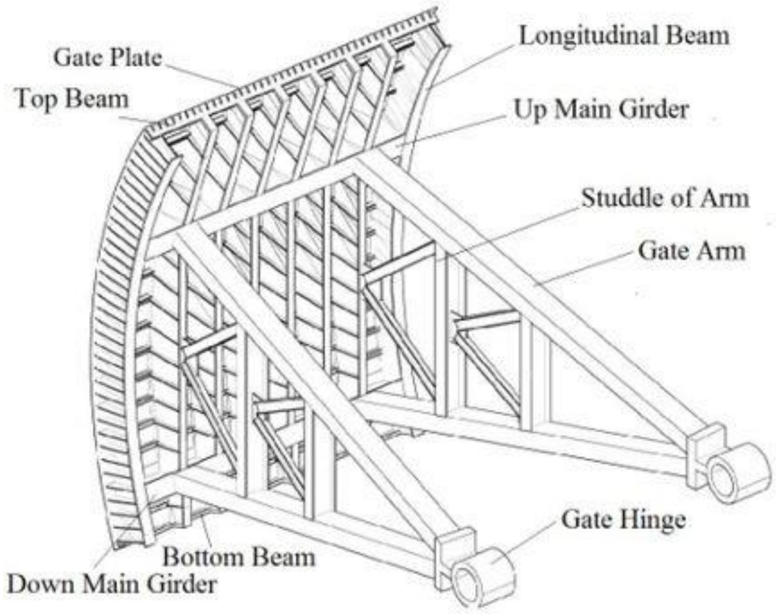


Figure 5 Radial gate with parts [5]

The skin plate of segment gates is made up of curved plates joined by butt welds. The minimum recommended thickness is 8 mm [3].

3.1.2.2 Gate framing

The strengthening of the skin plate is made with the aid of horizontal and vertical girders and stiffeners.

3.1.2.3 Horizontal beams

The dimension of horizontal beams with both ends overhanging usually falls into one of the following cases [2].

1. Rounded connections – occurs when the length of the overhanging section is made equal to 0.225 times the beam length.
2. Rigid connections – occurs whenever the length of the overhanging differs from 0.225 times the beam length.

3.1.2.4 Vertical beams

Support of vertical beams is made on the main horizontal girders, where the radial arms are also connected. In more recent designs, the use of two pairs of radial arms per gate prevails, which results in vertical beams with two supports.

In the choice of the arms geometry in the vertical plane (which also defines the position of the main horizontal girders), two methods may be used.

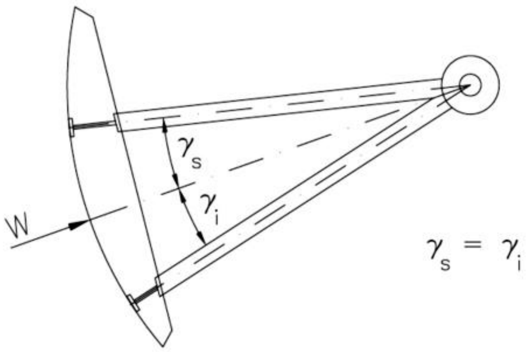


Figure 6 Equally loaded arms.

a) arms equally loaded in the axial direction – this situation occurs when the direction of the maximum water thrust coincides with the bisectrix of the angle between the upper and lower arms see figure 5, in the case of gates with two pairs of radial arms.gequal bending moments on the main vertical girder supports.

3.1.2.5 Radial arms

Axial load on arms

The radial arms of segment gates transfer the water thrust acting on the gate leaf to the bearings. The distribution of the water thrust to the arms in gates with two pairs of arms is made as follows.

a) Case of radial arms parallel to pier face

- Axial load on each upper arm

$$R^*{}_s = \frac{w}{2}\frac{Sin\,\gamma_i}{Sin\,(\gamma_i+\gamma_s)}$$

- Axial load on each lower arm

$$R^*{}_i = \frac{w}{2}\frac{Sin\,\gamma_s}{Sin\,(\gamma_i+\gamma_s)}$$

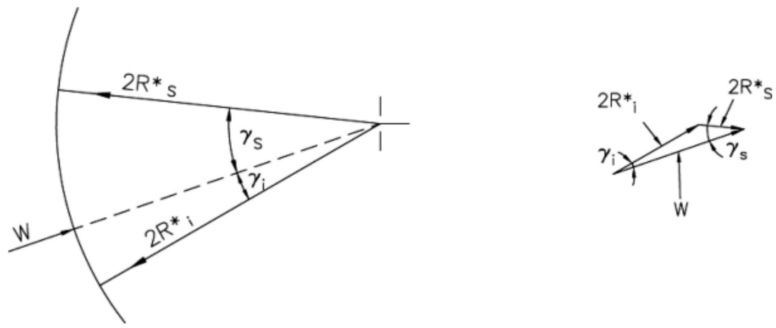


Figure 7 Radial gate radial arm reaction [2].

b) Case of sloped radial arms

- Axial load on each upper arm.

$$R_s = \frac{W}{2cos\omega}\frac{Sin\,\gamma_i}{Sin\,(\gamma_i+\gamma_s)}$$

- Axial load on each lower arm

$$R_i = \frac{W}{2cos\omega}\frac{Sin\,\gamma_s}{Sin\,(\gamma_i+\gamma_s)}$$

3.1.3 Bearing loads

For gates with sloped radial arms, the load transmitted to the bearing may be divided into two orthogonal components Fn and Fr.

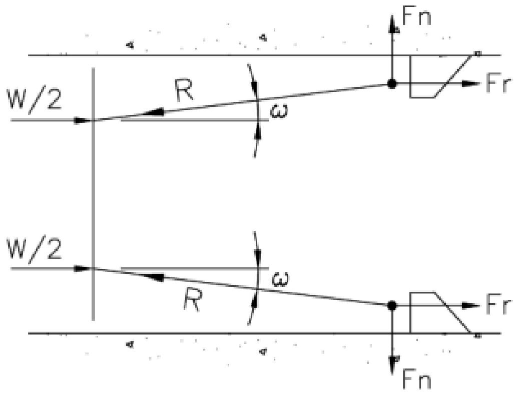


Figure 8 Radial gate bearing loads [2].

whose values are, Fn = R sin ω and Fr = R cos ω

also,

$$R = \frac{W}{2\cos\omega}$$

So,

$$F_n = \frac{W}{2} tan\omega\ , \qquad F_r = \frac{W}{2}$$

3.1.3.1 Buckling check

The arms of segment gates should be checked against buckling caused by the combination of axial and bending loads, both on the vertical plane and on the planes formed by the main horizontal girders and their respective arms. The following loads should be considered,

a) axial compression due to hydraulic loads.
b) own weight of arms.
c) friction on the bearings.
d) operating forces due to the action of hoists.
e) bending moments on supports (rigid fixing) and bearings.

3.2 Force analysis.

3.2.1 Hydrostatic forces

When we are calculating the gate size, firstly, the water pressure on the gate at different positions needs to be considered. The gate is subjected to highest pressure when the gate is completely closed, and the upstream water level is at its maximum level. If the gate is in the middle of two bodies of water, the highest pressure comes when there's a big difference in water levels between the place where the water comes from and the place where it goes to.

The water thrust on radial gates is directed through the centre of curvature of the gate's skin plate. To simplify the calculations, we determine the total water thrust by breaking it down into its horizontal and vertical components. The formulas provided below are applicable to a wide range of gate types, including weir and submerged segment gates, sector gates, and flap gates featuring a radial skin plate.

- The horizontal component of the water thrust is calculated as follows [5]

$$W_H = \gamma B h \, (H - h/2)$$

- The vertical component is [5]

$$W_v = \gamma BR \, [D_m (\cos\alpha_s - \cos\alpha_i) + R\,(\alpha_i - \alpha_s)/2 + R\,(\sin\alpha_s \cos\alpha_s - \sin\alpha_i . \cos\alpha_i)\,/2]$$

where, γ =specific weight of water=9.81 kN/m^3, B =side seal span,

R =skin plate radius (measured on the wet surface), H=maximum headwater on sill

h =gate sealing height, D_m =difference between the elevations of the water level and the centre of curvature of the skin plate

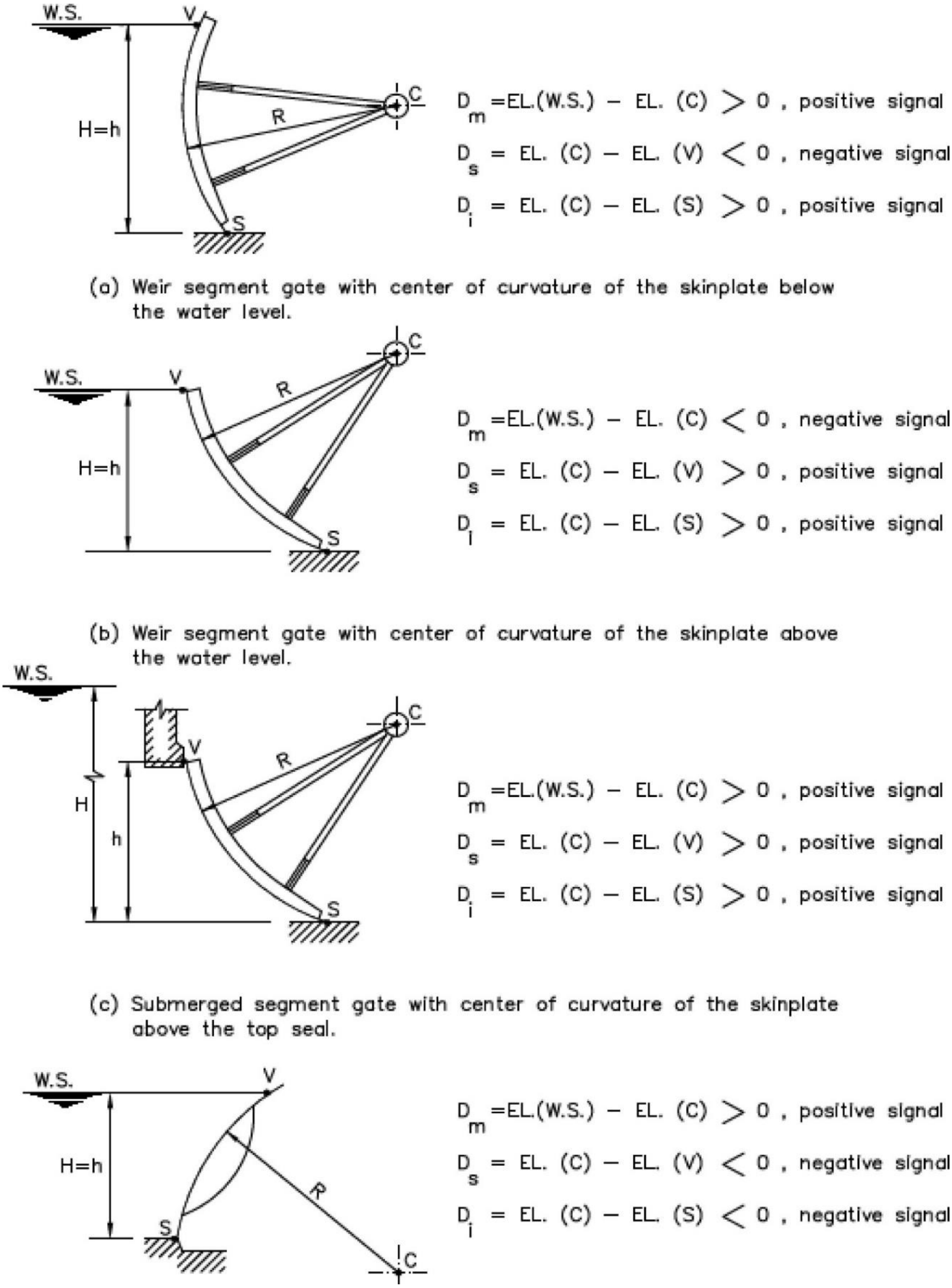


Figure 9 Parameters for calculation of the maximum hydraulic thrust [1].

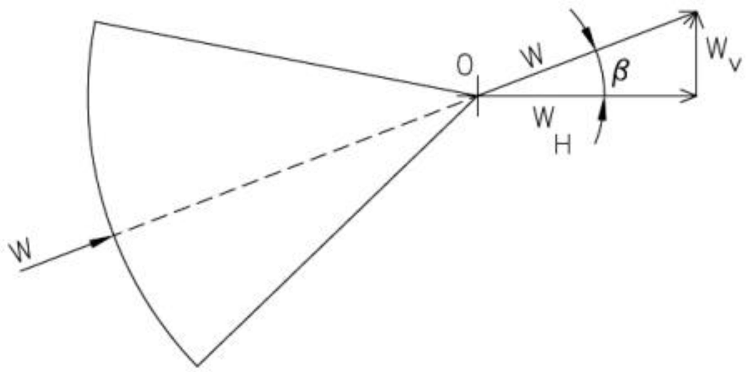


Figure 12 Direction of maximum hydraulic thrust on radial gates [1].

$$\alpha_s = \text{arc } \sin D_s/R$$

$$\alpha_i = \text{arc } \sin D_i/R$$

D_s = difference between the elevations of the centre of curvature of the skin plate and the top seal (for submerged gates) or the water level (in case of weir gates); D_i = difference between the elevations of the centre of curvature of the skin plate and the sill. See figure 12 for identify Ds.

a) D_m, D_s and D_i refer to difference of elevations and may assume positive or negative sign, depending on the gate arrangement.
b) The angles α_s and α_i are taken in radians and can also assume a positive or negative. sign.

c) The direction of the vertical component is given by its sign:
    - positive: upward
    - negative: downward.

- The magnitude and direction of the resultant water thrust are calculated by:

W= $(W_h{}^2 + W_v{}^2)^{0.5}$

β= arc Tan (W_v/W_h)

3.2.2 Hydrodynamic forces

When a gate is fully closed, and the water is motionless, the pressures adhere to hydrostatic principles, making it relatively straightforward to calculate hydraulic forces using analytical methods. In the absence of any water flow, assessing the vertical component of the hydraulic forces acting on the gate primarily involves determining its buoyant force. This static condition is characterized by a consistent piezometric head value [2].

However, when the gate is partially open, the hydrostatic equilibrium is disrupted, leading to an uneven distribution of the piezometric head in the vicinity of the gate. This irregularity is attributed to high flow velocities along the gate's lower surface, which diminishes local pressure and gives rise to this phenomenon.

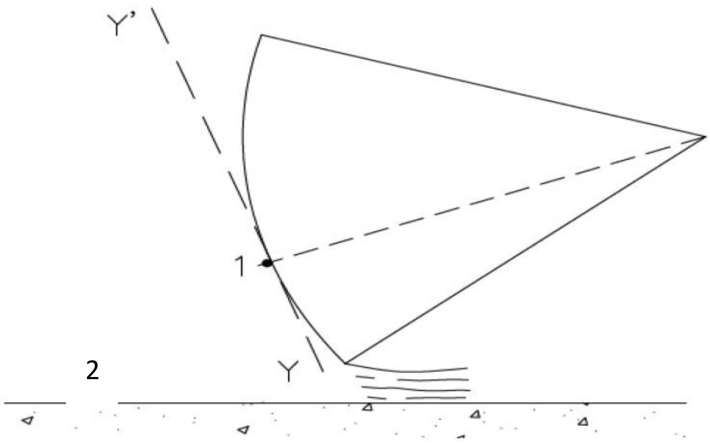


Figure 10 Radial gate partially open [1].

Applying the Bernoulli equation to points 1 and 2, we get:

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g}$$

Assuming that the water is at rest at point 2, $V_2 = 0$. As Z_1 is practically equal to Z_2, above becomes.

$$\gamma \frac{V_1^2}{2g} = P_2 - P_1$$

Since the left side of the equation is positively oriented, it indicates a pressure disparity between points 1 and 2, which intensifies with the swiftness of water passing beneath the gate. The pressure at point 2 closely approximates the hydrostatic pressure. Consequently, the gate's lower surface experiences a pressure differential, resulting in a vertical downward force known as the down pull force.

3.2.3 Gate operating forces

The gate hoist is made to help move the gate by overcoming the forces that try to stop it from moving. Typically, we need to think about the forces that push back on the gate when it's being moved.

G = gate weight

E = buoyancy of the submerged part

Fa = friction forces on supports

Fv = friction forces on seals

Fh = down pull (or uplift) forces.

For radial gates the hoist capacity is determined by means of the torque exerted by the resistant forces about the rotation axis[5]

3.2.3.1 Gate weight

The parts of the gate weights are:

a) weight of the gate structure
b) weight of accessories and mechanical parts (wheels, pins, seals and so on) attached to it;
c) weight of paint.
d) weight of debris eventually retained in the gate structure.
e) weight of water eventually retained in the gate structure, in case of weir gates.
f) weight of ballast, if any.

3.2.3.2 Friction on support and hinges

Friction on the supports and hinges of the gate depends on the weight of the water pressing against the gate and the smoothness of the surfaces touching each other. This is calculated using a well-known formula [5]

Friction force (Fa) = Friction coefficient (μ) × Normal force (N)

The normal force (N) is usually a combination of the force from the water (hydrostatic thrust) and the weight of the gate itself.

When it comes to friction, it is often assumed that the friction coefficient (μ) remains constant, but this might not be the case. Gates that stay still for long periods tend to develop additional friction due to surfaces sticking together. So, it is a good idea to use different values for the friction coefficient in situations where the gate is stationary versus when it's in motion[5]. Here are the specific friction coefficients given in the book of Hydraulic gates by Paulo C.F. Erbist[5]

For segment gates with sloped arms that pivot on trunnions, we also need to consider the friction forces on the washers caused by the force perpendicular to the pier face.

Materials	*Static conditions*	*Dynamic conditions*
Bronze on steel	0.30	0.18
Self-lubricating copper alloy on steel	0.15	0.10
Steel on steel	0.40	0.20
Steel on concrete	0.40	0.40
Rubber on steel	1.00	0.80
UHMWPE on steel	0.25	0.15
PTFE on steel	0.10	0.10
Timber on timber	1.10	1.10
Timber on steel (*)	from 0.45 to 0.55	from 0.45 to 0.55

(*) along the fibers, $\mu = 0.45$, across the fibers, $\mu = 0.55$.

Figure 11 Friction coefficients [1].

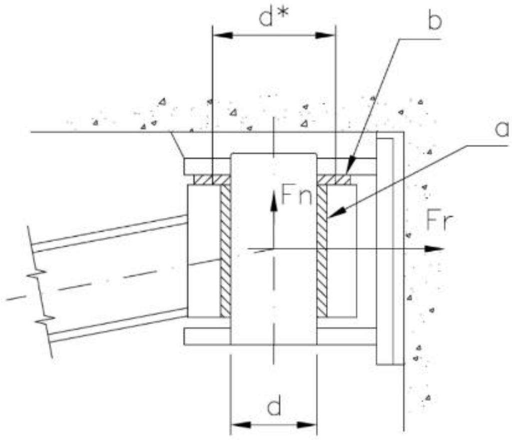


Figure 12 Bearing reactions. (a) cylindrical bushing; (b) thrust washer [1].

The total resisting torque on the gate hinge is [1].

$$M_m = \mu \,[\, F_r \times (d/2) + Fn \times (d*/2)]$$

where, μ = friction coefficient, d = inside diameter of bushing, d^* = mean diameter of the thrust washer, F_r = radial component of the hydraulic thrust on each bushing, F_n = axial component of the hydraulic thrust on each bushing.

- In segment gates with parallel arms, F_n is equal to zero and Equation becomes [1].

$$M_m = \mu F_r \,(d/2)$$

- The friction forces on the wheels are calculated by the formula [1].

$$Fr = W/R\,(\mu r + f)$$

where, Fr = friction force, W = wheel load, R = wheel radius, r = wheel pin radius or mean radius of bearing, μ = friction coefficient of bearing or bushing, f = coefficient of rolling friction

3.2.3.3 Seal deflection

In still water, the gate seals touch the seal plates and deflect in the opposite direction. After application of the hydrostatic pressure, the seals deform in the flow direction and become compressed against the seal plates. The seal pre-compression is defined in the manufacturing drawings.

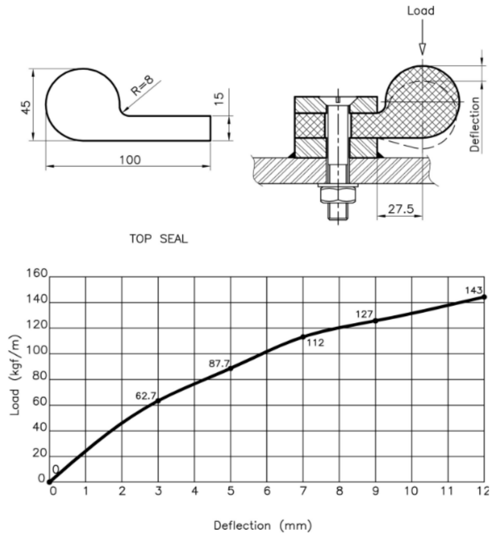


Figure 13 Force-deformation curve of a J-seal [1].

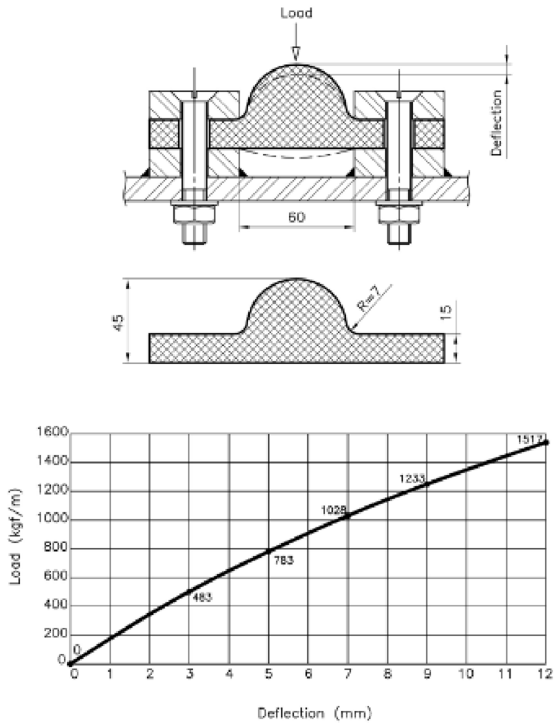


Figure 14 Force-deformation curve of a double-stem seal [1].

3.2.3.4 Seal friction.

- Seal friction forces are determined by the formula [1].

$$F_v = \mu N$$

where, μ = friction coefficient between seal and seat, N = reaction force of the seat.

The reaction force of the seat is calculated according to the type and geometry of the seal:

- **J seals.**

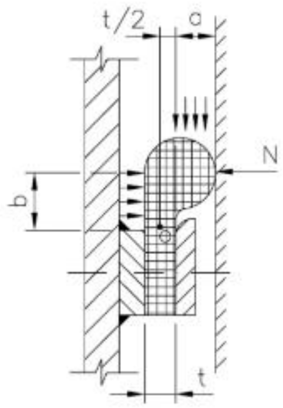


Figure 15 J seal [1].

- ♦ Moments of point O[5]

  PLb(b/2) + pLa(a /2 + t/ 2)− Nb = 0

  ∴ N = (pL/2b) (b2 + a2 + at)

where, p = hydrostatic pressure on the seal, L = seal length, a, b, t = see Figure 17.

- **Angle seals**

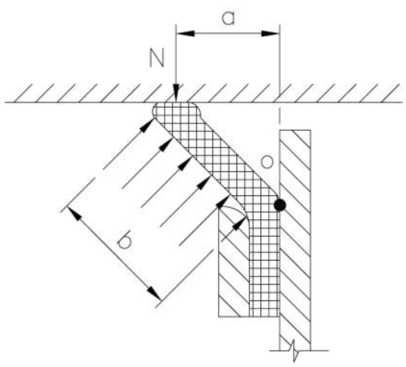


Figure 16 Angle seal [1].

- ♦ Moments about point O[1].

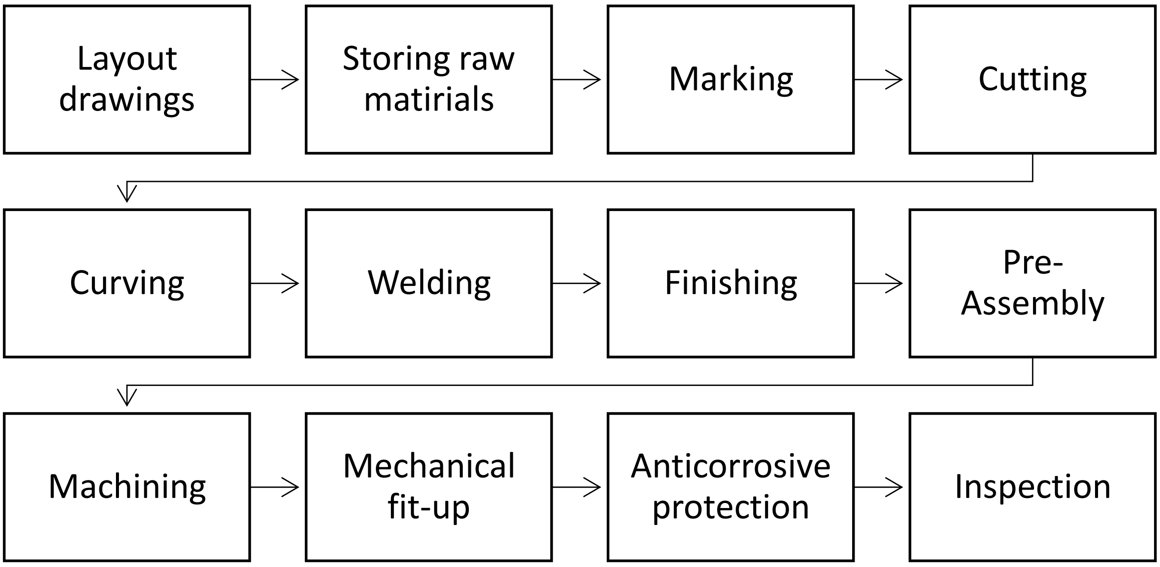
  PLb(b/2) − Na = 0

  $N = pLb^{2/}2a$

3.3 Manufacturing aspects and Vibration analysis

3.3.1 Manufacturing of spillway radial gate

The manufacturing of a radial gate includes various steps. Shapers, Boring and drilling machines, milling machines are commonly used for machining. It commonly deals with steel. Starting from the design and layout drawing to the final inspection, it includes the following main steps.



3.3.1.1 Layout drawing

Layout drawings are commonly used to make templates for the cutting and curving plan of sheet metals, pipes, and girders. It helps to effective use of raw materials and create a bill of materials.

3.3.1.2 Storing of raw materials

The design department should know the availability of raw materials so that they can make their specifications according to the raw materials. Through the inventory management of the raw materials, current and future works can be done without delay.

3.3.1.3 Marking, cutting, and curving

Marking is done once we have the cutting and curving plans. Usually, white paint, metal tracers, and punchers are used for marking. Cutting dimensions and edging details are marked. After the marking, the required part is cut and removed. For cutting Oxygen cutting and plasma arc or conventional machine cutting methods (Saw, shear) can be used. Oxygen and plasma cutting

can be done automated, semi-automated, and manually. After marking and cutting plates should be curved. Plate rollers and hydraulic presses are used to curve the plates [1].

3.3.1.4 Welding

Welding methods are selected before fabrication. Initially, sub-assembly parts are welded and then those sub-assemblies are joined to get the whole structure. Butt welding is used for skin plates. Jigs are used to hold the large assembly parts; Following are the common welding methods used in radial gate manufacturing [1].

- Arc welding (Manual and automation)
- MAG and MIG
- TIG

3.3.1.5 Finishing

After the welding temporary devices like clamps and wedges should be removed. After that dirt and weld splashes should be removed. Weld spatters are removed by grinder and sand machines.

3.3.1.6 Anti-Corrosive protection

After the manufacture, all the unfinished ferrous material should be done a anti-corrosive protection according to the environment and working conditions. Stainless steel parts, galvanized parts, and parts embedded in concrete have no need for any protective treatments. Painting can be done in a workshop or in the field. Commonly metal surfaces are protected by a shop primer coat and removed before painting. Before painting all dust, grease oil and oxides should be removed with brush, blasting, and sand machines. The most accepted steel surface preparation standard is Swedish standard SIS-02-5900-1967 [1].

Commonly protection is good when the thickness of the coating is greater than 3 times of anchor patterns. Following are some thickness levels with coating types and conditions [1].

- After the white metal blast cleaning – 120µm to 150µm
- If there is mechanical friction - 300µm
- Zinc-rich epoxy paints - 60µm to 70 µm
- High-built epoxy paints -200µm
- Acrylic polyurethane-based paints - 50µm to 75µm

According to the environment

- Permanently submerged parts
  Near-White blast cleaning, one coat of Zinc-rich epoxy paint (60 to 75 micrometres), Two coting of high build epoxy paint(2*150micrometers)
- Parts that one side in the water and the other side exposed to the weather.

- Parts that fully exposed to weather

  Power tool cleaning (Brush or sand disks), one coat of Zinc phosphate paint (40 micrometres), Two coats of alkyd resin paint (50 micrometres)

3.3.1.7 Inspection

Inspection is a critical step in a manufacturing process. What parts and places are needed to inspect is decided in the start of the manufacturing and marked in the manufacturing flow chart. Inspection is done in raw materials, welders and welding, dimensional and visual control, functional and destructive, and non-destructive tests.

Raw materials need to be inspected while purchasing and in inventory. Raw materials should have quality certificates. Plates that are higher than 19mm in thickness are inspected by ultrasonic sensors [1].

Welding should be done with an inspector and welding must follow the standard of AWS (American Welding Society).

The finishing of parts, welding lengths, assembly of parts, and edge preparations are visually inspected by an experienced person. From the weld inspection undercutting, overlapping, and more defects can be detected.

Non-destructive tests are commonly used in welding. Magnetic particle examination helps to find any big cracks in welds. The liquid penetrant examination helps to find any surface cracks. Ultrasonic tests help to find inner cracks. Radiography is used to inspect butt welds. Destructive tests are used to inspect the physical properties of raw materials and cast or forged parts. Functional tests are done to check the proper function of the parts. Wheels are tested by manual rotations.

3.3.1.8 Manufacturing tolerances

Parts are difficult to manufacture in designed sizes. So, there should be some tolerance. Tolerances may be shape, size, orientation, and position. Welding has tolerances according to their welding lengths. The following chart is indicating how tolerances differs with the weld length according to DIN standard 8570 [1].

Table 1 Permissible variation in linear dimensions for weld

Degree of accuracy	Nominal dimension range(mm)									
	30 to 120	120 to 315	315 to 1000	1000 to 2000	2000 to 4000	4000 to 8000	8000 to 12000	12000 To 16000	16000 To 20000	Over 20000
A	±1	±1	±2	±3	±4	±5	±6	±7	±8	±9
B	±2	±2	±3	±4	±6	±8	±10	±12	±14	±16
C	±3	±4	±6	±8	±11	±14	±18	±21	±24	±27
D	±4	±7	±9	±12	±16	±21	±27	±32	±36	±40

Usually, accuracy level B is used in manufacturing.

Following are some tolerances that gate dimensions up to 10m by 10m.

- Sill

  ±1mm/m and ±1.5mmin the total
- Seal seats

±1mm/m and ±1.5mmin the total

- Wheel track

  0.5mm/m and 1.5mm in the total
- Flatness of the lower edge of the skin plate

  ±1mm/m and ±1.5mmin the total
- Flatness of end vertical girders

  ±1mm/m and ±1.5mmin the total
- Flatness of seal base plates

  ±1mm/m and ±1.5mmin the total
- Variation of gate radius

  ±6mm

For gates exceeding the dimensions of more than 10m. the tolerances can be calculated by following equations.

$A = A_0(1+L/10)/2$

Where, A_0= tolerances, A_0= tolerances for 10m by 10m, L= Gate height

Figure 17 Fabrication of radial gates. ©Mueller hydro products

3.4 Analysis of Spillway gate Performance

For a long time, people used physical models to imitate the complicated water flow over a spillway. These models took a lot of time and money to create. There are other limitations of physical models, such as the effect of scaling, where they may be unable to capture behaviour such as cavitation and Surface tension readily. It was also hard to test and visualize different situations and understand the effects of turbulence.

But now, we can learn about how water behaves over a spillway quickly without having to building expensive, and time-consuming physical models with the help of computer models. This technology is called Computational Fluid Dynamics (CFD). It is a branch of fluid mechanics that solves flow problems using numerical methods [4]. Researcher will have validated this by comparing the results from CFD with those from physical models to see how well they match up.

3.4.1 Theory and basic equation regarding CFD.

The governing equation of CFD is fundamental physical principles equation of fluid dynamics [4]. Mass conservation, momentum and energy show the conservation form of the partial differential governing equations. In a fluid dynamic state, the continuity equation is the mass rate that enters a system compared to the mass rate that leaves the system and the mass accumulation in the system. Although a fluid element's shape and volume change as it moves, its mass remains constant because its mass changes at a constant rate (conserved mass) as it moves along the flow.

The conservation equation or continuity equation is considered as below.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \left(\rho \vec{V}\right) = 0$$

where, ρ- fluid density (kg/ m3). t - time (s), $\vec{V}$ - velocity vector(m/s).

The second governing equation is a momentum equation. The momentum equation expresses Newton's second law; it involves relating the sum of the forces acting on a fluid element to its acceleration.

❖ Geneal Navier-stokes governing equation shown as below,

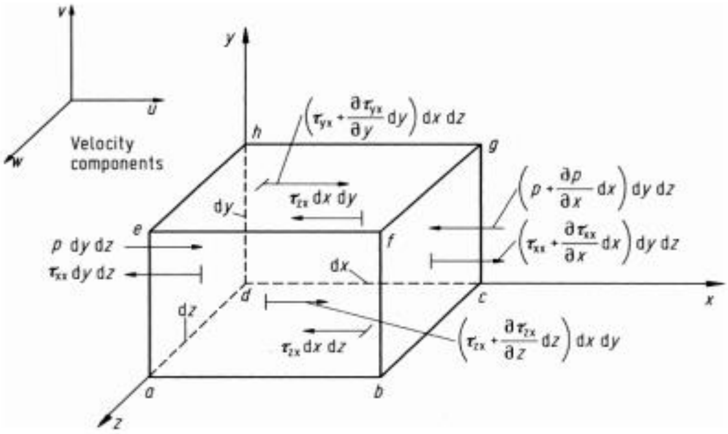


Figure 18 Infinitely small, moving fluid element [1].

$$\rho \frac{Du}{Dt} = -\frac{\partial p}{\partial x} + \nabla.\left(\mu(\nabla u)\right) + S_{Mx}$$

$$\rho \frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + \nabla.\left(\mu(\nabla v)\right) + S_{My}$$

$$\rho \frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + \nabla.\left(\mu(\nabla w)\right) + S_{Mz}$$

❖ The fluid can be taken as a Newtonian fluid for a hydrodynamic problem. Stokes in 1845 obtained the following equation for Newtonian fluids.

$$\tau = \lambda \nabla.\vec{V} + 2\mu \frac{\partial u}{\partial X}$$

where: (μ) is a viscosity coefficient and (λ) is a bulk viscosity coefficient.

3.4.2 Case study of Karkheh Dam spillway radial gate

Below analysis on this topic was a case study of Karkheh Dam spillway radial gate done by in the analysis of the topic, a case study on the radial gate of the Karkheh Dam spillway was conducted by Faridmehr et al. [4].

(a) (b)

Figure 19 Primary radial gate components of Karkheh Dam (a) truss and skin plate, (b) trunnion beam [4].

3.4.3 Finite element simulation

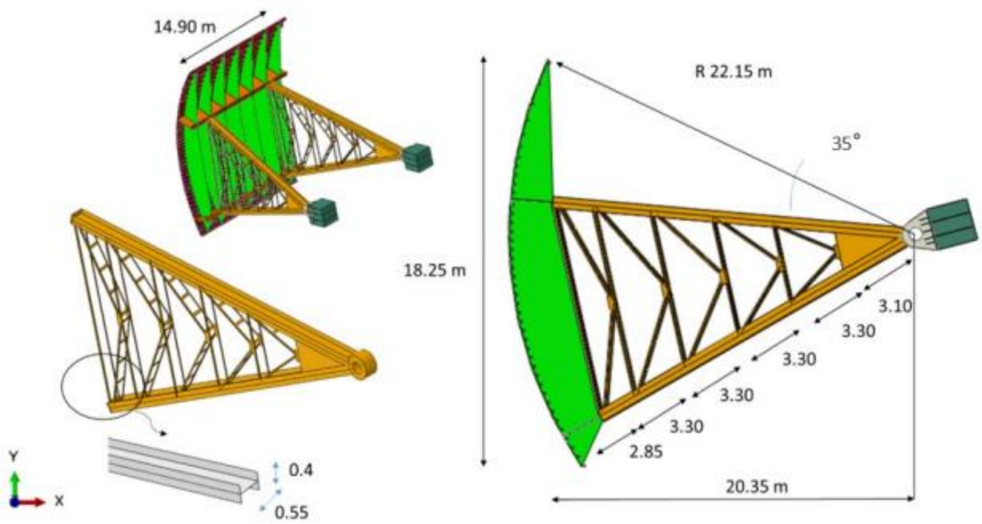


Figure 20 dimensions of skin plate and arms [4]

The model has over 485 components and it tells you geometrical complexity of structure. The thickness of skin plate taken 2mm less than due to corrosion. To generate solid part of 3D model, the shell element with 4 nodes and reduce integration point ability used. Mesh quality was evaluated based on geometrical criteria (e.g., element aspect ratio, element skew angle, minimum, and maximum angle of the element).

3.5 Vibration analysis on the design of a radial gate

3.5.1 Vibration analysis introduction

Vibration is the important factor in the design and analysis of any engineering structures. Damping vibrations in mechanical structures is crucial for several key reasons. Firstly, it helps to preserve the structural integrity of the components. Excessive vibrations can lead to material fatigue and structural failure and stress, potentially. It ensures the structural stability and durability of operations. In machinery and precision instruments, vibrations can disrupt accuracy and efficiency.

Gate vibration can be a big problem in controlling water flow through gates. It can lead to damage and stop gates from working as they should. Sometimes, these vibrations only show up many years after the gate was first used [3]. Even when we know about the conditions that can cause the vibrations, it is tough to recreate them for study. Sometimes, it seems like everything is okay, but a small disturbance in the water can start the vibrations, making them get worse over time.

This session includes the issue and some ideas on how to design gates to prevent these vibrations and some case studies. Some gates have things that could make them vibrate, but they still work fine. This could be because the forces causing the vibrations are small, or the conditions that trigger the vibrations haven't happened yet. It is important to note that gates with the same design may behave differently when they are used in different places or at different sizes. Most research on gates focuses on this vibration issue because it is a common reason why gates don't work properly.

There are three main types of gate vibrations [3].

1. Extraneously induced excitation
2. Instability induced excitation.
3. Movement-induced excitation

Recent evaluations of the safety of several gates have brought to light a concerning issue. It has been observed that the arms of raised radial gates on these dams may become partially submerged during extreme flow events that exceed the originally anticipated design flood levels for the dam. To address this problem, different design solutions have been proposed to reinforce and secure the radial gates. However, a significant concern is the potential for flow-induced vibrations [1].

During severe flood conditions, the flow near the gate arms can become high-velocity and create free-surface flows that strike the arm beams at a steep angle. Traditional hand calculations, typically used to predict vibrations, are not well-suited for this specific situation. Moreover, there is a lack of available published data that considers the unique combination of these flow conditions and the geometry of the gate arms.

To address this knowledge gap, an extensive study was carried out using Computational Fluid Dynamics (CFD) modelling to explore the potential for vibration around the radial gate arms at Wyangala Dam.

Influence of different openings on flow-induced vibration response of radial gate

Gate vibration changes with the different levels of openings. When the gate is 10% open, the highest vibrational response peak is observed at the centre of the gate's bottom edge.

Displacement and vibration are showing a non-pattern change with different gate openings.

The acceleration response follows a similar pattern, Maximum displacement and acceleration occurring at a 50% gate opening.

The flow-induced vibration response in the gate leaf structure consistently decreases along the gate height. Furthermore, the flow-induced vibration at the midspan section of the upper and lower chord of the downstream left and right arm trusses is lower than the gate leaf structure.

The Maximum of the flow-induced vibration follow a complex pattern as the gate opens and closes, and there is no clear trend related to gate opening. In light of these findings, it is advisable to calculate and manage flow-induced vibration responses during the design, operation, and maintenance of radial gates to prevent the accumulation of damage due to long-term micro-vibrations and to safeguard the gate's integrity [4].

3.5.2 Vibration analysis case study with computer model

Case study

Hydrodynamic forces act on the radial gate fluctuate with time as in the water-induced pressure time history is shown with different opening positions. With the hydrodynamic forces flow flow-induced vibration and displacement also change. By applying the time history of the dynamic forces to the model, vibration characteristics can be obtained.

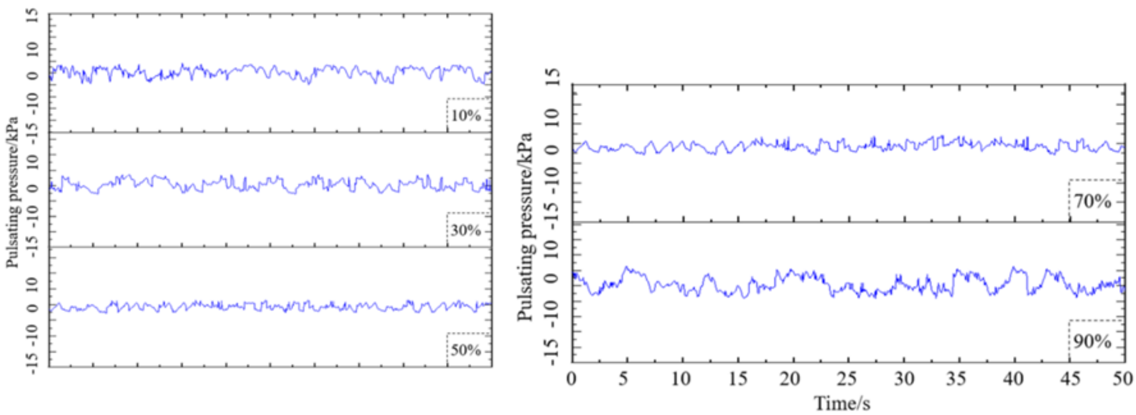


Figure 21 Dynamic load history [4]

When taking 10% opening as an example nephograms of structural displacement responses in X, Y, and Z directions, and the nephogram of total displacement response are as shown in the **Error! Reference source not found.** below.

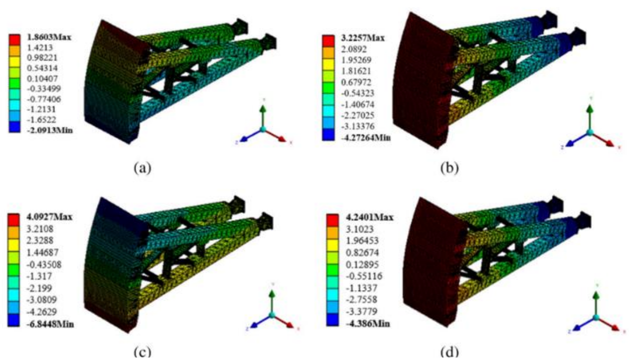


Figure 22 Nephogram of Displacement [4]

4. Progress of the project

4.1 Field visits and meetings in person to gain knowledge on dam radial gate.

During our visit to the Irrigation Department's hydrology branch, we acquired insight into their approach to dam construction and the various types of dams utilized. We learned about the criteria involved in selecting suitable sites for dam construction. Additionally, they elaborated on the significance of spillways for dams and the procedural aspects of spillway design. They mentioned referencing a military book for designing spillways and various spillway types including ogee and labyrinth spillways.

Furthermore, they provided detailed information on the utilization of dam spillway gates, highlighting different types such as flat gates and radial gates, which are predominantly used in Sri Lanka. We were briefed on the essential components of these gates and the consideration of loads acting on radial gates during the design process.

According to Irrigation department they are doing static structural analysis of radial gate and unable to do a for dynamic analysis. They mention practical difficulties on conducting experimental analysis of dynamic cases, also they wished to know about our project outcome they suggested to find different sequences of radial gate opening.

Figure 23 Meeting with Irrigation Department, Hydraulic Laboratory

We visited the Iraniamdu Dam and Maintenance department of the dam. where we meet the engineers and technicians, from them we got information about the function of dam components, materials of gate and spillway, manufacturing methods and gate operation process during flood time. we analysed about the radial gate and spillway structure, Got the engineering drawing of radial gate and ogee spillway, we identified the dimensions of the radial gate components such as horizontal girders, vertical girders, skin plate thickness, radial arms, and ogee shape spillway dimensions.

Figure 24 Iranimadu dam

4.2 Validating our framework

We worked on validation of our approach to solve CFD problems before starting the project because it is an important and integral part of CFD simulation framework. For the validation we decided to get match results using our approach to a research paper results, through literature we find out evaluating flow depth parameters with experimental data is enough to conclude our approach will give the right result,

The research paper we chose focuses on the Modelling of Flow Patterns over a Spillway with CFD. It serves as a case study for Haditha Dam in Iraq.

Here they build a protype of Haditha Dam in Iraq in scale of 1:110 refer Figure 25. The scaling was done using Froude number similarity and evaluate the parameters such as flow depth, pressure using piezometers. Numerical model done in Ansys fluent 2020 software; you can see numerical model with boundary conditions shown in Figure 26. They evaluate pressure and flow depth parameters using the software below we shown their results.

Figure 25 Physical model of hadith dam.

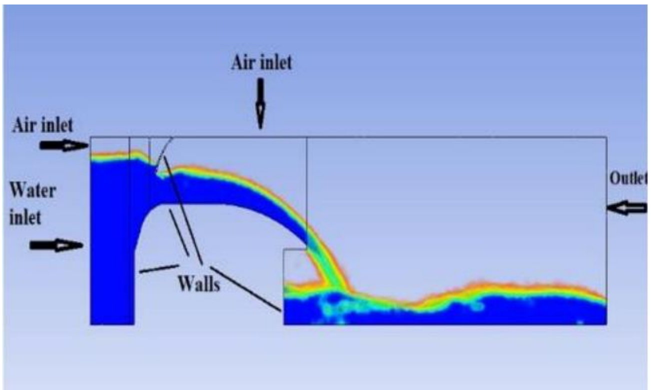
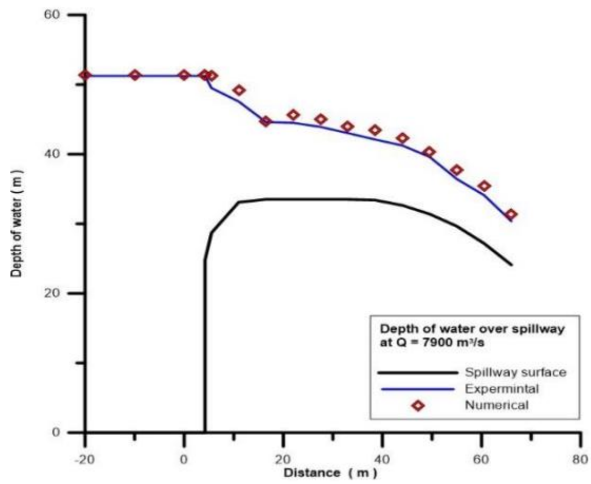


Figure 26 Boundary conditions.

4.2.1 Results of the research paper



c) discharge = 7900 m^3/s

Figure 27 Flow depth of Haditha dam.

You can see in Figure 27 flow depth parameters over the water flow. Max head was at nearly 51m. Experimental graph shown in blue and CFD graph shown in red colour points. By looking both graph you can view the experimental results and CFD results are matching, they are work done was validated.

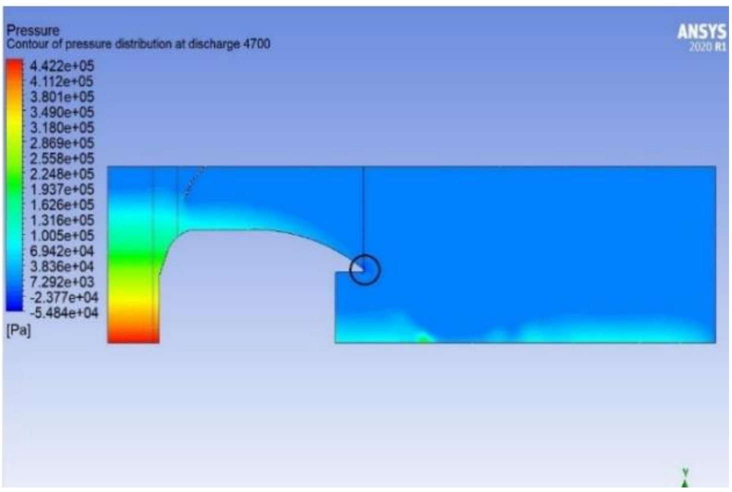


Figure 28 pressure distribution.

Pressure distribution of flow in Figure 28, in pressure you can see there is negative pressure gradient in downstream noted by circle, it can cause possible cavitation in ogee spillway structure.

4.2.2 Our approach on solving this problem.

Our approach on solving flow induced vibrations related issues come from extensive research where we use a Ansys fluent because the Realizable (k–ε) model has a more harmonic flow on surfaces with large curves, Fluent software employed it for the current study. One of the best closure turbulence models that is widely utilized in CFD modelling is the k-ε model [1].

The model for volume of fluid (VOF) has been chosen to model multiphase flows. There are two phases to the definition of air and water, primary and secondary, respectively.

4.2.2.1 Geometry creation

2D model of Haditha dam was created in SolidWorks 2020 software with its fluid domain also as you can see in Figure 29 ANSYS fluent supports Step file format so we convert it step file format then we import it ANSYS fluent,

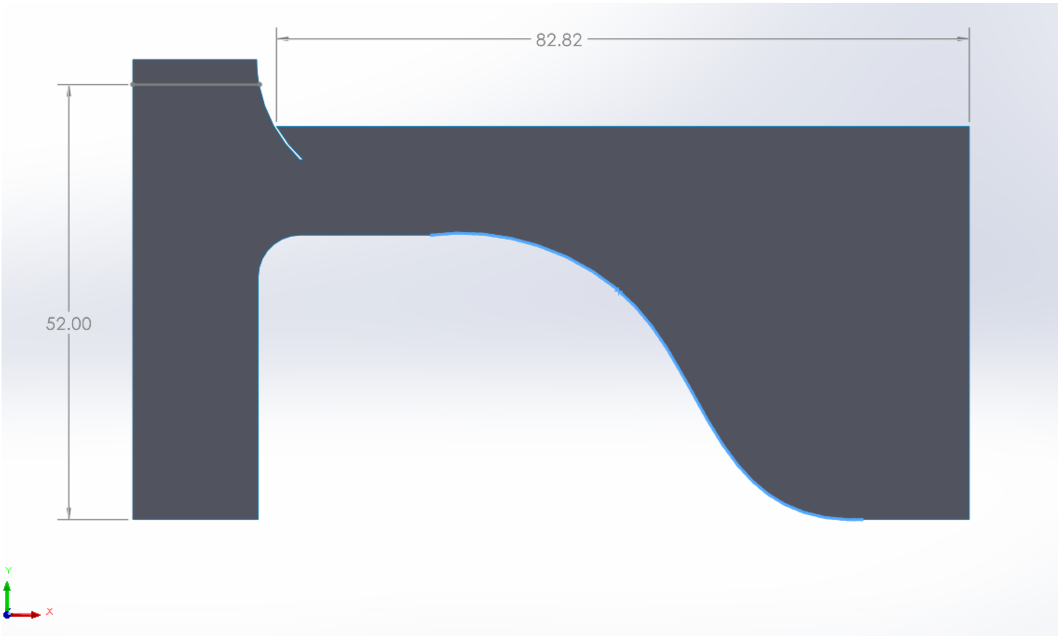


Figure 29 2D Cad drawing of Haditha dam

4.2.2.2 Mesh generation.

It is an important step in geometry construction, require considerable attention when you are doing. It is necessary to divide the domain into smaller cells to analyse the fluid movement. In essence, the cell count determines how accurate precise the solution, the finer the mesh, finer the quality. The two-dimensional meshing method offers a variety of possibilities, including triangular and quadrilateral meshing. The precision and stability of numerical computations are significantly influenced by the quality of the mesh.

The mesh metric quality criteria, as listed in the ANSYS Fluent User's Guide (2013) [11], include element quality, aspect ratio, Jacobean ratio, warping factor, parallel deviation, maximum corner angle, skewness, and orthogonal quality, all of which were found to be consistent in the current investigation.

4.2.2.2.1 Orthogonal quality

It uses an improved definition of the orthogonal quality measure, which incorporates several quality measures, such as a metric for identifying poor cell shape at a local edge and the orthogonality of a face with respect to a vector between the face and cell centroids. There is a range of -1 to 1. In a perfect world, the orthogonal quality approaches 1, but for a cell to be considered valid, its quality must exceed 0. The range of orthogonal quality levels and the accompanying cell quality are listed in the following tables.

Table 2 Recommended Orthogonal Quality Ranges and Cell Quality

Orthogonal quality	Cell quality
1	Orthogonal
0.9<1	Excellent
0.75-0.9	good

4.2.2.2.2 Skewness

One of the main criteria for evaluating a mesh's quality is its skewness. Skewness measures how close a face or cell is to being ideal, or equilateral or equiangular. A number of 0 denotes an equilateral cell (highest quality), while a value of 1 denotes a fully degenerate cell, according to the definition of skewness. Nearly coplanar nodes are a characteristic of degenerate cells, also known as slivers. Invalid cells have a skewness value greater than 1. Avoid using highly skewed faces and cells as they can produce less accurate results than using faces and cells that are roughly equilateral or equiangular.

Table 3 Recommended Skewness Ranges and Cell Quality

Skewness	Cell quality
1	Degenerate
0.9<1	Bad
0.75-0.9	poor

4.2.2.2.3 Aspect ratio

Aspect ratio, the longest edge length divided by the shortest edge length is known as the aspect ratio of a face or cell. The degree to which a face or cell approaches perfection can also be ascertained using the aspect ratio.

The aspect ratio of an equilateral face or cell is 1. Examples of these include equilateral triangles, squares, and so forth. Because the lengths of the edges vary, the aspect ratio for less consistently formed faces or cells will be greater than 1.

Figure 30 shows our generated mesh for the hadith dam fluid domain structure in Ansys 2021 software and.

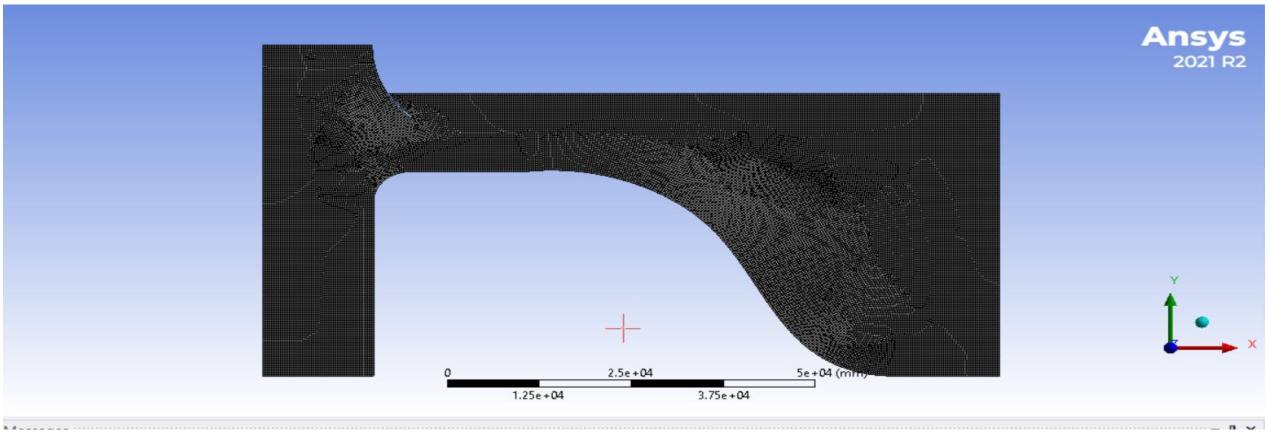


Figure 30 Mesh generation of hadith dam.

The mesh quality of our generated mesh is listed below as tables.

Table 4 Aspect ratio quality

Mesh metric	Aspect ratio
smoothing	Medium
Min	1.
Max	2.4728
Average	1.0493
Standard deviation	7.4622e-002

Recommended aspect ratio should be near equal to 1, in our case we able to reach it.

Table 5 Skewness

Mesh metric	Skewness
smoothing	Medium
Min	8.0345e-009
Max	0.62618
Average	4.3471e-002
Standard deviation	7.2501e-002

Here recommended value less than 1, in our case it's less than 1.

Table 6 Orthogonal quality

Mesh metric	Orthogonal Quality
smoothing	Medium
Min	0.64301
Max	1.
Average	0.99327
Standard deviation	2.059e-002

Here recommended value is 1, we get close to 1.

By referring Ansys fluent guidebook, our mesh quality is good enough to carry forward to next step. In the setup region Transient case was selected, multiphase was set on VOF method was selected, the water and air selected as materials then boundary conditions were set, the conditions are explained below.

4.2.2.3 Boundary conditions

The outcomes of domain simulation are significantly influenced by the accuracy of boundary conditions. Boundary conditions refer to the boundaries of the flow, both input and output, which must be established along with the flow characteristics, including pressure, velocity, and turbulence parameters. Additionally depicted were the inside walls and faces that directly interact with the flow.

$$Q = C_g DL\sqrt{2gh}$$

where,

Cg = discharge gated coefficient, D = gate opening in meter, L = net length of the spillway crest, g = gravity acceleration, H = vertical distance between the total upstream head and the centre of the gate opening.

In our case $Q=7900m^{-3}$, according conservation mass, the inlet flow rate to domain and inlet to gate should be equal,

$C_g = 0.6$, D= 0.3, H=2, L=1

So, Q = 0.6*0.3*1*$\sqrt{2 * 9.81 * 2}$ = 8*1*V

$V=0.15ms^{-1}$

- For water inlet condition, we choose constant velocity inlet condition for stable fluid flow where inlet velocity calculated using above formula. Velocity was set at $0.15ms^{-1}$
- Air inlet condition set to be pressure condition with pressure equals to atmospheric pressure because it opens to air,
- Water outlet condition set to be non-backflow conditions and air outlet conditions set to equal to atmospheric pressure so that water and air can go freely.

After defining boundary conditions required animation and report files set to be save under a folder.

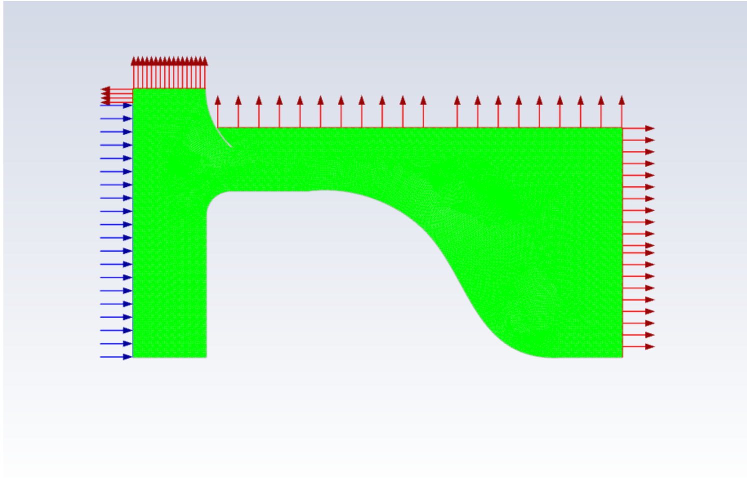


Figure 31 Boundary conditions of Hadith dam.

4.2.2.4 Time step

The discrete intervals at which the solver computes the solution during transient simulations are referred to as time steps in ANSYS Fluent. Transient simulations split time into discrete intervals known as time steps rather than solving for the entire time domain at once. The solver determines the answer at each time step by considering the existing circumstances and any changes that take place during that period.

Condition of Courant-Friedrichs-Lewy (CFL): A common method for choosing the right time step size is to apply the CFL condition. By capping the size of the time step according to the grid resolution and the velocity of physical processes in the domain, it guarantees numerical stability.

Time Step Control: ANSYS Fluent offers both automated and manual time step control options. Automatic time step control maximizes computing efficiency while preserving accuracy by modifying the time step size during the simulation depending on predetermined parameters.

So, finding the right time step is important in our simulation, time step in our case calculated using CFL condition. Max courant number = 0.25

After hybrid initialization we went to run calculation where we set time step size as and number of time steps to automatic and iteration numbers as 500, then we run the calculation solution converged.

4.2.3 Results and discussion

In the results region we created a contour to see water volume fraction and pressure distribution of flow through ogee spillway as in Figure 32and **Error! Reference source not found.**.

The current numerical model tracks the interface between the phases of water and air using the volume of fluid (VOF) model. VOF calculates the volume fraction of every mesh cell by tracking the movements of the fluid mass. Any value between 0 and 1 can be used for the fraction of phase.

Water depth or water height over the spillway, which is measured to determine the free surface flow, is another parameter used for model validation.

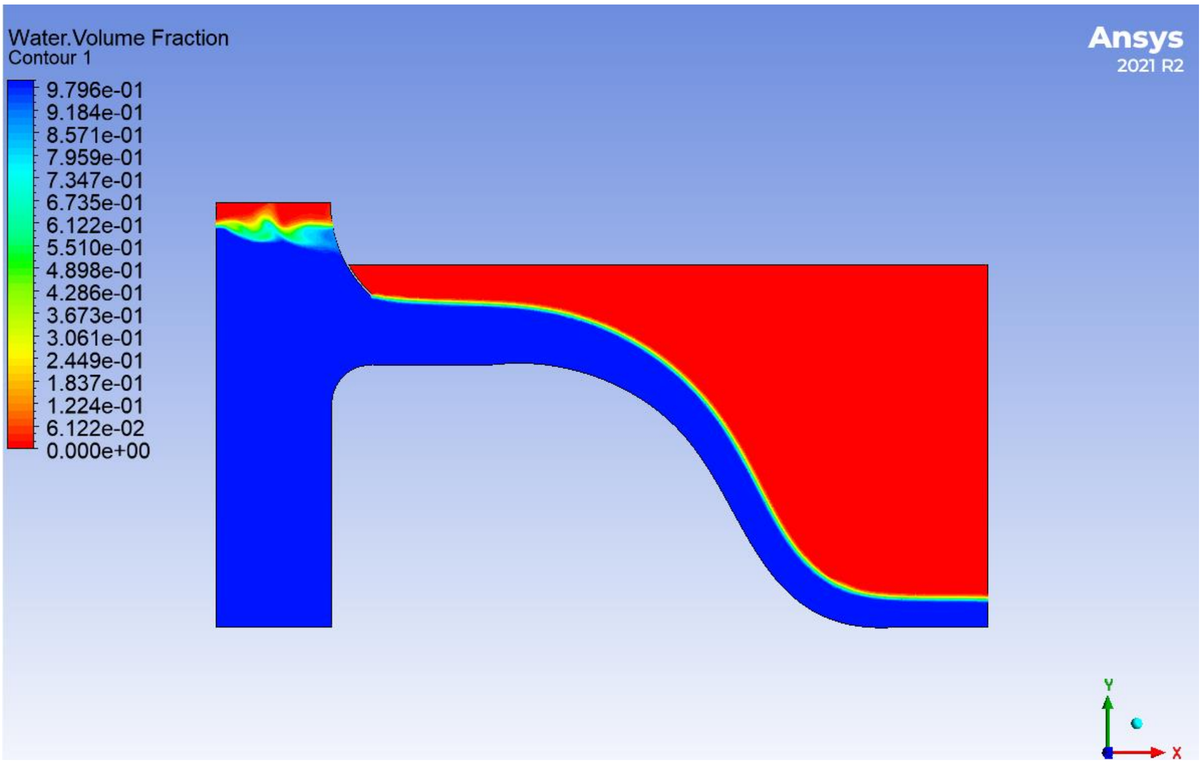


Figure 32 water volume fraction of hadith dam.

Error! Reference source not found. shows the pressure distribution as a contour line throughout the whole domain and in the vicinity of the surface spillway. Figure shows the negative pressure over the crest in the area that extends downstream from the end of the arching spillway and may have resulted in cavitation damage.

When the flow velocity is high, a process known as cavitation takes place in which vapor cavities form in a liquid. Cavitation damage can increase in the presence of cracks, uneven surfaces, ramps, and offsets.

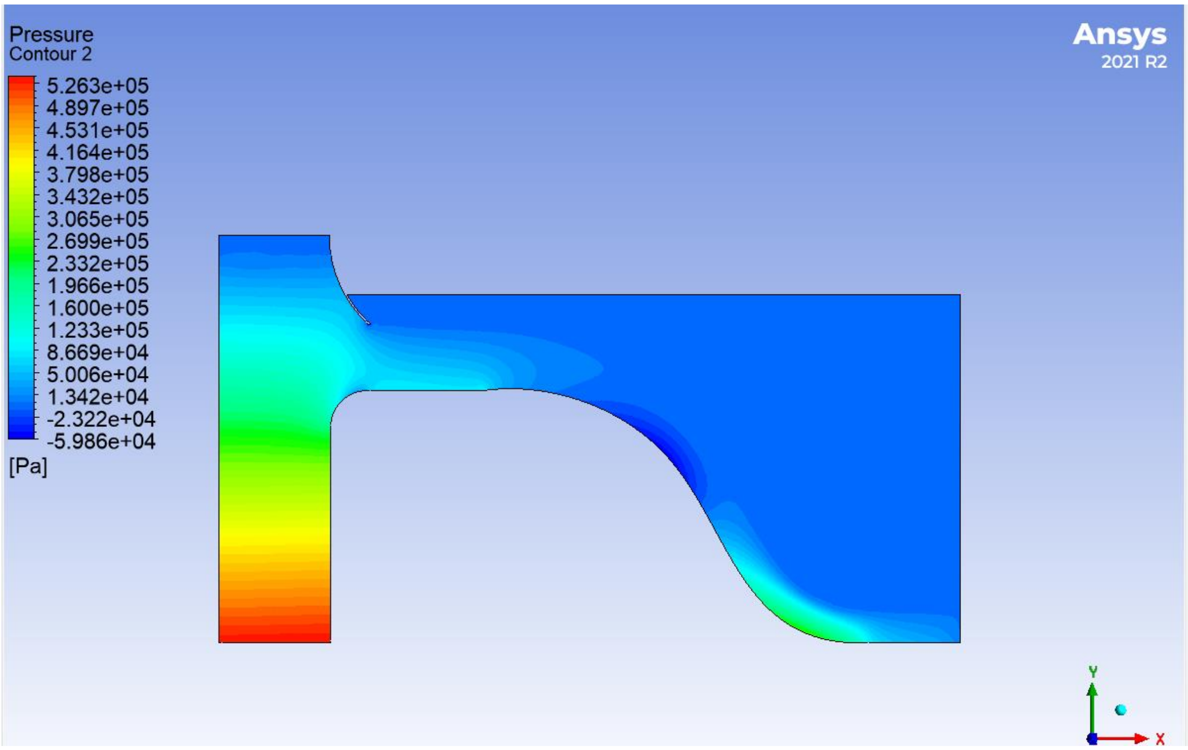


Figure 33 Pressure distribution of Haditha dam

4.2.4 Comparison with research paper.

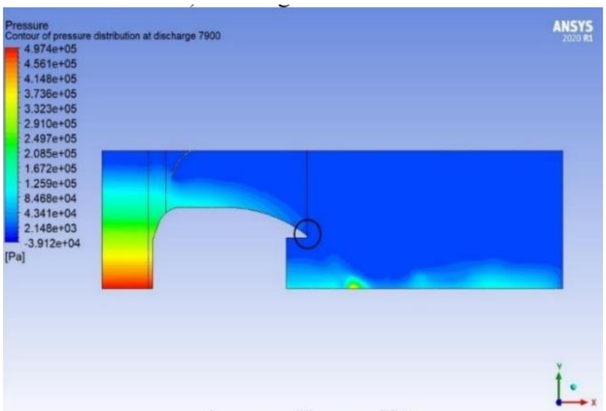


Figure 34 Pressure distribution from research paper.

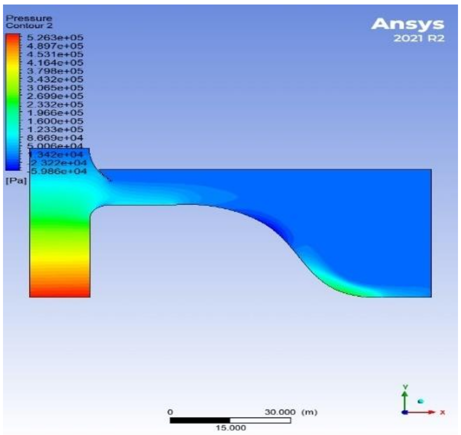


Figure 35 our pressure distribution from our work.

As you can see in Figure 34 and Figure 36, pressure distribution and flow parameters similar to research paper, and our CFD result also show possible cavitation in the same region as they research paper identified. So, with these results we can conclude our approach has been right.

So, we can apply this method to our final year project to study Kilinochinchi Iranimadu dam radial gate.

4.3 Kilinochchi Iranamadu dam VIV analysis

We decided to do simulation for vortex induced vibrations and finding natural frequencies of radial gate with the help of above information we got. We decided to use Ansys fluent to simulate vortex induced vibrations of Kilinochchi Iranamadu dam and Ansys structural analysis used to find the natural frequencies of radial gate structure. Ansys Fluent is a robust numerical modelling programme that can handle a wide range of fluid problems. Ansys Fluent use the finite volume technique (FVM) to solve the 3D RANS equations, and continuity.
From literature we found out during gate opening operation, high velocity and potential vortex creation can be observed in small gate openings. So, we also get into simulation began with a

small opening and high upstream head for the water because if we proved for worst scenarios then won't be problem for other scenarios.

But for this time being we did this simulation with 2d model of kilinochi irainmadu dam as 3D model to run we need hight performance computers which we requested yet to get so, we did with our limited resources.

4.3.1 Geometry creation

First through this information we get from Kilinochi dam, a 2D CAD design of the radial gate with ogee spillway structure was created in SolidWorks 2020 software and fluid domain also created their fluid domain parameters can be seen in Figure 36.

Figure 36 Solid Work file of Kilinochchi Iranamadu dam spillway.

4.3.2 Mesh generation.

Cad file is imported into Ansys Fluent as step file as explained above, then the solid part was meshed with an element size of 200mm, we used edge sizing to make it as fine mesh in surface of gate and bottom surface of gate because to capture eddies near gate bottom surface we need fine mesh and then included inflation to make the mesh more quality, we check mesh quality through mesh metric skewness ratio is average of 0.13, element quality is 0.80117 which is less than 0.9, so with these parameters we can say our mesh generation is good quality.

Mesh statists are 5745 elements and 5982 nodes. Named sections were used to define to represent the inlet, outlet, and walls of the structure.

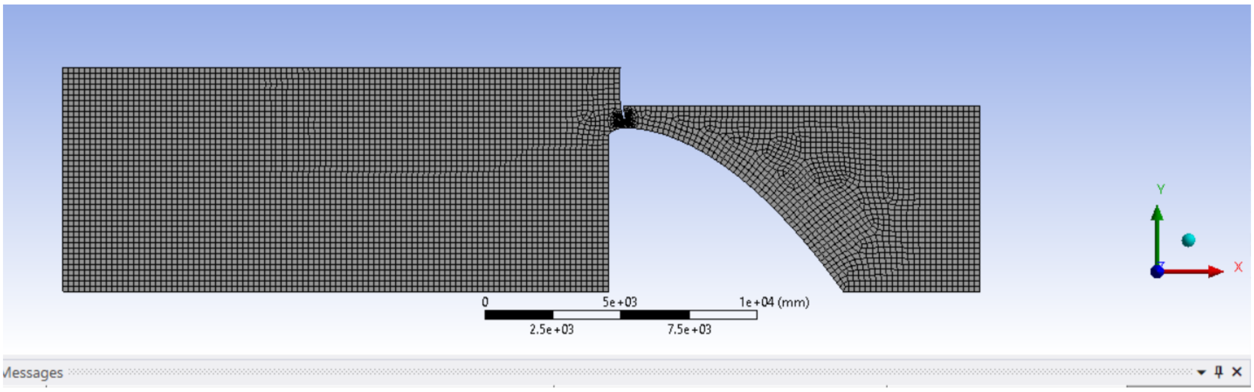


Figure 37 mesh of Kilinochchi Iranamadu dam

4.3.3 Ansys fluent setup

In the setup region, transient case was chosen because we need force paraments such as drag force and lift force fluctuating with time so to capture it we need transient case, gravity was selected with downward direction of $9.81ms^{-1}$

then water specified as the fluid with properties such as a density of 998.2 kg/m^3 and a constant viscosity of 0.001003 kg/ms. The model utilized a multiphase volume of fluid open channel flow approach, where phase I represented air and phase 2 represented liquid water. A constant surface tension coefficient of 0.073 N/m was assigned for both water and air. The SST k-epsilon viscous model was adopted to account for turbulence effects. Boundary conditions were defined to accurately simulate the real-world scenario.

$$Q = C_g DL\sqrt{2gh}$$

By using the same formula,

$C_g = 0.6$, D= 0.3, H=2, L=1

So Q = 0.6*0.3*1*$\sqrt{2 * 9.81 * 2}$ = 8*1*V

V=$0.15ms^{-1}$

4.3.3.1 Boundary conditions applied.

- For water inlet condition mixture velocity inlet was used with an initial velocity of 0.15 m/s.
- For air inlet condition, pressure outlet condition used with external pressure equals to atmospheric pressure.
- Water outlet condition set to be non-backflow conditions.
- Air outlet conditions set to equal to atmospheric pressure.
- atmospheric pressure at the pressure outlet, and walls defined as the pier surface.

Hybrid initialization was performed, and then move into calculation option,

4.3.3.2 Calculation

Time step < min mesh size/ velocity of fluid travel

$< \quad 15mm/0.15ms^{-1}$

After input the time step size we need to define number of time steps and max iteration per time step, we should give enough steps for solution to converge, we input number of time steps as 20000 and max iteration as 30. Then calculation was made to run, after solution converged, we got the results, we created the contours to see pressure and velocity distribution along the water flow. Subsequently, attempts were made to simulate possible vortex creation in the flow.

Calculation was run for about 24hrs, solution converged we get a simulation of 25s. in results region we created pressure, velocity, and water volume fraction contours.

4.3.3.3 Results and discussion

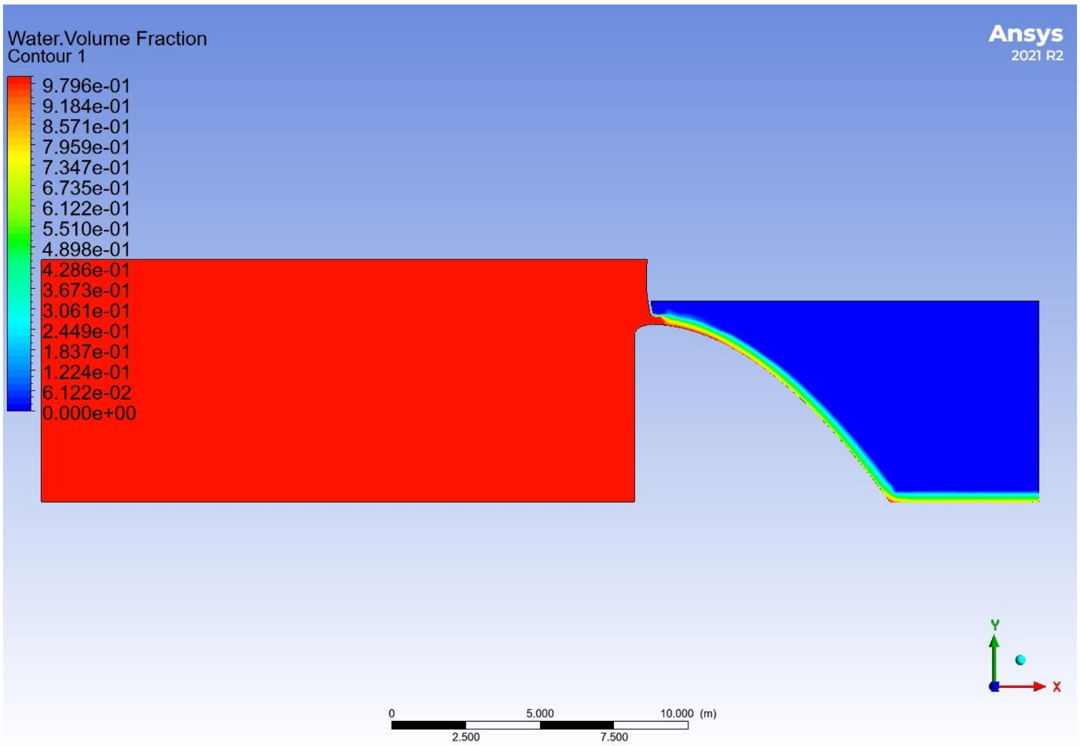


Figure 38 Water volume fraction of Kilinochchi Iranamadu dam

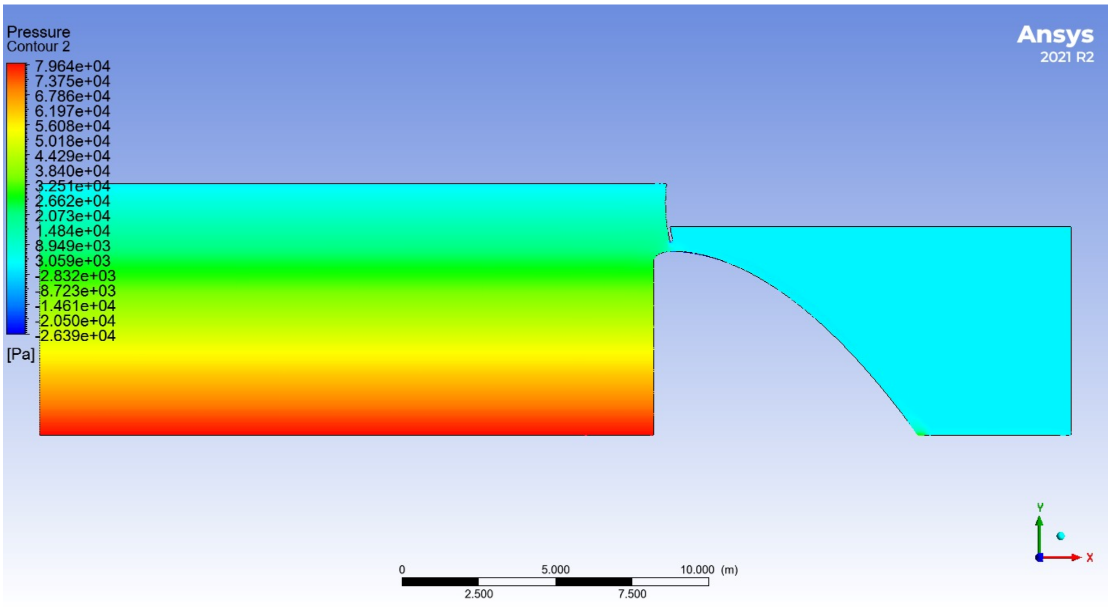


Figure 39 Pressure distribution of kilinochchi dam

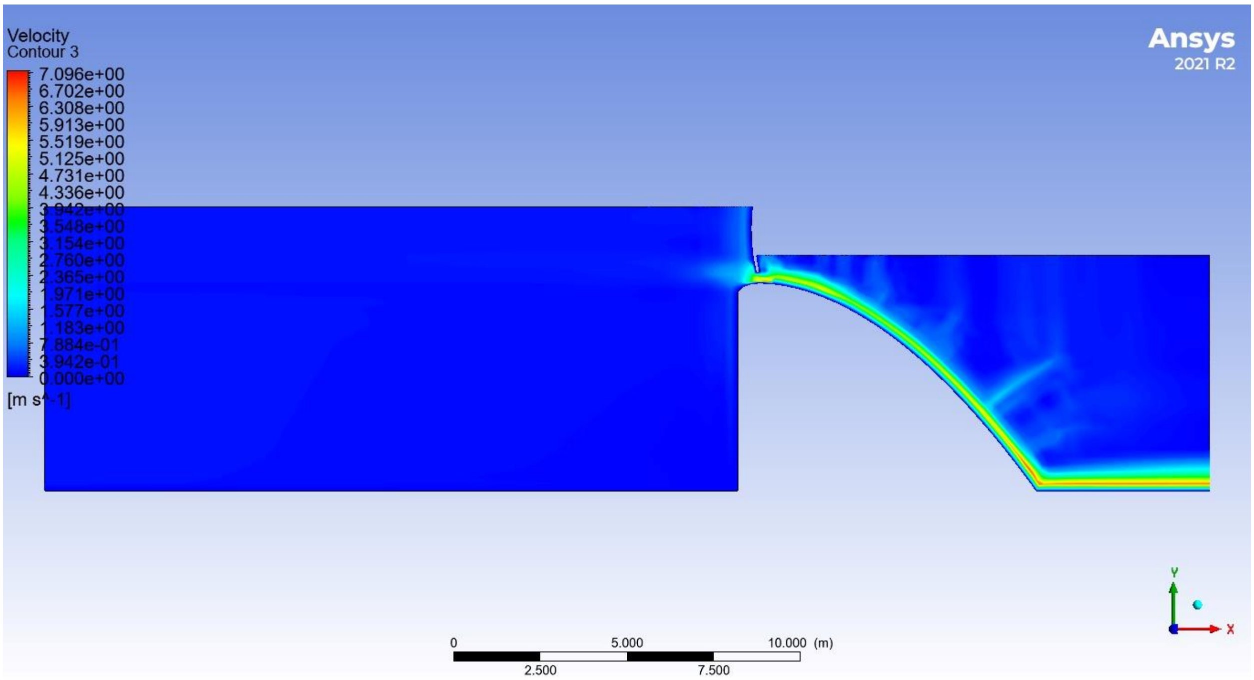


Figure 41 velocity distribution.

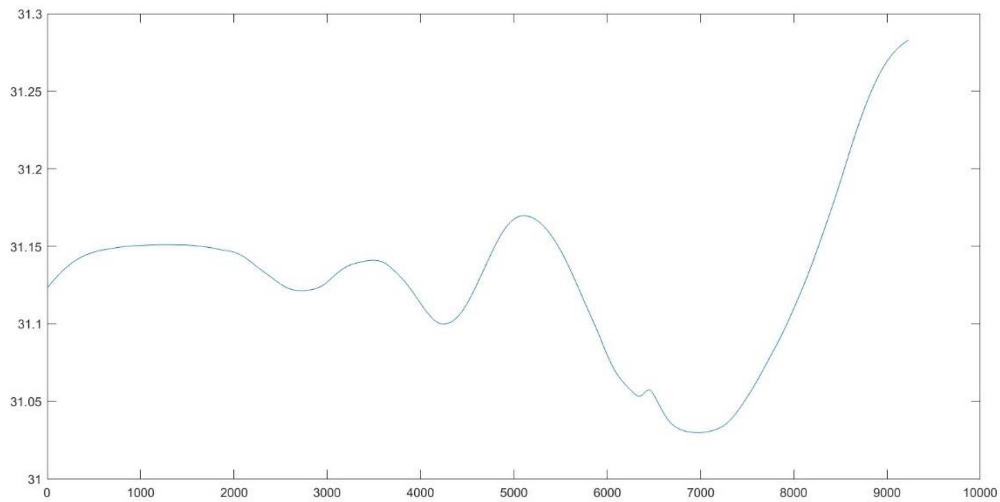


Figure 40 lift coefficient value vs time graph.

Discussion

We have obtained pressure and velocity distributions from the results. Upon observation, we have identified no negative pressure gradient, indicating the absence of cavitation issues.

For the vortex-induced vibrations analysis, we require fluctuations in lift and drag forces near the gate. Our results depict a graph of lift coefficient varying with time, demonstrating noticeable fluctuations. However, the oscillatory nature of vortex shedding fluctuations necessitates a longer observation time to reach a steady state. Ideally, we would need results for more than 20 minutes. Presently, due to resource limitations, our observations are restricted to 25 seconds. Nevertheless, we anticipate conducting simulations on a high-performance computer in the near future, enabling simulations for durations exceeding 20 minutes."

4.4 Static Analysis of radial gate

Static analysis is a fundamental engineering technique used to evaluate the structural behaviour of mechanical components under static loading conditions. In the context of radial gates, which are critical for controlling water flow in hydraulic structures such as dams and irrigation systems, static analysis helps engineers ensure the gate's stability and integrity under the forces exerted by water pressure and other environmental factors.

For radial gates, static analysis involves assessing the distribution of forces and stresses acting on the gate structure when it is in an equilibrium state. This analysis considers factors such as the weight of the gate, hydrostatic pressure exerted by the water, and any additional loads imposed by operating conditions or external forces. By calculating the internal forces and deformations within the gate structure, engineers can determine whether it can withstand the applied loads without exceeding its strength or causing excessive deflections.

In static analysis, equilibrium refers to the balance of forces and moments acting on a structure, where the sum of all external forces and moments equals zero. For a radial gate, equilibrium is achieved when the forces exerted by water pressure, gate weight, and any applied loads are counteracted by internal reactions within the gate structure. Ensuring equilibrium is essential for maintaining the gate's stability and preventing unintended movements or deformations.

Stress analysis involves evaluating the distribution of internal stresses within a structure in response to applied loads. In the case of radial gates, stress analysis helps engineers assess the strength and durability of the gate components, such as the gate leaf, trunnion, and supporting structure. By calculating the magnitude and distribution of stresses, engineers can identify potential areas of concern, such as regions experiencing high stress concentrations or approaching the material's yield strength.

The factor of safety is a measure of how much stronger a structure is compared to the maximum loads it is expected to experience during its intended service life. In static analysis, engineers typically design radial gates with a factor of safety to ensure that they can withstand the anticipated loads without failure. By considering factors such as material properties, loading conditions, and environmental uncertainties, engineers can determine an appropriate factor of safety to mitigate the risk of structural failure.

Static analysis plays a crucial role in the design, analysis, and maintenance of radial gates across various engineering applications. During the design phase, engineers use static analysis to optimize the gate's geometry, material selection, and reinforcement to ensure it can withstand the expected loads while minimizing weight and cost. By conducting parametric studies and finite element analysis, engineers can iteratively refine the gate design to meet performance and safety requirements.

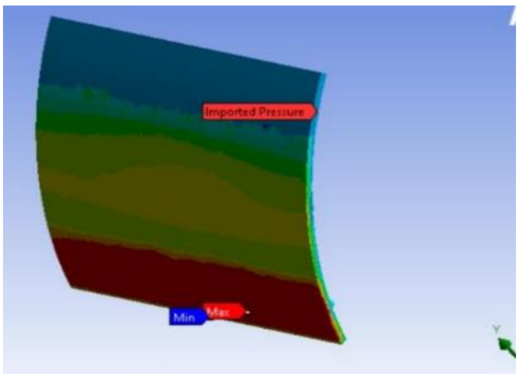


Figure 42 Hydrostatic pressure on skin plate

In the operational phase, static analysis helps monitor the condition of radial gates and measure their structural health over time. By periodically inspecting the gate components and conducting structural assessments, engineers can identify any signs of deterioration, fatigue, or damage that may compromise performance or safety.

4.4.1.1 Natural Frequency

Natural frequency is a fundamental concept in engineering dynamics, representing the inherent vibrational frequency of a system. For radial gates, which are commonly used in hydraulic structures to control water flow, understanding their natural frequency is crucial for assessing their dynamic behaviour. The natural frequency of a radial gate is influenced by several factors, including its mass distribution, stiffness, and geometrical characteristics.

In the context of a radial gate, natural frequency can be visualized as the frequency at which the gate vibrates when subjected to external disturbances, such as fluctuations in water pressure or flow rates. This vibration occurs due to the gate's tendency to oscillate about its equilibrium position, driven by the forces acting on it. The magnitude of the natural frequency depends on the stiffness of the gate structure and the mass distribution, with stiffer gates typically showing higher natural frequencies.

4.4.2 Modal Shapes

Modal shapes, also known as mode shapes or eigenmodes, are patterns of vibration exhibited by a mechanical structure at its natural frequencies. In the case of radial gates, modal shapes describe the spatial distribution of displacements and deformations across the gate's surface during vibration. Each natural frequency of the gate corresponds to a specific modal shape, illustrating how different parts of the gate move relative to each other.

Modal shapes are characterized by nodal lines, which represent points of minimum displacement, and anti-nodal regions, where the amplitude of vibration is maximized. These patterns provide valuable insights into the dynamic behaviour of radial gates, highlighting areas

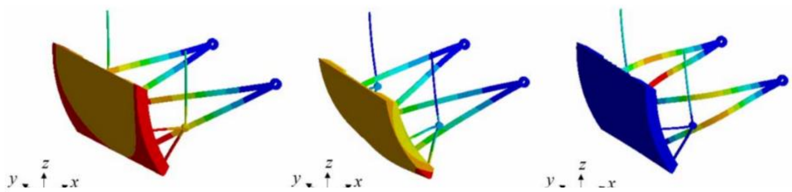


Figure 43 Different mode shapes obtain for a case study

of potential stress concentration or weakness to fatigue failure. By analysing modal shapes, engineers can identify critical modes of vibration that may need to be addressed in the design or operation of radial gates.

4.4.3 Modal Analysis

Modal analysis is a computational technique used to determine the natural frequencies and corresponding modal shapes of a mechanical system. In the context of radial gates, modal analysis involves mathematical modelling and numerical simulations to predict the vibrational response of the gate structure under various loading conditions. By solving the equations of motion for the gate and considering its boundary conditions, engineers can calculate the natural frequencies and modal shapes that characterize its dynamic behaviour.

Modal analysis allows us to assess the dynamic characteristics of radial gates and identify potential resonance frequencies that may lead to structural failure. Resonance occurs when the frequency of external excitation matches one of the natural frequencies of the gate, resulting in amplified vibrations and potential damage. By understanding the natural frequencies and modal shapes of radial gates, design gates that exhibit stable dynamic behaviour across a range of operating conditions, minimizing the risk of resonance-induced failures.

The knowledge of natural frequency and modal analysis has several practical applications in the design, analysis, and maintenance of radial gates. For example, in the design phase, engineers can use modal analysis to optimize the structural configuration of the gate to achieve desired natural frequencies and modal shapes. By adjusting parameters such as material properties, geometric dimensions, and support conditions, engineers can design the gate's dynamic response to meet specific performance requirements.

During the operational phase, modal analysis can be used to monitor the condition of radial gates and detect any changes in their dynamic behaviour. By comparing measured modal parameters, such as natural frequencies and modal shapes, with baseline values obtained during the design phase, engineers can identify potential issues, such as structural degradation or fatigue damage, and take corrective actions before they go into serious problems.

Modal analysis can inform the development of maintenance and inspection protocols for radial gates, helping prioritize maintenance activities based on the criticality of different modes of vibration. By focusing resources on monitoring and modifying the most significant modes of vibration, engineers can optimize the reliability and longevity of radial gates, ensuring their continued safe and efficient operation.

4.5 Case study Vibration analysis of spillway radial gate of Kilinochchi Iranamadu dam

Vibration analysis is also one of a major aspect of our project. Vibration can be occurring mainly two ways in our case. First one is because of the vortex creation by partially open gate and the second one is by partially submerged radial arm. Vibration occurs when the natural frequency of the gate and frequency of the dynamic forces are equal. It will cause resonance and damage the gate structure.

We are doing the gate analysis for lower Iranamadu dam spillway radial gate. We have visited Iranamadu dam and got the gate dimensions from the Iranamadu region of irrigation department. Gate was designed and the natural frequency was found.

Figure 44 The Radial gate from Iranamadu Dam

By referencing the drawing, we got from Engineers SolidWorks model has developed.

Soid works model before simplification is given in Figure 45.

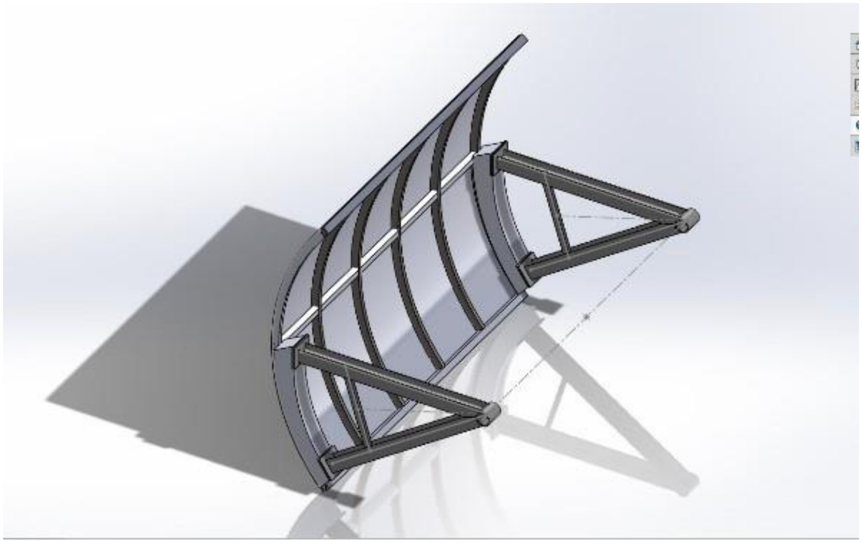


Figure 45 SolidWorks model of the gate.

All the design aspects in the gate are no need in analysis and if it is there is required high computational power. We keep design simply with beams and plate for the analysis.

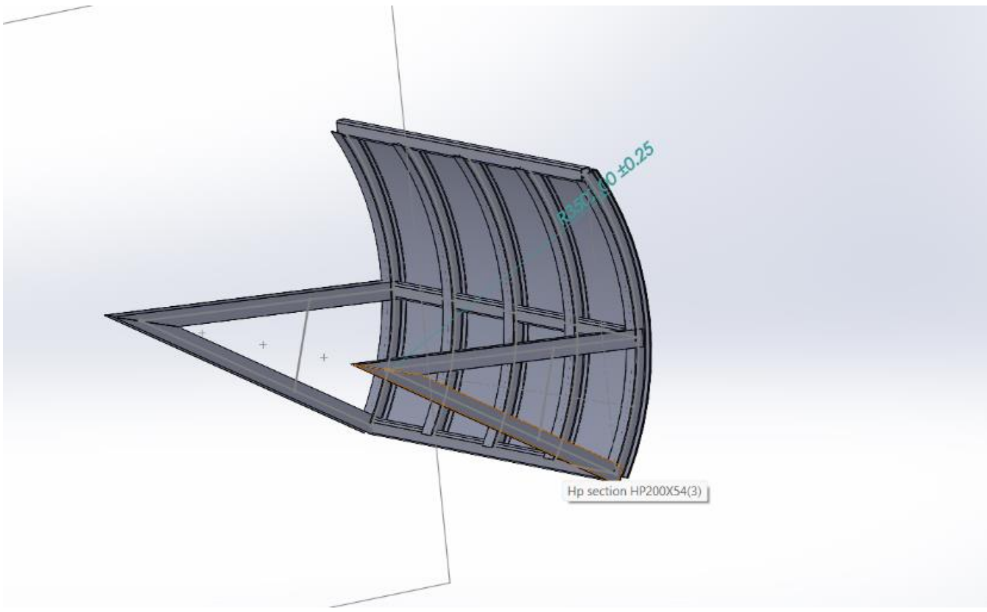


Figure 46 Simplified model

Simulation was done with 5 mode shapes as in Figure 47.

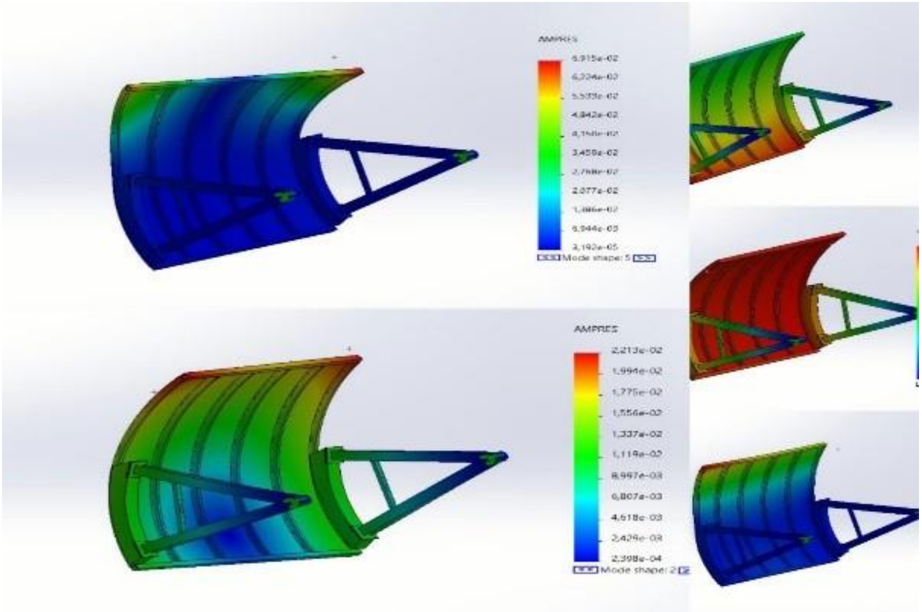


Figure 47 Mode shapes

Following Table 7 contains frequency details we got from the simulation.

Table 7-Natural frequency values

Mode No	Frequency (Rad/sec)	Frequency (Hertz)
1	8	1.27
2	14	2.22
3	24	3.81
4	43	6.84
5	69	10.98

Here is the mesh and mesh details with auto mesh with high element size of 338 mm and low element size 16mm. Gate is with radius of 3420mm and width of 5420 mm.

Before inserting the model to Ansys, it is better to modify in SpaceClaim. Here is the model that modified in Ansys SpaceClaim in Figure 48.

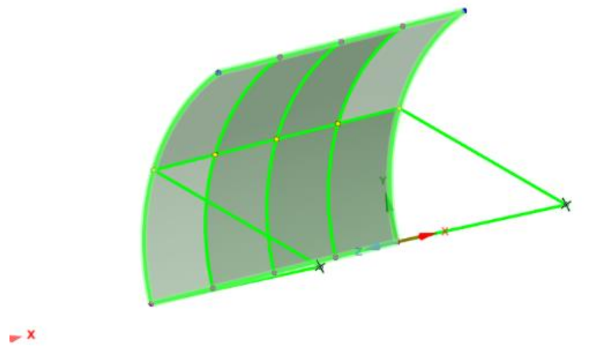


Figure 48 Space claim model

After that SpaceClaim model is imported into ANSYS and mesh has done with 0.2m element size.

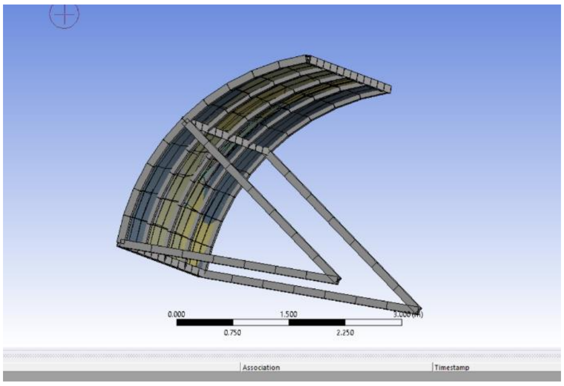


Figure 49 Ansys meshing.

We are working on to find the excitation frequency and natural frequency in Ansys. In the Final version of this report, Natural frequency of the gate structure will be compared with excitation frequency to check the existing of resonance in the gate operation .

If natural frequency of gate is less than the actual frequency gate should be modified to increase the natural frequency by analysing the strain density. Natural frequency can be increased by controlling stiffness and mass.

References

[1] A. S. Almawla, A. H. Kamel, and A. M. Lateef, “Modelling of Flow Patterns over Spillway with CFD (Case Study: Haditha Dam in Iraq),” *International Journal of Design and Nature and Ecodynamics*, vol. 16, no. 4, pp. 373–385, Aug. 2021, doi: 10.18280/ijdne.160404.

[2] Paulo C.F. Erbisti, “Design of Hydraulic Gates,” 2014.

[3] D. 20314-1000 Department of the Army U.S. Army Corps of Engineers Washington, “Engineering and Design DESIGN OF SPILLWAY TAINTER GATES,” 2000.

[4] I. Faridmehr, A. F. Nejad, M. H. Baghban, and R. Ghorbani, “Numerical and physical analysis on the response of a dam’s radial gate to extreme loading performance,” *Water (Switzerland)*, vol. 12, no. 9, Sep. 2020, doi: 10.3390/w12092425.

[5] Paulo C.F. Erbisti, “Design of Hydraulic Gates,” 2014.

[6] Bonneville Locks and Dam. [Online] Available from Wikipedia, https://en.wikipedia.org/wiki/Bonneville_Locks_and_Dam. [Accessed: October. 30, 2023].

[7] Kotmale Dam. [Online], Available from Wikipedia, https://en.wikipedia.org/wiki/Kotmale_Dam. [Accessed: November. 01, 2023]

[8] K. R. a. D. Ho, "Assessment of flow-induced vibration in radial gates during extreme flood," *WorleyParsons Services ,* 2010.

[9] J. Lewin, “Hydraulic gates and valve”, London: Thomas Telford Publishing, 2001.

[10] B. Z. &. X. Jing, "Theoretical analysis and simulation calculation of hydrodynamic pressure pulsation efect and flow induced vibration response of radial gate structure," *Scientific report,* 2022.

[11] ANSYS, Inc. and ANSYS Europe Ltd, “Ansys fluent user guide”, 2023