Government of India
Ministry of Water Resources,
River Development & Ganga Rejuvenation
Central Water Commission

Training Program on
Design of Hydro-mechanical Equipment
(Gates & Hoists)
For officials of Govt of Bihar
20-24 July, 2015

Organised by
National Water Academy, Pune
At WALMI, Patna

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National Water Academy, Pune, Maharashtra  
at  
Water and Land Management Institute, Patna, Bihar

Program Co-Ordination

Shri D S Chaskar, Director, National Water Academy, Pune &  
Shri Sanjay Kumar Srivastava, System Administrator, WALMI, Patna
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Author</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Overview of Hydro-mechanical Equipments</td>
<td>Shri D S Chaskar, Director-Designs, National Water Academy, CWC, Pune</td>
<td>01</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Design of Vertical Lift Gates</td>
<td>Shri Harkesh Kumar, Director – Gates (E&amp;NE), CWC, New Delhi</td>
<td>33</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Failure of Barrage Gates – a case study</td>
<td>Shri Harkesh Kumar, Director – Gates (E&amp;NE), CWC, New Delhi</td>
<td>60</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Hydraulic Hoist for Gates</td>
<td>Shri Harkesh Kumar, Director – Gates (E&amp;NE), CWC, New Delhi</td>
<td>74</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Calculations for design of Vertical Lift Gate and Hoist capacity for Gates</td>
<td>Shri Harkesh Kumar, Director – Gates (E&amp;NE), CWC, New Delhi</td>
<td>83</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Design of Radial Gates</td>
<td>Shri Vaseem Ashraf, Director- Gates(N&amp;W), CWC, New Delhi</td>
<td>85</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Radial Gate – a case study</td>
<td>Shri Vaseem Ashraf, Director- Gates(N&amp;W), CWC, New Delhi</td>
<td>93</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Design of Rope Drum Hoists for Hydraulic Gates</td>
<td>Shri Vaseem Ashraf, Director- Gates(N&amp;W), CWC, New Delhi</td>
<td>147</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>35t_Rope Drum Hoist- Case Study</td>
<td>Shri Vaseem Ashraf, Director- Gates(N&amp;W), CWC, New Delhi</td>
<td>158</td>
</tr>
<tr>
<td>Chapter 10</td>
<td>Flow Characteristics and Design Considerations for Hydraulic Gates</td>
<td>Dr R G Patil, Scientist ‘B’, Central Water &amp; Power Research Station, Pune</td>
<td>177</td>
</tr>
<tr>
<td>Chapter 12</td>
<td>Manufacturing and Erection</td>
<td>Shri Amit Ranjan, Deputy Director – Gates (E&amp;NE), CWC, New Delhi</td>
<td>243</td>
</tr>
<tr>
<td>Chapter 13</td>
<td>Operation and Maintenance of Gates and Hoists</td>
<td>Shri Amit Ranjan, Deputy Director – Gates (E&amp;NE), CWC, New Delhi</td>
<td>258</td>
</tr>
<tr>
<td>Chapter 14</td>
<td>Operation and Maintenance of Radial Gates</td>
<td>Shri Jayant Khade, Executive Engineer – Mechanical Circle, Water Resources Department, Govt of Maharashtra, Kolhapur</td>
<td>270</td>
</tr>
<tr>
<td>Chapter 15</td>
<td>Sealing Arrangement for Vertical and Radial Gates</td>
<td>Shri Jayant Khade, Executive Engineer – Mechanical Circle, Water Resources Department, Govt of Maharashtra, Kolhapur</td>
<td>288</td>
</tr>
<tr>
<td>Chapter 16</td>
<td>Safety Assurances of Hydro-Mechanical Equipments</td>
<td>Dr S K Srivastava, Chief Engineer, National Water Academy, Pune</td>
<td>294</td>
</tr>
</tbody>
</table>
Chapter – 1

Overview of Hydro-mechanical Equipments

Interestingly Hydro mechanical equipments i.e. Gates and their associated equipments are often not given due importance in the preparation of DPR. This results in serious anomalies in the overall planning of the project later on. The common reasons given for ignoring these vital components of project are:

1. Hydro mechanical equipments are not site specific. One size fits all.
2. Hydro mechanical equipments can be designed later on at the time of detailed planning.
3. Cost of Hydro mechanical equipments is only a small part of overall project cost.

But a designer can ignore the importance of Hydro mechanical equipments at his own peril. Their proper selection and planning is a vital part of preparation of DPR. Working group guidelines instructs that the type, size and number of gates and their hoisting be specifically mentioned in the DPR. Often these are the components of project whose trouble free performance is essential for the success and safety of the project. Progress of many projects is held up due to them. And many projects have failed (partially or wholly) due to their malfunctioning.

Hydro mechanical equipments are site specific. For example some types of Gates would not be suitable for water with heavy sediment load. For barrages the cost of Hydro mechanical equipments forms a major part of overall project cost. Sometimes an improper selection of gates makes the project cost substantially more. In today’s world of water scarcity, the importance of these equipments has increased as these regulate pond level and discharge.

A brief description of various types of Hydro mechanical equipments shall be provided in the following pages. Their design criteria and various requirements for planning shall be discussed. For further design details list of important IS codes are given in Annexure “A”. Some prevalent gate weight estimate formulas are given in Annexure “B”. It is stressed that these gates weight estimates are only approximates. For more reliable estimate it is recommended that some basic design may be carried out with along study of similar gates in existing projects.

Hydro mechanical equipments used in the Water Resources structures can be broadly categorized as:

A. Hydraulic Gates and Valves
B. Control Equipments for Hydraulic Gates and valves
   (e.g. Screw Hoist, Rope Drum Hoist, Hydraulic Hoist, E.O.T. Crane, Gantry Crane etc.)
C. Special Equipment (e.g. Trashrack, Trashrack cleaning Machine etc.)

A. Hydraulic Gates and Valves

Hydraulic Gates are structures or devices to control the flow of water as desired. These are essentially closure devices in which a leaf or a closure member is moved across the fluid way from an external position to control the flow of water. In case of valves, the closure
member is generally rotated or moved from a position within the fluid to restrict discharge passage. Viz Butterfly valve, tube valve, spherical valve etc.

Prevalent types of gates used in Dam & Barrage structures in India

- Vertical Lift Gates
- Vertical Lift fixed wheel type
- Vertical Lift Slide type
- Radial Gates

Components of Gate:

Any gate can be visualized as composed of following two parts:
A. Embedment and other fixed parts: It comprises of all those components of gate which are fixed and it includes first stage embedded parts, second stage embedded parts, sill beam, track plate, seal seats, liners, gate body, bonnets, gland stuffing box etc.

B. Gate Leaf: It is that portion of gate which moves across the fluidway in order to control it. It includes skin plate, vertical stiffeners, horizontal girder, end vertical girder or end arms, wheel / slide assembly, seal assembly etc.

A brief description of various main components of gate leaf of vertical lift gate and radial gate is as follows:

Vertical Lift Gate:
As the name implies, these gates are flat and are operated in vertical direction. They consist of a flat plate called skin plate which is supported by a system of horizontal girders and vertical stiffeners which in turn are connected to end girders and wheels or sliding pads. These wheels (or sliding pads) transfer the load to concrete through tracks embedded in it. Figure given below illustrates a typical arrangement for vertical lift gate for spillway.

1. Skin Plate: A membrane which transfer the water load on the gate to other components.
2. Vertical Stiffeners: The structural vertical members used to divide the skin plate into panels.
3. Horizontal girder: Main structural member spanning horizontally to transfer the water pressure from skin plate and vertical stiffeners to the end vertical girder.
4. End vertical Girder: Main vertical structural members which take load from the horizontal girders.
5. Wheel Assembly / Slide Pads: Structural arrangements which take load from the end vertical girder and transfer it to the track plate.

**Radial Gate:**

![Diagram of Radial Gate and Stoplogs](image)

*Fig-1*
Radial or tainter gate is in the form of a curved plate, storing water usually on convex side, having an arc of a circle as its main member which is supported on a system of steel framework which in turn transfers the thrust of water to concrete through another system of steel grillage or anchorages. Radial gates do not require grooves in the piers. They move on side guide plates which are in flush with the concrete surface.

For spillways, simplicity of operation and smooth flow pattern past the gate and avoidance of flow disturbance due to absence of grooves are positive features for radial gates. If the head over the spillway is 8m or more, overall arrangement of radial type gate generally proves economical in comparison to other types of gates.

1. Skin Plate:A membrane which transfers the water load on a radial gate to the other components.
2. Horizontal Girder:The main structural members of a radial gate, spanning horizontally to transfer the water pressure from skin plate and vertical stiffeners to end arms of the gate.
3. End Arms:Main structural members which carry the reactions from horizontal girder to the gate trunnion.
4. Trunnion Hub:A hub to which the converging arms of a radial gate are rigidly connected. It houses the trunnion bushing / bearing and rotate about the trunnion pin.
5. Trunnion Assembly:An assembly consisting of trunnion hub, trunnion bush or bearing. Trunnion pin and trunnion bracket.
6. Yoke or Trunnion Girder:A structural member supporting the trunnion bracket and held in place by load carrying anchors or tension members embedded in piers / abutments.
7. Anchor flats / Anchors:Structural tension members provided for transfer of water load from trunnion girder of a radial gate to the piers / abutments.
8. Anchor Girder:An embedded structural member, transferring load from a radial gate to its surrounding structure.
9. Thrust Pad or Thrust Block:A structural member designed to transfer to the pier or abutment that component of water thrust on a radial gate caused by lateral force induced due to inclination of end arms.
10. Trunnion Tie:A structural member connecting the two trunnion assemblies of a radial gate to cater to the effects of lateral force induced due to inclination of end arms.
11. Wall Plate:A plate embedded flush in a pier / abutment to provide a track for the seal and guide rollers of the radial gate.
Gates for Outlets

The basic function of any outlet is to provide an efficient, economical means of releasing water from a reservoir to obtain the desired downstream use or uses. The conduits, pipes or penstocks for high head outlets are usually metal, and have gates or valves located at the upstream entrance, at an intermediate point or at the downstream end. Such outlets may also utilize a combination of these arrangements, and have a guard gate at the entrance or at an intermediate point with a regulating gate or valve at the downstream end.

Each outlet should be provided with two gates or valves capable of closing under flow. An upstream guard gate or valve is required primarily to ensure the safety of the conduit and equipment downstream and also to permit inspection and maintenance of the downstream pipe and the equipment.

Guard gates must be capable of closing under the full head and maximum possible flow, but are normally operated under balanced pressure/ no flow conditions.

In addition to gates or valves which can be closed with water flowing, most outlets are provided with a bulkhead gate or stoplogs at the upstream end to permit inspection or repair at the entrance of the conduit. Bulkhead gates and stoplogs are normally designed to be placed and removed under balanced head no flow conditions.
Slide Gates:

These gates are usually adopted where high pressure application is called for. They are used for both guard as well as regulating services. Basically, a slide gate consists of a leaf which is either closed by being positioned across the fluid-way in the body or opened by being withdrawn into the bonnet by a hoist mounted on the bonnet cover. The mating seats on the gate leaf, body and bonnet serve as sliding surfaces for carrying the hydrostatic load on the leaf and as the sealing surfaces when the gate is closed. The body and bonnet are sufficiently stiffened to eliminate any distortion when the gates frame/embedment are embedded in concrete. The bonnet cover is designed to resist internal water pressure. Figure given above indicates typical details of a slide gate.

Main applications, advantages and disadvantages of various type of gate:
<table>
<thead>
<tr>
<th>Type</th>
<th>Main Applications</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gate in open channels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flap gate-Bottom hinged</td>
<td>Tidal barrages. Sluice installation. River control.</td>
<td>Complete separation of saline and fresh water. Overflow to clear debris. No visually intrusive overhead structure. Can in some cases be designed to open under gravity in emergency.</td>
<td>Requires extensive side staunching for side sealing or very accurately constructed pier walls. Hinge bearings not easily accessible and permanently immersed.</td>
</tr>
<tr>
<td>--------------------------</td>
<td>--------------------------------------------------------</td>
<td>-------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vertical lift intake gate- Rope drum hoist operated.</td>
<td>Bulkhead gate.</td>
<td>Can be roller or slide type. Does not require air admission.</td>
<td></td>
</tr>
</tbody>
</table>
Criteria for Selection of Type of Gate in a Water Resources Structure

It is difficult to give an exhaustive criterion for selection of type of gate in a Water Resources structure because every location is unique. Advances in manufacturing and design offer new efficient and economical solutions to old problems. However, following may be considered while making a selection of type of gate in a dam structure with following criteria.

1. Discharge Capacity
2. Discharge of floating debris and Ice
3. Silt and bed load passage
4. Headwater Pressure operation
5. Loads on Concrete structure
6. Absence of Vibration
7. Hydraulic Regulation
8. Automatic closure in emergency

This criteria is achieved not only by selecting the proper gate type but also by arrangement of its components like placement of skin plate, seals, rollers etc. which makes the design even more interesting.

Diversion Channel / Tunnel:

For diverting the flow of water during the construction stage, some arrangements i.e. a diversion channel / tunnel is made. The flow takes place through this channel / tunnel during the construction stage. This channel / tunnel is closed finally after construction or sometimes it is employed for some other purpose. For inspection or for final closing of diversion arrangement, gates are employed. These can be classified as:-

A. Diversion Arrangement outside the body of Dam

When Diversion channel is provided outside the body of dam, following is used for closure of diversion channel after the construction period.

a. Coffer Dam
b. Needles
c. Stoplogs
d. Vertical lift gates
   i. Vertical Lift Slide Type
   ii. Vertical Lift fixed wheel type

B. Diversion Arrangement inside the body of Barrage Dam

Sometimes diversion tunnel is provided through the body of dam or barrage. Sometimes it is called construction sluice also. After construction of specific blocks, the water is allowed to pass through this tunnel for the duration of construction period. Gates are required for final plugging of this tunnel after the completion of construction. Sometimes this tunnel is used as undersluice afterwards with or without provision of gooseneck tunnel. In this case gates are provided for regulation purposes.
a. Vertical lift gates
   i. Vertical lift slide type
   ii. Vertical Lift Fixed wheel type
b. Sluice radial Gates (with top seal)
c. Stoplogs (for maintenance of tunnel gates)

Spillway:

A. Maintenance / Emergency Gate
   a. Stoplogs
   b. Emergency Bulkhead Gate
B. Regulation Gates
   a. Vertical Lift Gate
      i. Vertical Lift Slide Type
      ii. Vertical Lift Fixed Wheel Type
   b. Radial Gate

Please refer to the table below for relative merits and demerits of vertical lift as well as radial gates.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Vertical lift Gate</th>
<th>Radial Gate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hoisting effort required is more</td>
<td>Hoisting effort required is less</td>
</tr>
<tr>
<td>2</td>
<td>Deeper and bigger gate slots in piers are</td>
<td>No such problem.</td>
</tr>
<tr>
<td></td>
<td>required for high wheel loads which is not</td>
<td></td>
</tr>
<tr>
<td></td>
<td>good for hydrodynamic conditions.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Length of pier required is less</td>
<td>Longer piers are required</td>
</tr>
<tr>
<td>4</td>
<td>Downstream water level may be high</td>
<td>Trunnion should be above downstream water level</td>
</tr>
<tr>
<td>5</td>
<td>Width of pier required is less</td>
<td>Width of pier required is</td>
</tr>
<tr>
<td></td>
<td></td>
<td>comparatively more as it has to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>house the anchorage system</td>
</tr>
<tr>
<td>6</td>
<td>Gate vibration especially under partial</td>
<td>Gate vibration problem is less under</td>
</tr>
<tr>
<td></td>
<td>opening is more</td>
<td>similar loading.</td>
</tr>
</tbody>
</table>

Undersluice:

B. Maintenance / Emergency Gates
   a. Stoplogs
   b. Emergency Bulkhead Gate
B. Regulation Gates
   b. Vertical Lift Gate
      i. Vertical Lift Slide Type
ii. Vertical Lift Fixed Wheel Type

C. Sluice Radial Gate (top seal)

**Design Principles**

Every gate is designed as per its operating conditions. A gate is generally designed to counteract following types of forces:

1. Hydrostatic head of water
2. Silt Pressure
3. Wave Effect
4. Ice load
5. Seating load
6. Earthquake load
7. Hydrodynamic Load
8. Self Weight (usually small in comparison to other forces)

The sequence of load transfer for vertical lift gate and radial gate is as follows:

**Vertical Lift Gate:**

From Slide Block or Wheel Assembly the load is transmitted to Pier or abutment through Track Plate and embedments.
Radial Gate:

Every gate is designed as per relevant codal provisions (a list of codes is given in annexure – A) and on the basis of accepted design practices. A full discussion of design of all types of gates is not possible here. However, some concepts are discussed as follows:

1. Permissible Mono-axial Stresses for structural components of Hydraulic Gates:

The permissible stresses for various components are taken as per dry and wet condition and further as per assessable and non-accessible conditions as per table given below:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Material and Type</th>
<th>Wet condition</th>
<th>Dry condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Accessible</td>
<td>Non-accessible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>YP</td>
<td>UTS</td>
</tr>
<tr>
<td></td>
<td>Structural Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>i)</td>
<td>Direct Compression</td>
<td>0.45YP</td>
<td>0.40YP</td>
</tr>
<tr>
<td>ii)</td>
<td>Compression / Tension in bending</td>
<td>0.45YP</td>
<td>0.40YP</td>
</tr>
<tr>
<td>iii)</td>
<td>Direct Tension</td>
<td>0.45YP</td>
<td>0.40YP</td>
</tr>
<tr>
<td>iv)</td>
<td>Shear Stress</td>
<td>0.35YP</td>
<td>0.30YP</td>
</tr>
<tr>
<td>v)</td>
<td>Combined Stress</td>
<td>0.60YP</td>
<td>0.50YP</td>
</tr>
<tr>
<td>vi)</td>
<td>Bending stress</td>
<td>0.65YP</td>
<td>0.45YP</td>
</tr>
<tr>
<td></td>
<td>Bronze or Brass</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bearing stress</td>
<td>0.035UTS</td>
<td>0.030UTS</td>
</tr>
</tbody>
</table>

YP stands for minimum guaranteed yield point stress and UTS stands for ultimate tensile strength. For material which have no definite yield point, the yield point may be taken as 0.2 percent proof stress.
2. Co-acting width of skin plate with beam or stiffeners

For design of stiffeners and girders, the skin plate thickness is also taken into account. The coacting width of the skin plate in non panel construction is restricted by least of the following:

1. \[40t + B\]
   \[\text{where}\]
   \[T = \text{thickness of skin plate}\]
   \[B = \text{width of stiffness flange in contact}\]
2. 0.11 times the span
3. Center to center distance of stiffener and girder
   (Hydrostatic force, Hydrodynamic forces, model studies also)

For panel construction it is limited by the width = 2 V B where

\[V = \text{Reduction factor depending upon ratio of support length to the span of the plate and action of the moment as determined in the design codes viz IS 4622-2003.}\]

\[B = \text{Half the span of the plate between two girders}\]

However care should be taken that the width so calculated does not exceed limits set in IS 800-1980.

3. Semi flexible Design

For the eventuality of one of the roller not in contact with the track plate and extreme loading conditions arising thereof, our IS codes have made a provision for designing the gate as semi flexible, fitted with number of elements with only two wheels on either side. The vertical girder in this case is discontinuous. While this features enables saving of steel in design of roller and tracks but at the same time care has to be taken to provide flexible joints between various elements at skin plate and end girder.

4. Hydrodynamic Loading

The gate is subjected to static water loading when the flow does not take place. When water flows past the gate at partial opening, hydrodynamic forces also occur which may be extreme in some cases causing vibration, cavitation, non-operability and sometimes even failure of gate. The gate has to be designed carefully for following factors:

- Gate Slot
- Gate lip
- Aeration (air demand)

Sometimes model studies become necessary to find out the amount of hydrodynamic forces and air demand. The problem of hydrodynamic loading becomes extreme at high head of water. Placement of sealing also plays a major role in the design of hydrodynamic loading.

5. Provision of Stoplogs:
For maintenance of gates, Stoplogs usually 10% of total number of spillway bays is kept. However care should be taken to ascertain the condition if the Stoplogs are required to be lowered in flowing water. In such cases, provision of emergency bulkhead gate may be provided.

A brief description of design of vertical lift gate is as follows:

1. **Skin Plate**

   Skin plate thickness is taken 1.5 mm more for account for corrosion. For non panel construction it is designed for bending across stiffeners or horizontal girder. For panel construction is designed for various end conditions as given in design code viz IS 4622-2003.

2. **Vertical Stiffeners / horizontal girder**

   Vertical stiffeners or horizontal girders are designed as simply supported or continuous beams depending upon framing adopted for the gate and take the load from the skin plate. Design principle at S. No 2 is also taken into account in design.

   The spacing between horizontal girders is adjusted in such a way that all the girders carry equal loading. The following methods may be used for this:

   a. Trial and error method
   b. Analytical method
   c. Graphical method

   Care is also taken that the deflection of the gate does not exceed the permissible limit, especially so for the top seal gates.

3. **End vertical girder**

   The end vertical girder is designed as continuous beam resting on wheel contact point with concentrated loads coming from horizontal girders, at the points where they meet the end vertical girder. Torsional effects are also accounted for where applicable. Design principle at S. No 3 is also taken into account in design.

4. **Wheel Assembly**

   Wheel assembly consists of Roller, wheel pin, Wheel bearing or bushing. Care should be taken to ensure the proper design for point contact or line contact loading. The wheel may have to be crowned for ensuring proper contact.

5. **Wheel Track**

   The wheel track may be designed as beam resting on elastic foundation. Care should be taken that the bearing stress as well as shear stress in the concrete does not exceed the permissible stresses.
6. Seal Assembly

Earlier wooden sealing or leather sealing was adopted for minor works. Nowadays sealing is generally of rubber. It should be as per IS 15466-2004 “Rubber Seals for Hydraulic gates – Specification” and it should be designed in accordance with IS 11855-2004 “Guidelines for Design and use of different types of Rubber seals for hydraulic gates”. However care should be taken to take the friction coefficient of cladded seals in such a way that takes into account the wearing of cladded surface after repeated usage. Sometimes (for slide gates) metal seals are used which are generally of Brass or Bronze and are fixed to the gate leaf by countersunk screws of stainless steel or of same material.

A brief description of design of Radial gate is as follows:

Geometry of Gate:

1. Gate Sill Location

Gate sill is located downstream of crest and as close to the crest as possible to economise on the height of gate and size of pier. Placement of hoist and bridge etc should also be considered. As a general guideline sill may be placed at about 0.3 to 0.8 m below the crest.

2. Radius of Gate

The radius of gate should be ideally between 1.0 times H to 1.25 times H. Where H is the distance between top of gate and gate sill. However this guideline is for crest radial gate. For top seal radial gate provided in sluices, consideration for placement of trunnion above water level and for minimum hoisting effort also needs to be taken into account.

3. Gate Trunnion;

Trunnion is generally placed 1.5 m above the upper nappe of water along piers to prevent damage to trunnion due to floating debris and ice etc. However this guideline is for crest radial gate. For top seal radial gate provided in sluices, consideration for placement of trunnion above water level and for minimum hoisting effort also needs to be taken into account.

4. Location of hoist.

If the radial gate is operated with rope drum hoist. The hoist may be located upstream or downstream. Upstream location of rope drum hoist involves less hoisting effort but its connection with gate becomes inaccessible and should be designed for extra safety. Downstream arrangement of hoisting involves more hoisting effort but the connection to gate is accessible and possible damage due to flowing debris etc is avoided.

A brief description of design of various components of Radial Gate is as follows:
1. Skin Plate

Skin plate thickness is taken 1.5 mm more for account for corrosion. For non panel construction it is designed for bending across stiffeners or horizontal girder. For panel construction is designed for various end conditions as given in design code viz IS 4623 - 2003.

2. Vertical Stiffeners or horizontal girders

These are designed in the same way as in vertical lift gates. However the effect of curvature in design of vertical stiffeners is taken into account. Sometimes horizontal stiffeners are also used. The total number of horizontal girders depends upon the gate height. But it should be kept minimum to simplify fabrication and maintenance as more horizontal girder implies more end arms which have to be accommodated in trunnion. As a general guidance the number of horizontal girders may be adopted as follows:

a) For height of gate upto 8.5 m 2 Nos
b) For height of gate between 8.5 m to 12 m 3 Nos
c) For heights above 12 m 4 or more

3. Bracing for Horizontal girder:

Bracing for horizontal girders are designed as per shear force shared by bracing panels at thir locations.

4. End Arms:

End arms may be straight or inclined to economize on horizontal girder. But in case of inclined arms, lateral force has to be accounted for by provision of thrust block or trunnion tie beam. These are designed as columns for axial force and bending transmitted by horizontal girders.

5. Trunnion hubs:

Trunnion hubs are designed as thick or thin cylinders subjected to internal pressure generated by the resultant load on trunnion.

6. Trunnion bushing

Trunnion bushing should be of Aluminum bronze or self lubricating type. Overall economy is to be considered before selecting a type of bushing.

7. Anchorages;

The anchorage system of the radial gate is provided for the transfer of water load through the gate trunnion to the piers or abutments. These may be of following types:

a) Bonded anchorages
b) Unbonded Anchorage
c) Combined Anchorage
d) Pre stressed Anchorage

In bonded anchorage the load transfer takes place in bond between the anchors and the concrete. In unbonded anchorage the transfer takes place in bearing between the anchor girder and concrete. For large size radial gates nowadays pre stressed anchorages are becoming popular.

**Latest Trends in Gate Design:**

1. SCADA and operational innovations
2. Unconventional Radial Gates
3. Inflatable Gates and Fuse gates
4. New Materials

1. SCADA and operational innovations:

SCADA stands for Supervisory Control and Data Acquisition. It is an old concept but with increased availability of rugged and reliable PLC (Programmable logic controller- kind of computers allowing man-machine interface), gate operation is now capable for discharge optimization any with any other control factors.

2. Unconventional Radial Gates

To meet the demand of increasing spans and other requirements, a number of innovative radial gates are being used e.g Eccentric Radial Gates, Visor Gates etc.

3. Inflatable Gates and Fuse Gates

These are latest addition to the ever growing gate innovations. These are easy and fast to install and suitable for automatic control.

4. New Materials

New materials for bushings (e.g Deva Glide – Self lubricated bushing), seals (e.g H. fontaine- Canada -Ultra High Density Molecular Weight polythethylene) and Gate (Japan- Fiber reinforced Plastics) are some of the examples for new exciting field of innovative material solutions to gate design problems.

**Control Equipments for Hydraulic Gates and valves**

The control equipment for the Hydraulic gate is the equipment used for their operation. These have to be designed for safe and efficient operation of gates. Following types of control equipment are used for the operation of gates:

1. Screw Hoist
2. Rope Drum hoist
3. Chain Hoist
4. Hydraulic hoist

1. Screw Hoist

This is the very simple type of operating equipment used extensively earlier but at present due to its limitation in hoisting capacity and inefficiency it is not finding much use for new
installation. It is designed as per provisions of IS 11228- “Recommendations for design of screw hoists”. It is operated either by hand or by electric motor. Sometimes even today it is used for very low head installation where a positive downward thrust is desired for closure of gate.

2. Rope Drum hoist

It is being extensively used these days where the downward positive thrust is not required for closure of gates and the gate is to close by its own weight. It is placed on a trestle whose height is determined by the height of gate and water level. Drums are designed to accommodate the required length of rope. It is designed as per provisions of IS 6938 – “Code of practice for design of rope drum hoist and chain hoist for hydraulic gates”

3. Chain Hoist

Here sprocket and chain is used in place of drum and rope. This type of hoist is not being used extensively these days due to more maintenance requirement and operational problems.

4. Hydraulic Hoist

This type of hoist is being extensively used for high head installation where downward positive thrust is required for closure of gate. It is designed as per provisions of IS 10210: “Design of Hydraulic Hoist for gate”. At present the length of cylinder that can be honed in India is limited but with the increasing capability of manufacturing this is finding favor in new installations. Its use leads ease to gate operation programming as gate opening / closing speed can be more easily manipulated.

Special Equipment (e.g. Trashrack, Trashrack cleaning Machine etc.)

Trashracks are used to exclude the trash in the intake. These are designed as per provisions of IS 11388- “Recommendations for design of trashracks for Intakes”. The trash racks are cleaned manually or with machines. These Trashrack cleaning machines can clean trash rack and also have provision for removal of floating logs etc. These can also have attachment for removal and placement of trashrack panels.
Annexure –A

List of important IS codes

- IS 800: Code of practice for general construction in steel
- IS 4410: Glossary of terms relating to river valley projects Part XVI Gates and Valves
- IS 4622: Recommendations for structural design of fixed wheel gate
- IS 4623: Recommendations for structural design of radial gate
- IS 5620: Design criteria for low head slide gates
- IS 9349: Recommendations for structural design of medium and high head slide gates
- IS 7718: Recommendation for inspection, testing and maintenance of fixed wheel gate and slide gates
  - Do- Part 1: Inspection, testing and assembly at manufacturing stage
  - Do- Part II: Inspection at the time of erection
  - Do- Part III: After erection
- IS 10096: Recommendation for inspection, testing and maintenance of radial gates and their hoists
  - Do- Part 1: Inspection, testing and assembly at manufacturing stage Section I Gate
  - Do- Part 1: Inspection, testing and assembly at manufacturing stage Section II rope Drum hoist
  - Do- Part II: Inspection, testing and assembly at the time of erection
  - Do- Part III: After erection
- IS 6938: Code of practice for design of rope drum hoist and chain hoist for hydraulic gates
- IS 10210: Design of Hydraulic Hoist for gates
- IS 11228: Recommendations for design of screw hoists
- IS 10021: Recommendations for de-icing system for hydraulic installations
- IS 15466: Rubber Seals for Hydraulic gates – Specification
- IS 11855: Guidelines for Design and use of different types of Rubber seals for hydraulic gates

Latest edition of these codes should be used.
516  GATES AND VALVES

(b) For free surface flow discharges (no jump)
U.S. Army Engineers equation
\[ \beta = 0.0066 \left( F - 1 \right)^{1/4} \]  (16.13)

(vi) Determine air demand.
\[ Q_a = Q_e \beta \]  (16.14)

(vii) Determine vent area based on allowable air velocity
(45 to 90 m/s)
(viii) Check losses in vent to be sure that they are less than
1.5 m of water head.

16.6 WEIGHT ESTIMATES

The following data and formulas will help in evaluating
weights of different types of gates, their hoisting capacities etc.
Some of the curves and formulas are given by C.V. Davis in the
2nd edition of his book "Applied Hydraulics". (The original
information is in f.p.s. units which has been converted
in metric units by the author).

1. Welded steel fixed wheel gates
(a) The Table 16.2 gives data for small width of the gate.
The following relation may be used to evaluate the weight of
the gate in tonne.

<table>
<thead>
<tr>
<th>Head in metre</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>4.0</td>
<td>7.5</td>
<td>15.0</td>
</tr>
<tr>
<td>60</td>
<td>5.2</td>
<td>12.0</td>
<td>20.0</td>
</tr>
<tr>
<td>90</td>
<td>6.7</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>9.7</td>
<td>22.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 16.2 Weight in tonne per metre of height for
gates of width (m)

\[ W_g = K L^{1/9} H^{2/9} \]  (16.15)

where
- \( W_g \) = weight of gate in tonne
- \( L \) = clear width of the gate opening in metre
- \( H \) = height of gate from spillway crest to normal
  water level on gate in m
- \( K \) = a coefficient which varies from 0.017 to 0.043;
  the mean value being 0.026.

(b) Weight of embedded parts
- 10% for small gates, and
- 50% for big gates; 35% being the average figure.

2. Ring Follower and Ring Seal Gate (Table 16.3)

<table>
<thead>
<tr>
<th>Head in metre</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>9</td>
<td>27</td>
<td>50</td>
<td>72</td>
</tr>
<tr>
<td>60</td>
<td>11</td>
<td>32</td>
<td>57</td>
<td>82</td>
</tr>
<tr>
<td>90</td>
<td>16</td>
<td>36</td>
<td>64</td>
<td>100</td>
</tr>
<tr>
<td>120</td>
<td>20</td>
<td>39</td>
<td>77</td>
<td>110</td>
</tr>
<tr>
<td>150</td>
<td>23</td>
<td>52</td>
<td>85</td>
<td>127</td>
</tr>
</tbody>
</table>

3. Jet Flow Gate (Table 16.4)

<table>
<thead>
<tr>
<th>Head in metre</th>
<th>80</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>2.3</td>
<td>6.8</td>
<td>13.6</td>
<td>24.5</td>
<td>39.9</td>
</tr>
<tr>
<td>120</td>
<td>2.7</td>
<td>7.7</td>
<td>16.0</td>
<td>28.0</td>
<td>49.0</td>
</tr>
<tr>
<td>180</td>
<td>3.2</td>
<td>8.6</td>
<td>18.2</td>
<td>34.0</td>
<td>57.0</td>
</tr>
</tbody>
</table>

WEIGHT ESTIMATES

A lift beam weighing 10 to 20% of the gate weight is
necessary for a travelling hoist.

(c) Weight in tonne of machinery and bed plates of fixed
hoists without counter weights
\[ W = K \times \text{capacity of hoist in tonne.} \]

where
- \( K \) = a constant, having value of 0.23 for two
  drum hoist and 0.069 for single drum hoist.


For \( b^2 h H > 2000 \ m^4 \)
\[ W_g = 0.706 \left( b^2 h H \right)^{0.97} \]  (16.16)

For \( b^2 h H < 2000 \ m^4 \)
\[ W_g = 0.888 \left( b^2 h H \right)^{0.859} \]  (16.17)

where
- \( W_g \) = weight of gate in kN,
- \( b \) = span of gate in m,
- \( h \) = height of gate in m,
- \( H \) = maximum head on gate in m.

For double leaf fixed wheel gate
\[ W_g = 0.913 \left( b^2 h H \right)^{0.869} \]  (16.18)
GATES AND VALVES

Nand Gopal (1987) Formula
\[ W_g \text{(in kg)} = 0.8 \log (b^2h) + 5.66 \] (16.32)

16.7 ILLUSTRATIVE DESIGN OF RADIAL GATE

Design Example 16.2
Design tainter gates for an ogee spillway for the following data:
- Height of gate = 13.8 m
- Width of gate = 16.0 m
- Crest level of spillway = 786.0 m
- Full reservoir level = 799.0 m

Height of gate and location of Trunnion
It is usual practice to keep the sill of the gates a little lower than the spillway crest elevation and top of the gates a little higher than the F.R.L. In this case allowing 0.4 m on either side
- Sill El. of gate = 785.60 m
- Top El. of gate = 799.80 m
- Height of gate = 13.8 m

Usually the convenient trunnion height is kept between 1/2 H to 3/4 H or at least 1.5 m above nappe profile, with these considerations the trunnion level has been fixed at El. 788.00 m.

Economic Radius
According to Indian Standard Specifications the economic radius, \( R = 1.25 \times H = 1.25 \times 13.8 = 17.2 \) m.

Arrangement of gate structures
As proposed in the present design it shall be consisting of a skin plate with increasing thickness towards bottom. The skin plate shall form segment of a cylinder and shall be supported by vertical stiffeners placed suitably apart. The vertical stiffeners shall be supported by 5 nos. of horizontal girders which in turn shall be supported by two end frames converging radially to the horizontal pins, anchored to the piers. The skin plate shall be made concentric to these pins so that the resultant of water pressure passes through the pin creating no moment to be overcome while hoisting the gate.

ILLUSTRATIVE DESIGN OF RADIAL GATE

Design Stresses
(i) Tension or compression in steel = 1300 kg/sq cm.
(ii) Direct compression in struts with \( L/r > 120 \)
\[ f = 1200 - 0.483 \left( \frac{L}{r} \right)^2 \] (in kg/cm²)
\[ L = \text{eff. length} \]
\[ r = \text{radius of gyration} \] (min).
(iii) Strength of welded joint shall be assumed to have 100% efficiency.

Controlling dimensions of gate
The dimensions as actually measured from the gate drawing (Fig. 16.26):
\[ \alpha = 18^\circ, \beta = 66^\circ, \gamma = 80^\circ \]
\[ i = 49^\circ, g = 49^\circ, h = 82^\circ \]

Fig. 16.26 General dimensions of tainter gate-design example
Figure 1. Typical assembly of fixed wheel Gate
Figure 2. Radial Gate with parallel Arms

Figure 3. Radial Gate with inclined Arms
Figure 4. Sectional View of Radial Gate
Figure 5. Typical diagram of low Head Slide Gate
Figure 6. Typical Details of Low head Slide Gate
**Figure 7. Rubber Seals**

**Figure 7. Rubber Seals**

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Description</th>
<th>J</th>
<th>D</th>
<th>d</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Solid &amp; Hollow</td>
<td>57</td>
<td>22</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>2.</td>
<td>do</td>
<td>100</td>
<td>44</td>
<td>25</td>
<td>14/18</td>
</tr>
<tr>
<td>3.</td>
<td>do</td>
<td>155</td>
<td>44</td>
<td>25</td>
<td>14/18</td>
</tr>
</tbody>
</table>

**NOTE** — The dimensions of seals shown in the figure may be taken as indicative and nearest size seals as per moulds available with the manufacturers may also be used.

All dimensions in millimetres.

**COMMON SIZES OF MUSIC NOTE SEALS**

**NOTE** — The dimensions of seals shown in the figure may be taken as indicative and nearest size seals as per moulds available with the manufacturers may also be used. (Thickness of stem shall not be less than 14 mm.)

All dimensions in millimetres.
Figure 8. Skin Plate Various Cases – I

- **ALL EDGES SIMPLY SUPPORTED**
- **ALL EDGES RIGIDLY FIXED**

- **6 TWO SHORT AND ONE LONG EDGES FIXED AND ONE LONG EDGE SIMPLY SUPPORTED**
- **7 TWO LONG AND ONE SHORT EDGES FIXED AND ONE SHORT EDGE SIMPLY SUPPORTED**
Figure 9. Skin Plate Various Cases – II

- Three edges fixed and one (longer) edge free

- Three edges fixed and one (shorter) edge free
FLAP GATE

CYLINDER GATE

CATERPILLER GATE
Drum Gate

BEAR TRAP GATE

VISOR GATE
Chapter – 2

Design of Vertical Lift Gates

As the name implies, these gates are flat and are operated in vertical direction. They consist of a flat plate called skin plate which is supported by a system of horizontal girders and vertical stiffeners which in turn are connected to end girders and wheels or sliding pads. These wheels (or sliding pads) transfer the load to concrete through tracks embedded in it.

While designing a gate; the higher the head, the more serious the hydraulics problems, the larger the gate area, the more serious the structural problems and manufacturing difficulties, the larger the total dynamic pressure, the more serious the hoist problems. These three parameters, i.e. the water head, the gate opening area and the total dynamic pressure are the major indices, indicating the technical level of gates. Depending of water head; design and acceptance criteria is distinctly different for different types of gates. For high head gates installations, the design criteria are quite stringent as compared to medium and low head gates installations.
**LOADING ON THE GATE:**

**HYDROSTATIC LOAD:**

When dimensioning a gate, the first step is to calculate the water thrust acting on the skin plate for the various gate-opening positions. Its maximum value occurs with the gate closed and subject to the maximum head water level.

For gates with water on both sides of the skin plate, the maximum water thrust corresponds to the most unfavorable unbalanced level between the upstream and the downstream reservoirs.

(A) **WEIR/CREST GATES**

(a) For gates with only one side of the skin plate in contact with water, the maximum water thrust is given by the following formula:

\[ W = \frac{1}{2} \gamma B H^2 \]

Where:

- \( \gamma \) = specific weight of water = 9.81 kN/m³
- \( B \) = span of side seals
- \( H \) = maximum water head on the sill.

Its line of action is normal to the skin plate and passes through the centre of pressure of the surface, that is, at a distance of \( e = \frac{1}{3}H \) above the sill.

(b) For the gate with both sides of the skin plate in contact with water, the water thrust due to the upstream reservoir is:

\[ W_M = \frac{1}{2} \gamma B H^2 \]

And its centroid is

\[ e_M = \frac{1}{3}H \]

On the downstream side,
\[ W_J = \frac{1}{2} \gamma B h^2 \]

And
\[ e_J = \frac{1}{3} h \]

where \( h \) is the minimum downstream headwater on the sill.

The resultant water thrust will then be,
\[ W = W_M - W_J = \frac{1}{2} \gamma B (H^2 - h^2) \]

(B) **SUBMERGED GATES:**

(a) For submerged gates with only one side of the skin plate in contact with water, the water thrust is calculated by
\[ W = \gamma B h (H - \frac{h}{2}) \]

Where:
\[ \gamma = \text{specific weight of water} = 9.81 \text{kN/m}^3 \]
\[ B = \text{span of side seals} \]
\[ H = \text{maximum headwater on sill} \]
\[ h = \text{gate sealing height.} \]
The pressure diagram has a trapezoidal shape. In this case, the position of the resultant water trust is given by

\[ e = \frac{h}{3} \left(1 + \frac{H-h}{2H-h} \right) \]

Substituting in the above equations

\[ h = H - h_1 \]
results, after simplification,

\[ W = \frac{1}{2} y B \left( H^2 - h_1^2 \right) \]

And

\[ e = \left( \frac{H-h_1}{3} \right) \left( \frac{H+2h_1}{H+h_1} \right) \]

where \( h \) is the vertical between the free surface of water and the top seal.

(b) For submerged gates, with both sides of the skin plate in contact with water, the resultant water trust is the difference between the hydrostatic forces due to each reservoir.

Upstream water trust

\[ W = \frac{1}{2} y B \left( H^2 - h_1^2 \right) \]

And

\[ e = \left( \frac{H-h_1}{3} \right) \left( \frac{H+2h_1}{H+h_1} \right) \]

Downstream water thrust

\[ W_j = \frac{1}{2} y B \ h_j^2 \]

Where \( h_j \) is the minimum depth of the tailwater.

The centroid of \( W_j \) is calculated by

\[ e_j = \frac{1}{3} h_j \]
Since the pressure diagram has a triangular shape.

The result water trust is:

\[ W = W_M - W_J = \frac{1}{2} \gamma B (H^2 - h_1^2) - \frac{1}{2} \gamma B h_J^2 = \frac{1}{2} \gamma B (H^2 - h_1^2 - h_J^2) \]

**HYDRODYNAMIC LOAD:**

When a gate is totally closed and the water is at rest, the pressures obey the hydrostatic laws and the hydraulic forces are easily determined by analytical methods. In the absence of any flow, the calculation of the vertical component of the hydraulic forces on the gate comprises solely the determination of its buoyancy. This static condition is characterized by a uniform value of the piezometric head in the conduit, near the gate, is observed. However, whenever there is water flow past the gate, the high flow velocities at the bottom surface of the gate, which reduces the local pressure, cause the phenomenon of hydrodynamic forces on the gate structure. Hydrodynamic forces are generally determined by means of model tests. These tests are made in hydraulic laboratories and may substantially increase the cost of small gates. In such cases, it is usual to determine the hydrodynamic forces by analytical methods. However for critical and very high head gated installation help of model studies need to taken for more accurate and precise calculations.

**LOAD CASES:**

The three load cases for design of gates, according to the frequency of occurrence and the nature of the loads and the probability of their coincidence are considered:

- **Normal load case** – considers the most unfavorable values and combinations of the hydrostatic loads at normal water levels (including the influence of waves),
hydrodynamic effects, friction forces, silt load, dead weight, buoyancy, transit loads and driving forces. For gate located in the conduits sluices, provision for sub-atmospheric pressure d/s of the gate (generally 2 m for medium and 5m of water head for high head gate) shall be considered.

The simultaneous occurrence of these loads and water levels, as well their combinations, should only be considered when possible and probable.

- **Occasional load case** – considers the loads which occur less frequently, such as:
  1. Hydrostatic and hydrodynamic forces at unusual water levels;
  2. Wind loads;
  3. Temperature effects;
  4. Friction by ships;
  5. Ice impact and pressure.

The simultaneous occurrence of these loads and water levels, as well as their combinations, should only be considered when possible and probable.

- **Exceptional load case** – considers loads occurring during transportation, erection, maintenance services or other exceptional cases, as well as the following:
  1. Hydrodynamic effects and overloads due to the driving forces in the event of failure of lining or penstock;
  2. Asymmetrical loads and overloads due to the driving forces caused by jamming / or the impact of ships;
  3. Seismic effects;
  4. Changes in conditions of support.

The simultaneous occurrence of these loads should only be considered when their combination is possible and probable.

The influence of the operating forces on the structural elements should be considered according to the hoist rated capacity for the normal load case, or with the maximum capacity, for the exceptional case. The maximum capacity to be considered, in the case of fluid power systems (i.e. hydraulic hoist), is the one corresponding to the relief value pressure; in the case of mechanical hoists, that of the limiting device or, in its absence, that of the maximum torque of the driving motor. In gravity- closure gates, the preponderance of the closing forces should be proved with a safety margin of 20 per cent, for the normal load case, and 15 percent, for the exceptional case.

The seismic influence is taken into account in the gate design with their effect simulated as a horizontal force of magnitude equal to the gate mass multiplied by the probable horizontal seismic acceleration in the region. The possible occurrence of the resonance phenomena and its effects should be investigated.

The influence of ice pressure and impact is considered according to the local conditions.

**Design of gates is grouped as under:**

- Structural design of gate
- Hydraulic design
- Design of gate slots and embedments
Structural Design:

Structural design of vertical lift gates in India is covered in following Indian Standards brought out by Bureau of Indian Standards (BIS):

(i) IS 4622
(ii) IS 5620
(iii) IS 9349

Apart from above, there are many publications and manuals brought out by USBR, U.S. Army Corps of Engineers, CWC etc.-etc.

These standards cover in detail the criteria for the design of various components. Besides above there are few more standards available which are related to the assembly, erection and testing of gates. Basic standards like IS-456 and IS-800 for RCC and structural steel designs are also adopted.

MATERIALS:

In the manufacture of gates and appurtenances a great variety of materials, such as rolled, stainless, cast and forged steels, cast iron, bronze and its alloys, natural and synthetic rubber for seals and, in some cases, timber, is used. The wide range of types and the amount of materials available can satisfy all the needs and requirements of the gate designers, thus leading to an adequate and economic selection of the material. This selection must comply with sound criteria, in order to warrant reliable operation and long life for the equipment. Therefore, the designer should take into account not only the cost and availability of the material in the market but also its main characteristics such as the chemical composition, physical and mechanical properties (yield and tensile strength, elongation, toughness, hardness, weldability, machinability, heat treatment capability and the corrosion resistance. The material for various parts of gate leaf/embedded is given below.
ALLOWABLE STRESSES:

The allowable stresses are determined according to the yield strength of the material and should take into account the load case. The permissible allowable stresses for various conditions are given below.

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Component Part</th>
<th>Recommended Materials</th>
<th>Ref to, IS No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>i)</td>
<td>Wheel</td>
<td>Cast steel</td>
<td>1030 : 1998</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cast iron</td>
<td>210 : 1993</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forged steel</td>
<td>318 : 1981</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>305 : 1981</td>
</tr>
<tr>
<td>iii)</td>
<td>Wheel pins or axles</td>
<td>Chrome nickel steel or corrosion resistance steel, mild steel with nickel or hard chromium plating</td>
<td>2062 : 1999</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1068 : 1993</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1337 : 1993</td>
</tr>
<tr>
<td>iv)</td>
<td>Structural parts of gate leaf, track base, etc</td>
<td>Carbon steel, structural steel</td>
<td>1875 : 1992</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>2062 : 1999</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8500 : 1991</td>
</tr>
<tr>
<td>v)</td>
<td>Seal</td>
<td>Rubber</td>
<td>11855 : 1986</td>
</tr>
<tr>
<td>vi)</td>
<td>Wheel track</td>
<td>a) Stainless steel</td>
<td>1570 (Part 5) : 1985</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Corrosion resistance steel</td>
<td></td>
</tr>
<tr>
<td>vii)</td>
<td>Seal seat</td>
<td>Stainless steel plate</td>
<td>2062 : 1999</td>
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<tr>
<td></td>
<td></td>
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<td>8500 : 1991</td>
</tr>
<tr>
<td>viii)</td>
<td>Seal base, seal seat base, sill beam</td>
<td>Structural steel of convenient shape</td>
<td>1570 (Part 5) : 1985</td>
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<td>ix)</td>
<td>Seal clamp</td>
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<td>6603 : 2001</td>
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<td>x)</td>
<td>Guide</td>
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<td>8500 : 1991</td>
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<td>6603 : 2001</td>
</tr>
<tr>
<td>xi)</td>
<td>Springs</td>
<td>Spring steel</td>
<td>6527 : 1995</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stainless steel</td>
<td>2062 : 1999</td>
</tr>
<tr>
<td>xii)</td>
<td>Anchor bolts</td>
<td>Structural steel</td>
<td>6527 : 1995</td>
</tr>
<tr>
<td>xiii)</td>
<td>Guide rollers and guide shoes</td>
<td>Structural steel or corrosion resistance steel, cast iron, cast steel or forged steel</td>
<td>2062 : 1999</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8500 : 1991</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1030 : 1998</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>210 : 1993</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2004 : 1991</td>
</tr>
</tbody>
</table>

NOTES:
1 Grade of the material conforming to the specifications mentioned above shall be specified by the designer to suit to the particular requirement.
2 Cast iron shall not be used for wheels and tracks for high head gates.
3 The choice of material is governed by the type of installation, accessibility for maintenance, reservoir water properties, silt, etc.
The design of gates involves the design of the following components:

Skin Plate:

This is a thin plate and is designed for the span between supporting ribs (stiffeners) girders. As per the codal criteria, it is assumed to act effectively with stiffeners/ribs. The skin plate is generally designed for either of the two conditions:

i) In bending across the stiffeners or horizontal girders as applicable.

ii) As panels in accordance with the procedure and support conditions as per codal provisions.

While designing the stiffeners and horizontal girders the skin plate can be considered coacting with them as applicable.

(a) The coacting width of skin plate in non-panel fabrication shall be taken least of:

i) \(40t + B\) (t= thickness of skin plate and B= width of stiffener flange in contact with skin plate)

ii) 0.11 span

iii) C/C of stiffeners and girders
(b) When the skin plate coacts with stiffeners as well as horizontal girders to form a panel construction, the width of skin plate coacting with stiffeners and horizontal girders shall be taken as under.
Curves showing relationship between \( \frac{L}{B} \) and reduction factors \( V_t \) and \( V_e \).
THICKNESS

The skin plate comprises the greatest part of the gate weight. Therefore, the designer should pay particular attention to its dimensioning in order to achieve the smallest possible thickness consistent with the required structural strength. Generally, the smallest thickness used in skin plates is 8 mm, which permits welding of the reinforcing elements without significant plate warping.

PLATE STRESSES

The plate bending stresses from water pressure are calculated with the theory of plates based on the theory of the elasticity as under:

\[ \sigma = \pm \frac{k}{100} \frac{a^2}{t^2} \]

Where:

- \( k \) = non-dimensional factor is function of the ratio \( b/a \) (support length of the modules formed by the beams and/or stiffeners) and the support conditions of the panel given as per BIS code.
- \( p \) = water pressure relative to the panel centre
- \( a \) = minor support length
- \( t \) = plate thickness.
The shape of the deflected skin plate determines the stress type (tension/compression). In the present case, the skin plate deflects due to the water pressure as shown in figure given above. At points a, d and e, the fibers are stretched and, by convention, the stresses are considered positive. At points b, c and f, the fibers are compressed (therefore the stresses are, by convention, negatives). As result, the plate stresses in the downstream face of the skin plate are also shown in figure given below.

The values of mono-axial as well combined stresses thus computed shall not be greater than the permissible.

For bi-axial stress conditions, the combined stress is given by the formula:

\[ \sigma^* = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau_{xy}^2} \]

Where:

\( \sigma_x \) = sum of stresses along x-axis
\( \sigma_y \) = sum of stresses along y-axis
τ_{xy} = shear stress in plane normal to x-axis or y-axis

Permissible values of stress in welds shall same as for parent material. However, for site welds efficiency of 80% of shop welds shall be considered.

*Corrosion allowance of atleast 1.5mm shall be added to the theoretical computed thickness of skin plate. Minimum thickness of skin plate shall be 8mm including corrosion allowance.*

**HORIZONTAL GIRDERS:**

They are main support members of gate and are designed for reactions transferred from the vertical stiffeners. They span between end girders and are designed as simply supported horizontal girders. Spacing of horizontal girders is influenced by the skin plate thickness; the thicker the plate, the more spaced the beams may be. If, for constructive or economic reasons, the design specifies equal sized horizontal beams, their spacing should be gradual, increasing with height, so that all be subjected to the same part of the water thrust. If the beams are equally spaced, the lower ones must be stronger since they are subjected to greater loads.

**NUMBER OF HORIZONTAL GIRDERS:**

When starting the gate leaf dimensioning, the designer faces the following problem; how many horizontal girders should the gate have? The determination of the number of beams follows a trial and error procedure. Initially, the number and dimensions of the beams are set out; then, stresses and deflections are calculated. If the results prove unsatisfactory, new values are determined and the stresses and deflections recalculated. This procedure is repeated until the desired result is attained. To overcome this initial difficulty, the following empirical formula may be used for vertical lift gates:

\[
N = \frac{100h}{t} \sqrt{\frac{H_m}{2\sigma_{adm}}}
\]

Where:
- \(N\) = number of horizontal girders
- \(h\) = gate seal height, in meters
- \(t\) = skin plate thickness, in millimeters
- \(H_m\) = water head referred to the gate centre, in meters
- \(\sigma_{adm}\) = allowable bending stress, in MPa.

The number of beams thus determined serves as a reference for the preliminary calculations of the gate leaf and only for that purpose. The final number of beams, as well as their spacing, is indicated only through the complete dimensioning of the structure.
Spacing Of Horizontal Girders:

From the viewpoint of costs, it is worthwhile to have all horizontal beams equally loaded, in order to design a unique cross section for all beams. This is achieved by dividing the pressure diagram into equivalent areas and locating the centerline of each beam in the centroid of each area.

a) Weir/Crest Gates

The graphic method for division of the pressure into equivalent areas is shown in Figure above. The sequence is:

- To divide the height $h$ (segment AB) in $n$ equal parts;
- To draw a semi-circumference centered on C;
- To horizontally link the divisions of the segment AB to the semi-circumference;
- Centered on A, transport to the segment AB the intersection points marked in the semi - circumference.

The new points marked on the segment AB outline, in the load triangle ABD, $n$ surface of equivalent areas. The horizontal beams should be located in the centroid of each area; it should be noted that all areas have a trapezoidal shape, except the top one, which is triangular. The outlining of the equivalent areas and the positioning of the horizontal beams can be made, alternatively, by means of an analytical procedure, with the use of the following equations:

- depth $h_k$

$$h_k = h \sqrt{\frac{k}{n}} \quad \text{(where } k = 1, 2, 3, \ldots, n)$$

- depth of the horizontal beams

$$y_k = \frac{2h}{3 \sqrt{n}} \left[ k^{3/2} - (k - 1)^{3/2} \right]$$

Where $n$ is the quantity of beams or areas.
b) Submerged gates

The graphic method for division of the load diagram into n equivalent areas is similar to that suggested for the weir gates, except that the compass should be centered on point O located on the free surface of water, in the extension of the segment AB.

- Depth $h_k$

$$h_k = H \frac{k + \beta}{\sqrt{n + \beta}}$$  (where $k = 1, 2, 3, \ldots, n$)

Where

$$\beta = \frac{n(H-h)^2}{H^2-(H-h)^2}$$

$H$ = maximum headwater on sill
$h$ = gate sealing height.
$n$ = quantity of areas (orbeams)

Position of horizontal beams

$$y_k = \frac{2H}{3x} \frac{1}{\sqrt{n+\beta}} [ (k + \beta)^{3/2} - (k - 1 + \beta)^{3/2} ]$$

With this method, all beams will be equally loaded. It can be also used to determine the position of equally loaded wheels of fixedwheel gates.
GIRDER DIMENSIONS:

WEB THICKNESS

Once the number of horizontal girders is determined, the next step is the choice of their cross-section. For beams supported at the ends, the minimum thickness in the region of the support is given by the formula

\[ t = \frac{F}{2h \tau_{adm}} \]

where:

- \( F \) = water load on the girder
- \( h \) = web depth
- \( \tau_{adm} \) = allowable shear stress.

In the case of very wide gates, it is usually advantageous to build the web with plates thinner in the center region than at the ends of the beam, for shear is null in the centre and maximum at the ends. The minimum recommended thickness for the web is 8 mm.

WEB DEPTH

For structural reasons, the larger the head and the support span, the higher the depth of horizontal girders. As a reference for the preliminary calculations of the characteristics of the cross-section of flat gate girders, see the empirical relations given below.

**Depth of Horizontal Girders:**

<table>
<thead>
<tr>
<th>Head on Sill</th>
<th>Web depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 15 m</td>
<td>From 1/12 up to 1/9 ( L )</td>
</tr>
</tbody>
</table>
From 15 m to 30 m  
From 1/9 up to 1/7 L

Over 30 m  
From 1/7 up to 1/5 L

Where, L is the girder support length.

Girders may be designed with constant or variable depth along the span. Variable depth girders reduce the gate weight. Sloping of the horizontal girder depth at the ends permits reduction of the lateral slot dimensions.

**FLANGES:**

Flanges are made from plates with thickness equal to or greater than that of the web. Their width can be taken equal to 1/5th of the girder depth, in the preliminary calculations. When dimensioning the gate, the designer should consider as a whole the flange width, the spacing and depth of the horizontal girders, so as to facilitate access to the interior of the gate frame for welding. A minimum gap of 300 mm gap is recommended (see Figure below) for gates with very large numbers of girders.

![Flange Diagram](image)

**COMPRESSION FLANGES:**

For built-up beams with loads applied in the plane of the web, enough safety should be built in against lateral buckling. Checking of lateral buckling may have to be done according to the standard practices. The compression flange is considered stable when the following condition is fulfilled.
\( i_y > \frac{c}{40} \)

Where:

\( i_y \) = major radius of gyration of the section formed by the flange and 1/5 of the web area;
\( c \) = distance between the girder rigid points.

**WEB STABILITY**

When dimensioning girders subjected to bending, it is convenient to space the flanges as much as possible and work with low thickness webs. However, greater the ratio between the web depth and the thickness, the greater the possibility of buckling. The web buckling should be checked for the built girder where ratio of web depth/thickness is more than or equal 45.

**SIMPLE BENDING OF BEAMS:**

The load diagram of horizontal girders of flat gates (fixed-wheel, slide, stoplogs and caterpillar) is shown as under:

![Simple Bending of Beams Diagram](attachment:image)

The bending moment at any point, such that

\[
\frac{L}{2} \geq x > \frac{L-B}{2}
\]

Is given by

\[
M_x = R_x \cdot \frac{P}{2B} \left[ x - \frac{1}{2} (L-B) \right]^2
\]
And its maximum value occurs at the midspan \((x = L/2)\), being determined by the equation

\[ M = (2L - B) F/8 \]

Where:
\[ R = \text{support reaction} = F/2 \]
\[ x = \text{distance between the support and the considered point} \]
\[ F = \text{water load acting on the girder} \]
\[ B = \text{seal span} \]
\[ L = \text{support length} \]
\[ q = \text{load per unit length} = F/B. \]

The horizontal girder deflection under load should be limited so as not to affect the safety, the movement and, in the case of upstream seals, the gate water tightness. Maximum deflection occurs at midspan and is determined by

\[ \text{Deflection} = \frac{5 FL^2}{384 EI} \]

Where:
\[ F = \text{water load on the girder} \]
\[ L = \text{support length} \]
\[ E = \text{modulus of elasticity of steel} \]
\[ I = \text{moment of inertia of girder cross-section}. \]

**Deflection of the gate:**

**Maximum deflection of the Horizontal girders/gate under normal conditions of loading shall be limited to:**

1/800 of the span \((c/c \text{ of the wheels})\) – Fixed wheel gate

1/800 of the span \((c/c \text{ of the sliding track})\) – Low head slide gate

1/2000 of the span \((c/c \text{ of the sliding track})\) – Medium and high head slide gate

1/1200 of the span \((c/c \text{ of the sliding track})\) – Medium and high head slide Bulkhead gate
However, maximum deflection shall not be more than 80% of initial interference of the seal in case of gate with upstream top seal.

**Stiffeners:**

The load from skin plate is transferred to vertical stiffeners which are designed as continuous beams spanning over the horizontal girders.

It is possible to increase the critical buckling stress of a plate without increasing its thickness, through the use of stiffeners adequately provided. Generally, the installation of stiffeners obeys the following recommendations:

Pure compressions: longitudinal stiffeners placed symmetrically in relation to the longitudinal axis;

Simple bending: longitudinal stiffeners placed at a fourth or a fifth of the web depth, near the compression flange, on one side of the web plate;

Shear: transverse stiffeners, dividing the web into square plates with each side equal to the web depth.

**End Girders:**

They transfer the load to gate wheels /slide blocks. They are designed as beams spanning between supports at wheels or as continuous beams over slide blocks.

**Design of Wheel (line contact):**

The contact stresses between the wheel and the track shall be as under:

\[ f_c = 0.418 \frac{PE}{rl} \]

\( f_c = \) contact stress in N/mm²

\( P = \) wheel load in N
\( E = \) modulus of elasticity, N/mm²
\( r = \) radius of wheel in mm
\( l = \) tread width in mm

The contact stress shall not exceed the permissible value.
**Wheel pin**

Wheel pin shall be designed for bearing, bending and shear. The pin shall be given suitable eccentricity (normally 3 to 5 mm) for permitting alignment of wheels.

**Wheel bearing**

Wheel bearing may be of bronze bussing, self lubricating bushing or antifriction roller bearing. For bronze bussing bearing stress shall not exceeds the value given in table-

For antifriction roller bearing the outer dia of the roller bearing shall not exceeds 0.6 times the wheel dia in case of point contact and 0.8 times the wheel dia in case of line contact. The bearing shall have a factor of safety of 1.5 on the static capacity.

**Dimension of Bushing:**

Bearing pressure = \( \frac{P}{ld} \)

\( P \) = wheel load

\( l \) = effective length of bushing

\( d \) = inner dia of bushing

The combined stress, for mechanical elements (wheels, pins, bearings, bush, hook, shafts, etc) subjected to a normal stress and a shear stress, is given by

\[
\sigma^* = \sqrt{\sigma^2 + 3\tau^2}
\]

Where:

\( \sigma \) = tensile or compressive stress

\( \tau \) = shear stress.

The combined stress should not exceed 1.25 times the allowable stress for the cases of normal and occasional loads and upto the yield strength, in the case of exceptional loads.

**Gate Embedments:** Gate embedments are in the form of a steel track, guides, seal seat, seal base and sill beam and anchorages which are embedded in the concrete in the grooves. The minimum edge distance ‘\( e \)’ of the bearing flange plate shall in no case be less than 150mm
**Gate Slot/Groove:**

Vertical lift gate (Fixed wheel/Slide type) transfer water load on the embedded parts installed in the gate slot. Gate slot usually houses the gate support, guide elements, wheel and sliding tracks, seal seats, side guides, etc. Gate slots disrupt the boundary lines, create vortices and cause the separation of the flow at their boundaries resulting in low pressure in the vicinity of the slot. High flow velocity coupled with severe low pressures may cause erosion and cavitations in the downstream. It is desirable to keep gate slot dimensions as small as possible to minimize flow disturbances and to avoid trapping of any debris.

Offsetting (0.1 to 0.2 of slot length) the d/s slot edge considerably improves upon the local condition of the flow, eliminates or reduces the low pressure near the wall. In case of high head installation, the d/s edge of gate slot should be rounded and side wall given slope of 1 in 10 or flatter. Offsetting of gate slot is not required for the low head gated installations.

Rectangular gate slots should not be provided except for very low head gates.
Width (W) of gate slot should be kept as small as practicable. Depth (D) of slot has little effect on cavitations hazard. The optimum W/D ratio falls in the range of 1.4 to 1.8. In practice, higher values can be adopted as per physical requirements.

For gates operating under a head of say 10 m or more, the downstream edge of the gate slot should be off-set to reduce the cavitations hazard. A downstream offset of 0.075 to 0.10 of the slot width (W) with gradient of 1/10 to 1/12 for heads upto 30 m & 1/24 or flatter beyond 30m head, downstream of the gate slot and a rounded point of inter-section with Radius ‘R’ as 0.10 times the D (say R=3 cm to 5 cm) is recommended. Upstream slot face should have a sharp and not rounded corner.

**Guide rollers/guide shoes**

The guides shall be fixed inside the groove/slots. The guide shall be flat plate or a rail section as required. The minimum thickness of plate shall be 20mm (Low head gate), 32mm (Medium head gate) and 40mm (High head gate). The guide shall continue for the full range of gate travel.

**Seals/seal seats:**

Appropriate types of seals should be chosen to achieve water tightness. A variety of seals is available in India and different types of these are shown in figure given below. The seals are made from natural or synthetic rubber and should confirm to BIS standard IS: 11855.
Double stem type (preferably with cladding) for top and top corner seals, music note seal for sides of the high head gate.
Solid bulb music note type seal for the medium head gate.
Hollow/Solid bulb music note type or L-type seal for the low head gate.
Wedge type seal may be used at the bottom of the gate when the gate happens to rest on the sill.
However, if the gate slides on the face of the opening, music note or double stem seal may be
used. The minimum width of stainless steel seal seat shall be 80mm and minimum thickness shall be 6mm (low head) and 8mm (Medium and high head).

Upstream sealing gates have more chances of leakage as compared to downstream sealing. A seal guard is usually provided for those installations, where presence of debris is likely to damage the gate seals, particularly in case of bottom seals. Solid bulb music note seals are recommended at sides & top of gates operated under medium head (i.e. at a head of water $\geq 15m$ but less than $30m$). These seals are also recommended for high head installations (i.e. water head $\geq 30m$) as side seals. However, double stem seals are recommended for application as top seals because music note type seals at this location particularly for upstream sealing gates suffer from rolling action, when the gate is moved. Double stem seals should be clamped only on the extreme edges of seals. Projection of gate bottom seal should be restricted to the minimum possible as per design requirements as it can become one of the sources of gate vibration.

**Wheel/slides track:**

These tracks are designed as an infinitely long beams resting on elastic foundation subjected concentrated or uniformly distributed load transmitted by the wheel or sliding track respectively. The hardness of the wheel track shall be 50 point BHN higher than that of wheel tread to reduce its wear.
Thickness of Track plate (line contact):

\[ b = 1.55 \frac{P}{\sqrt{E}} \]

\( P \) = wheel load in N  
\( E \) = modulus of elasticity, N/mm²  
\( r \) = radius of wheel in mm  
\( l \) = tread width in mm  

Minimum thickness of track, \( t = 6 \times 0.786 \times b \)

**Thickness of Track plate (point contact):**

\[ t = \frac{1.27 P}{2cf} \]

\( t \) = thickness of track in mm  
\( P \) = wheel load in N  
\( 2c \) = track width in mm  
\( f \) = allowable track bending stress in N/mm²  

The minimum thickness of track plate any case shall not be less than 10mm.

**Bearing stress in concrete:**

The stress in bearing for concrete shall not exceed the value specified in IS: 456. Concrete in contact with track shall be of atleast M20 grade.

\[ p = 0.2833 \times P \left( \frac{E_c}{E_s} \times \frac{I}{w^2} \right)^{1/3} \]

\( p \) = bearing stress in concrete, N/mm²  
\( P \) = wheel load in N  
\( E_c \) = modulus of elasticity of concrete, N/mm²  
\( E_s \) = modulus of elasticity of steel, N/mm²  
\( I \) = moment of inertia of track base, mm⁴  
\( w \) = width of track base in contact with concrete, mm  

*If the pressure distribution under adjacent wheels overlaps, superposition of pressure shall be adopted and checked for the worst condition.*
Chapter 3

Failure of Barrage Gates – a case study

Introduction

Gates are structural components of barrages without which these civil hydraulic structures would be rendered dysfunctional. Barrages and cross regulators are provided with radial or sluice/ crest gates to maintain upstream water levels within the desirable range. These gated structures are essential for the hydraulic control of these channels to ensure proper feeding of lateral channels/ off-takes at all range of flow rates or to allow navigation when the canal discharges are not large enough to maintain deep normal depths. Barrages are designed as multi-vent structures to limit the span of their gates and to provide flexibility in their operation under a variety of operating discharges up to the design maximum discharge.

Causes of gate failures in Barrages:

1. Corrosion of gate structural components

Corrosion is destruction of metal by electro-chemical or simple chemical action. It is the single most destructive cause of failure of majority of barrage gates. Corrosion needs moisture and oxygen, both of which are abundantly present in atmosphere. In steels, carbon gets converted to carbonate and iron to oxide. Corrosion attacks the inter-crystalline boundaries of metal and thus causes pitting at the interface.

Initial corrosion or rust formation forms a protective layer and hence retards further corrosion, though not stopped altogether. Rate of corrosion is high in water but in flowing water, this is further accelerated due to increased contact of dissolved oxygen. The rate of corrosion also increases with increase in temperature i.e. it is faster in hot summers than in winters.
If two metals of different chemical compositions are in contact in presence of any media or water, an electro-potential or electric current is established between them leading to initiation of corrosion. This phenomena causes corrosion at weld joints of two pieces of steel, as the welding material does not have the same chemical composition as that of the metals joined together.

Stresses in the gates of the Barrage caused by static water pressure gets multiplied due to effects of dynamic (i.e., flowing water) pressure and natural vibrations produced at high discharges of water. Added to this are vibrations caused by heavy traffic across the road and rail bridge. The repeated stresses cause failure of metal at much below its ultimate tensile strength and such a phenomena is called fatigue failure. If metal is corroded, failure is still at much lower tensile strength. The combined action of corrosion and repeated stresses is called corrosion fatigue.

According to a study done by National Performance of Dams Program (NPDP) of Stanford University of 65 events of hydraulic gates failure, close to 50% had been because of corrosion leading to structural failures.

2. Obstructions in gate slot:
The gate slots/ grooves with obstructions like concrete projections/ bulge, uncut steel rods or wooden pieces etc. hinder free movement of the gate in the grooves. The presence of these may lead to malfunctioning in gate operation and structural damage to the gate components.

3. Inaccessibility of the gates:
Inaccessibility of the gated structure due to absence or weakening of inspection platforms, ladder rungs and hand rails etc. may lead to neglect in their regular inspection and maintenance which will ultimately cause their failures.
4. Accumulation of silt/ slush on gate components:
The accumulation of silt/ slush and other floating debris on gate girders etc. causes damage to the painted surfaces and this in turn accelerates their corrosion leading to loss of strength in structural components. The silt or slush accumulated between seals and their mating surfaces can also cause damage to the seals and cause operational problems due to increased friction. Their accumulation in the wheel assemblies causes resistance to roller movement or unequal movement. This condition may result in jamming or non-rolling of wheels.

5. Impact of floating logs/ Debris:
In hilly terrain the floating logs or trees can hit the gate leaf with considerable impact and damage it.

6. Missing oil caps or grease nipples:
The missing lubrication oil caps and grease nipples in assemblies of gates or their hoists allows ingress of water, dirt or silt which can block the narrow passage meant for forcing in the lubrication. Non-supply of lubricants to the bearing increases the frictional forces and damages the bearings. This causes failure of wheel assemblies and damage to the gate leaf.

7. Missing and Loose fasteners:
The fasteners (bolts, screws, studs, nuts, etc.) which are missing or not properly tightened to the required torque are vulnerable areas in maintenance of joints. The bolted joints between various components of the gate leaf if loosely fixed or missing may result in failures of adjoining components or gate itself, due to insufficient strength of joint.

8. Absence or choking of drain holes:
Girder webs are susceptible to water accumulation in absence of sufficient numbers of drain holes of suitable sizes. The accumulated water on girders etc., due to non provision of drain holes or choked holes due to trash intrusion need to be drained on regular basis as it may result in corrosion and loss of load bearing capacity of gates.

9. Weakening of welds:
All weld joints made may undergo cracking or rusting due to aging factors and if not attended to may lead to structural failures. Weld repairs should be performed as per standards during the inspection/ maintenance at regular intervals.
10. Lack of Greasing and Lubrication:
The greasing and lubrication of bearings of wheel assemblies meant for their intended purpose is essential and if not attended to as per standards may lead to their seizure or jamming thus jeopardizing the safety of gates. The rotation of wheel assemblies could be simply checked by rotating with one or two hands when the gate is fully raised.

11. Misalignment of Rollers with Track face:
It is essential to ensure that all rollers are in contact with track face in the closed position and during its vertical travel. The pitting of track shall be examined and smooth contact established throughout travel of rollers.

12. Misalignment of Guide roller/Guide shoe:
Loose fastening of guide rollers assembly/shoes to gate body may dislocate their path of travel on the track leading to gate sway or jamming. If the guide roller faces are rusted or no free rotation is ensured, they offer additional friction and malfunctioning.

13. Gate fouling with surfaces of piers/grooves:
Fouling of gate components with surfaces of piers/grooves, and other allied civil mechanical structures due to certain omissions in designs and construction such as insufficient gap between guide system, misalignment of track & gate wheels, unequal rope tensions and suspension points out of C.G. plane etc is not desirable. In radial gates, care should be taken that the ropes do not foul with any part of concrete bridge or components of gate, during its entire travel.

14. Rubber Seals:
Excessive seal interference (preferably 3-4 mm, or as specified) between seal and its seat, uneven seal contact, back folded or damaged seals, intrusion of foreign materials between the seal and seat etc, create additional frictional forces and have adverse effect on functioning of gate. Caulking of seal gaps with grass, gunny bags and other materials to arrest leakage at any stage, shall not be resorted to.
Prevention

Corrosion being the primary reason of gates failure shall be focus of preventive methods adopted to prolong the economic life of steel structural components. There are various detectors like ultrasonic equipment, magnetic crack detectors, nuclear flow detectors and X-Ray detectors which can show the depth of corrosion damage, but the extent to which the tensile strength has been reduced by corrosion, pressure load and vibration could only be found by taking out some of the components and putting them under various laboratory tests for assessing both tensile and compression strength.

Rust is permeable to air and water, therefore the interior metallic iron beneath a rust layer continues to corrode. Rust prevention thus requires coatings that preclude rust formation. A brief overview of methods is presented here:

a. Corrosion-resistant alloys

Stainless steel forms a passivation layer of chromium (III) oxide thereby inhibiting the process of corrosion to large extent. Designs using this material must include measures that avoid worst-case exposures, since the material still continues to corrode slowly even under near-ideal conditions.

b. Galvanization/ Metallising

Galvanization consists of an application of a layer of metallic zinc by either hot-dip galvanizing or electroplating. Zinc is traditionally used because it is cheap, adheres well to steel, and provides cathodic protection to the steel surface in case of damage of the zinc layer. In more corrosive environments (such as salt water), cadmium plating is preferred. Galvanization often fails at seams, holes, and joints where there are gaps in the coating. In these cases, the coating still provides some partial cathodic protection to iron, by acting as a galvanic anode and corroding itself instead of the underlying protected metal. The protective zinc layer is consumed by this action, and thus galvanization provides protection only for a limited period of time.

Metallisation is the most efficient corrosion protection system for application in aggressive conditions. The process involves application of a layer or zinc and/or aluminium to a blast-cleaned surface. It results in a layer that remains stuck to parent material for longer duration.
More modern coatings add Aluminium to the coating as zinc-alume; aluminium will migrate to cover scratches and thus provide protection for a longer period. These approaches rely on the aluminium and zinc oxides re-protecting a once-scratched surface, rather than oxidizing as a sacrificial anode as in traditional galvanized coatings.

c. Cathodic protection

Cathodic protection is a technique used to inhibit corrosion on buried or immersed structures by supplying an electrical charge that suppresses the electro-chemical reaction. If correctly applied, corrosion can be stopped completely. In its simplest form, it is achieved by attaching a sacrificial anode, thereby making the iron or steel the cathode in the cell formed. The sacrificial anode must be made from something with a more negative electrode potential than the iron or steel, commonly zinc, aluminium, or magnesium. The sacrificial anode will eventually corrode away, ceasing its protective action unless it is replaced in a timely manner.

d. Coatings and painting

Prevention of corrosion by painting in itself is a highly specialized field. Corrosion can be controlled with coatings, such as paint, lacquer, or varnish that isolate the iron from the environment. Covering steel with cement latex can provide some protection to steel because of the alkaline pH environment at the steel-concrete interface. However rusting of steel in concrete can still be a problem, since expanding rust can fracture or slowly "explode" concrete from within.

The metallic components of gates have to be cleaned by sand blasting; use of any manual method would not remove all the corrosion or rust and it would simply be waste and any amount of paint will go off from corroded section, the corroded spots will expand to adjoining areas underneath the paint. After sand blasting, the surface is cleaned with chromic acid (\(M_2Cr_2O_7\)). This would ensure removal of any residual corrosion and also forms a protective coat. Paints for underneath water services have greatly improved in recent years. The lead based primer followed by application of coal tar epoxy paints, metallising etc. have been used with some degree of success. Paint technology is an ever evolving subject and has undergone revolutionary changes and hence present day recommendation may not apply after a few years.
Special anti-seize lubricant mixtures are available, and are applied to metallic threads and other precision machined surfaces to protect them from corrosion. These compounds usually contain grease mixed with copper, zinc, or aluminum powder, and other proprietary ingredients.

Corrosion is retarded if the metal is cleaned (by sand blasting in case of barrage gates) and repainted every 4-5 years. However, the process of sand blasting results in removal of corrosion (rust) and small thickness steel. This periodical cleaning of rust from gate sections keeps reducing their thickness specially the lower braces and in due course of time they are not able to stand the pressure of water and other loading conditions. But there is no escape from it. This would in general reduce the life of the gates and there would be a time limit when the gates would need replacement. It is not being suggested that the gates may be replaced immediately, but it is only to point out that there will be a time limit to the life of gates. If one of the gates failed, it is an indication that some of its components had worn out to their yielding point.

**Planning aspect for Operation and maintenance of Barrage gates**

It is well understood that certain aspects if taken care of during planning or design stage for the gates may result in ease of their inspection, repairs and maintenance and in turn increasing the longevity of these structures. The components of the barrage gates subjected to harsh environment i.e. acidic water etc. need to be fabricated from stainless steel plates to increase their longevity. The provision of antifriction spherical bearing in place of conventional spherical bearing can reduce the maintenance requirement in wheel assemblies. While designing the wheel assemblies, these shall be planned in a manner facilitating easy
removal from the gate for their maintenance. It has also been noticed that at certain installations provision for stop logs have not been kept to isolate the bay for inspection and maintenance requirements. This requirement should be taken care during the planning stage itself. Similarly, the provision of catwalk Bridge is essential to attend the inspection and maintenance of the gates and provision for the same shall be kept at the planning stage. Another aspect which can be taken care of during the planning stage is the requirement of adequate height of the trestles so that gates could be fully lifted above the gate groove for maintenance and repairs. An instance has come to notice at a certain installation where it was not possible to take out the gate from gate groove due to inadequate height of the hoist trestle thus hampering the maintenance and repairs.

**Operation and maintenance of Barrage gates:**

Proper maintenance of Hydraulic gates and hoists is very important for satisfactory operation of gates and to achieve the envisaged benefits from the project. For systematic operation and maintenance of the gates and their accessories, it is very important to have a comprehensive operation and maintenance manual which shall include the design features of various components, particulars of bought-out items and source of availability, operating instructions, type of lubrication oil and grease or their equivalents and schedule of maintenance and repairs.

The O&M manuals are prepared for each hydraulic gate installation and the operating personnel shall be properly trained and experienced for the job so that they can use their initiative and judgment based on their past experience for situations which may arise during operation. Day-to-day experience on operation and difficulties encountered, if any, should be faithfully recorded in the log book of gates so as to be available for analysing the behavior of various structures and equipment. Detailed instructions for inspection and normal maintenance and repairs of gate installation should be given in operation and maintenance manual. However, for carrying out special repairs of gates, if any, it is advisable to refer the matter to Experts. Inspection and maintenance experience are compiled in the form of History register of any installation so as to be useful for future designs, investigation of any failure, improper and unusual operation of gates.

IS: 10096 for Inspection of Radial Gates and Rope drum hoists and IS: 7718 Inspection of Vertical and slide gates are the Indian Standards issued by BIS which provides broad guidelines for inspection, testing and maintenance of gates and their hoists.
Failure of gates at Farakka Barrage Project – A case study

Farakka Barrage Project on river Ganga was commissioned in the year 1975. The operation and maintenance of various components of the barrage is being done by Farakka Barrage Project (FBP). The Project is situated at about 220 Km. north of Kolkata in Murshidabad district of West Bengal. The Farakka Barrage and other ancillary works have been constructed with the main objective of preservation and maintenance of the Kolkata Port and to improve navigability of the Bhagirathi-Hooghly-Ganga River. The water from main barrage is diverted to Bhagirathi through a 36 Km. long feeder canal, off-taking from right bank, with a design discharge of about 1130 cumecs. The desired purpose is achieved by maintaining the pond level on the upstream of barrage. The designed pond level as envisaged in the plan is 21.95m (72.00 feet). When water in the river is in excess, the surplus water is allowed to flow downstream towards Bangladesh by opening the gates and during lean season, the flow of water to the downstream is either reduced or cut off to maintain desired pond level. The Project has international ramifications and at present the sharing of Ganga water between Indian & Bangladesh is being done as per Treaty of 1996. The Treaty stipulates sharing of water between two countries during January-May period wherein India shall maintain the flow at Farakka at an average level of previous 40 years.

![Aerial view of Farakka Barrage](image)

The Hoogly-Bhagirathi-Ganga waterway between Haldia & Allahabad (1620Km) is an inter-state navigational waterway and has been declared as a National waterway (NW) No.1 by GoI. Navigational Lock at Farakka was constructed as a part of Farakka Barrage Project to
facilitate movement of vessels on NW-1 through Feeder Canal. The Project is also the lifeline for North-East Indian states as these are connected via NH-34 and rail line running over the barrage. The entire development of NTPC Super Thermal Power Station (2100MW) at Farakka has happened due to the barrage. The total length of the barrage from abutment to abutment is 2245m and the clear waterway provided in the barrage is 1990m.

**Barrage gates and Head Regulators**

The barrage consists of 24 under sluice bays provided with vertical under sluice gates of size 18.29m (60.00 feet) x 7.93 m (25.00 feet) each, 2 fish lock bays with 4 nos. Fish pass gates of size 7.62m x 2.90m each and 84 spillway bays with vertical crest gates of 18.29m (60.00 feet) x 6.40m (21.00 feet) each. The gates have been provided with electrically operated rope drum hoists with counter weights attached between gates and their hoists to reduce the hoisting effort.

The provision of eight set of stop logs with 8 pieces per set has been made for the maintenance of main gates. These stop logs are operated with the help of 25t gantry crane. The stop logs units are operated under balanced head conditions except the top unit which is raised under unbalanced head of water.

The feeder canal head regulator has been provided with 11 sets of regulator gates in three tiers with each tier operated with the help of independent rope drum hoist.

**Chronological order of failure of barrage gates and action taken:**

a. **Gate No. 8:**
   
   i. **Case-I:** Originally installed under sluice Gate no. 8 of Farakka Barrage was washed-out in December 1999 due to weakness of structural elements caused by substantial corrosion. The work of lowering the spare gate in Bay no. 8 was completed in March, 2000. In the meanwhile, a committee was constituted under the Chairmanship of Chairman, CWC by MoWR to investigate the causes of failure of gate no. 8, review the existing condition of various gated structures, and review the progress of repair works on existing gates being done by M/s NPCC & M/s Jessop and any allied matter. The Committee held two meetings and made wide ranging recommendations for comprehensive rehabilitation of gated
structures to avoid a future mishap like Bay no. 8. The Committee had also stressed upon the need to carry out a comprehensive health status of all gates so that the replacement/repairs of highly distressed gates could be taken-up on priority basis. However, this could never be implemented.

ii. **Case-II:** The said gate no. 8 again developed operational problems in December, 2003. The gate had remained stuck in lower region (approx 7’ from sill) and its further movement had ceased. Experts from CWC inspected the gate in April, 2004 and suggested to lower the stop logs in the bay and take remedial measures to make the gate operational. The non-functioning gate was lifted above water level and the cause was found to be failure of right side bottom end-box assembly. Subsequently, the bay was plugged with stop logs. All the 4 end box assemblies were modified and repaired by M/s TSPL finally in Dec, 2005. However, the gate could not be made fully operational and TAC recommended for its replacement as per advice of CWC.

b. **Gate No. 17:**

It was reported in February, 2007 that debris in the form of heavy log of wood/stone carried by swift water current from upstream of Barrage struck the Gate no. 17 in its bottom portion resulting in bending/buckling of the horizontal member at the bottom. The movement of debris reportedly occurred due to sudden increase of flow following rainfall in the upper catchments of river Ganga. Expert Team of CWC after inspection attributed the failure of gate no. 17 to weakness & loss of strength of structural members caused due to extensive corrosion.
In June, 2008, top central portion of spillway gate in Bay no. 74 got bent in V-notch shape in downstream direction resulting in water flowing over the top of gate. Expert Team from CWC inspected the gate and recommended lowering of stop logs to prevent further damage to gate. The team was of the opinion that this damage could have been either due to sudden impact by floating objects or general weakening of structural components. The work for lowering stop logs in flowing water conditions was awarded to M/s Jessop & Co. who had been associated with original fabrication, erection and subsequent repairs of these gates & hoists. The lowering of stop logs was finally accomplished thus completely blocking the bay.

c. **Gate No. 13:**

In June, 2011, the under sluice gate at Bay no. 13 failed structurally. Expert team from CWC inspected the gate on and found the gate to be in buckled and mangled state lying downstream of its grooves, held by wire ropes tied to hoist. The gate was found damaged beyond repair and was recommended for replacement.

d. **Gate No. 16:**

In December, 2011, the under sluice gate at Bay no. 16 failed structurally. Expert team from CWC inspected the gate on and found the gate to be in buckled and mangled state lying downstream of its grooves, held by wire ropes tied to hoist. Again the gate was found damaged beyond economic repair and was recommended for replacement.

Since then the gate Nos. 13 & 16 have already been replaced with spare gates available with FBP. The replacement of gates in bay Nos. 13 & 16 posed numerous problems due to acute prevailing circumstances causing limited access to the gate grooves. The access from downstream was hindered due to busy rail-cum-road bridge running over barrage and hence
handling of gates’ segments and erection aid material from d/s side was totally ruled out. The high flow velocity through these bays made it practically impossible to transport the gate segments and other materials from upstream. The availability of barge mounted with heavy duty crane and capable to stay stable under flowing water may have helped to some extent. However, the same was not readily available for the task at hand. The Farakka Barrage Project had neither means nor machinery to execute this task in flowing water conditions. The only material handling device that could be of some use and available at site was a 25t Gantry crane meant for operation of stop log units.

In addition to limited resources available, the task required trained manpower for execution. Mechanical staff of FBP, comprising of a few persons, was neither trained for this job nor did they have competency to undertake such a difficult task. The only other alternative was to hire an outside agency specialized to execute such works. The situation was further aggravated due to paucity of time with FBP as lean season was fast approaching and pond water level was continuously reducing due to uncontrolled discharge through the bays. It did affect the navigability of NW-1 for short span of time till the bays were blocked. Initially, the plugging of bays was tried by lowering stoplogs units in flowing water conditions with adequate precautions but did not succeed as these stop logs are designed for operation under balanced head condition. Eventually, an outside specialized agency was hired to execute the works.

Causes and Recommendations:

As evident from failures cited in above Paras, corrosion has been the most significant cause leading to loss of designed strength of gates and finally resulting in structural failures. This stage has been reached due to lack or near absence of preventive maintenance program. A brief recommendation has been made to avoid such mishaps in future and to keep the Barrage functional in order to achieve the intended objectives:

- Strengthening & refurbishing of 3 spare spillway gates lying in parts in storage yard and placing them in bays where the gates are in severely distressed condition.
- Procurement of additional sets of stoplogs, if felt necessary.
- All the bays must be well lit with adequate luminescence to enable inspection and operation even during night. Catwalks to be fabricated and erected on downstream side of gate for easy access for regular maintenance works.
• All necessary equipments such as chain pulley block, welding sets, drilling machines etc for carrying out regular maintenance & emergency repair works be procured.

• Formulation of Preventive maintenance program and strict adherence to provisions for existing as well as expected new gates. Log-books for all gates and equipment should be strictly maintained.

• Immediate repair of 2nd Gantry crane for reducing the turn-around time for movement of stoplog units and spare gate parts.

• Deployment of dedicated and trained staff for carrying out routine maintenance works.

• Immediate filling of vacant posts and posting of additional staff for maintenance program. The existing staff need be motivated to take the respective responsibilities.

• Identification of distressed gates and timely action for repairing them, if any, either departmentally or through outside agencies.

**Future Road Map**

To conclude, most of the gates of main barrage and head regulator are in precarious condition and unless some urgent measures are adopted to restore their design strength, their collapse seems inevitable any time. These gates have already outlived their economic life and any future special repairs on these gates can only postpone the disaster in waiting for a couple of years. Instead of tackling the problems in a solitary & piece-meal basis, a comprehensive solution of replacing these gates in a phased manner needed to be devised. Considering the importance of this Project, it was felt that the most distressed gates need to be replaced first on a priority basis and the least distressed ones on a later date over a period of five years of current 12th five year plan. Accordingly, the Project Authority would need to propose the phasing based on their day-to-day experience while dealing with these gates during their operation and maintenance. As a follow up action, procurement of 6 new gates is already in advanced stage and gates are likely to be erected in the current financial year. The tendering process for procurement of 33 new gates is also in advance stage and LOI for their procurement is likely to place in near future. The replacement of remaining gates of main barrage and head regulator shall be taken up at appropriate time.
Chapter 4

Hydraulic Hoists for Gates

Introduction:

Hydraulic Gates are used for controlling and regulating of water in various water resources structures. Selection of particular type of hoist depends on the functional requirement as well as economy, availability, and ease of maintenance etc. The functional requirement include type of gate, life of gate, location of gate, head of water on the gate, speed of operation required and whether the gate is self-closing or not.

There are different types of hoisting mechanism available for operation of the gates. These includes Screw hoists, Rope drum hoists, Chain hoists and Hydraulic hoists, etc., The Screw hoists can be operated either manually or electrically and are easy for operation and inexpensive. These hoists can exert downward force for closing but have the limitation in respect of higher capacities of hoist. These also have limitations of speed of operation and when the operating chamber is located at a higher elevation from the location of the gate. Other commonly used types of hoists are Rope drum hoists. These are electro-mechanical hoists. Speed of the operation is generally low and these hoists cannot exert downward force for closing the gates. The Gates are to be designed for self-closure. Thus the Rope drum hoists have limitations when the capacities are very high, gate is not self-closing and speed of operation is variable.

The various constructional elements of the mechanical drive, such as lifting elements, gearboxes, frames etc. are normally designed for one particular installation and produced as one off design. Spare parts therefore difficult to supply, as opposed to this, oil hydraulic drives are assembled using constructional elements produced in large quantities. The cylinder alone is one-off designs, depending on the circumstances. Hence the recent trend is to use Hydraulic hoists for the operation of gates. The Hydraulic drive systems are modern, more sophisticated and offer better control of gates. These offer higher degree of operational reliability, long life, higher degree of automation and minimum maintenance.
**Hydraulic Hoists Construction**

The Hydraulic hoists consist of a hydraulic cylinder with an upper and lower head, piston with seals, piston rod or stem rod passing through a packing seal in the lower cylinder head. The gates can be closed or opened with the movement of the piston rods. The cylinder is mounted on a structural work or bonnet cover depending upon the location and requirements. The piston rod extends and is linked to the gate by a hook or an eye type coupling. Hydraulic hoists can be double acting or single action depending upon the operational requirement.

Fig.1 Represents of a Hydraulic Cylinder, Piston Rod, Connecting Stem, etc. and other components which are listed below and Fig-2 indicates schematic diagram of a Hydraulic Hoist:

![Fig-1 Diagram](image)

<table>
<thead>
<tr>
<th>a- Clevis</th>
<th>f- Piston Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>b- Upper Head</td>
<td>g- Piston rod/stem</td>
</tr>
<tr>
<td>c- Cylinder Shell</td>
<td>h- Piston rod guide-bush</td>
</tr>
<tr>
<td>d- Piston</td>
<td>i- Seal</td>
</tr>
<tr>
<td>e- Bottom Head</td>
<td></td>
</tr>
</tbody>
</table>

**Operation:**

The hydraulic hoists are operated by power pack comprising of a motor, Oil pump with directional flow of oil controlled valves which are actuated by electric contacts from any
desired position. An oil tank with filter, strainers and piping will be provided to supply or receive oil. The hydraulic oil which is admitted into the cylinder under pressure, forces the piston to move up or down. The circuit diagram is shown in fig-2

Fig-2
**Design trends:**

The Hydraulic hoists installations earlier had an operating pressure limit of 70 Kg/cm². But as reliable components of higher pressure are available, now day’s hoists are designed at higher pressure to reduce the size of cylinder. Presently the hoists are designed for pressure ranges of 100 to 200 Kg/cm². Also, the BIS code IS: 10210 specifies a design pressure range between 10N/mm² to 20N/mm². DIN 19704 permits a maximum pressure of 220 bar for loading under normal operations. Hoists used for Spillway Service Gates are normally operated around 0.3 to 0.7 Metres/minute, while penstock gates are operated around 2 Metres/minute for lowering and lifting 5 to 10 Metres/minute for emergency closure.

**Technology trends:**

The sealing arrangement and selection of material: The sealing arrangement and selection of material require careful consideration. Chevron seals are used for the seals at system and at lower cylinder head position. The Chevron seals on the rod are to be adjustable type. The sealing technology has been improved and in recent years modern wear resistance material and function related design of seals and bearing elements are developed. The base material for these seals is Poly Tetra Floro Ethylene (PTFE) and PTFE compounds for the sliding elements and Poly Urethane for the elastic packing material. These seals offer low friction and smooth sliding even at very low or high rubbing speeds.

The materials for bearing and supports in cylinder also require careful consideration and selection. Swivel Clevis eyes with corrosion protection are being provided now a days.

Cylinder tubes with diameter of 250mm or less are made from seamless precision steel tubes. The material used for cylinders shall be at least St-52 or equivalent.

The cylinders operating in open air and humid conditions should be equipped with stainless steel piston rods. The specification for the material is to be chosen depending upon the environmental conditions and water characteristics. X 20 Cr Ni 17 or X 22 Cr Ni 17 or equivalent corrosion resistant steel is normally used for piston rods. In special cases better quality materials are also to be used. The stem rods should also be hard chrome plated to 30 to 50 microns on the surface. The application of nickel and chromium layers has given good results for corrosion resistance. Piston rods coated with Ceramics are also being used.
It is also desirable to provide corrosion protected screws to connections. The manufacture and process technology of the Hydraulic Cylinders involve high precision. The tolerances involved in the various components are in microns. Use of special purpose and precision machines with improved measuring, inspection and testing equipment are required. Further, use of improved surface treatment and surface finishing techniques such as honing are also called for. The surface roughness inside the tubes shall be less than or equal to 1.3 to 1.6 microns and for piston rods less than or equal to 0.2 microns.

**Power packs:**

The designs of power packs operating hydraulic gates require special attention. The power packs are to be designed to handle large volume of oil to be discharged in a limited and specified period of time. The power pack can be divided into three units, a pressure generation unit consisting of a liquid tank, pump, motor and its components, the transmission unit comprising of the pipe line, and the pressure conversion unit with isolating valves, control valves and cylinder. The isolating blocks are provided where the gates are to be held for long periods in intermediate position. Cartridge valves are now a day used for discharging large volume of liquid/oil. For high liquid/oil flows, variable pumps with proportional controls are used so that in the event of failure of any pump the gate can at least be operated with another motor pump set at reduced velocity or at the same velocity depending upon the motor and pump provided.

The speed of motor is generally limited to 1000 rpm and noise level to 80 dB to protect environment. Other liquids are also being tried instead of mineral oil. Polyalkl glycols under certain conditions are being tried. The pressure of the fluid in the pipe lines is limited to 3 m/sec in pressure lines and 0.6 m/sec in suction lines. For better operation filters with of 10 microns are used. The control valves are grouped together in control blocks. Venting cocks at the highest cylinder connections for venting air entrapped in the pipes are provided.

The Hydraulic drive systems are modern, more sophisticated and offer better control of gates. These offer higher degree of operational reliability, long life, higher degree of automation and minimum maintenance.

**Advantages:**

The Hydraulic hoists have the following advantages over other types of hoists:
1. Higher degree of operational reliability.
2. More practicable to have variety of capacities and particularly higher capacities.
3. Large range of lifting and lowering speeds can be easily achieved.
4. Positive thrust.
5. Higher degree of automation.
6. Occupy less space, compared to Rope-drum hoists.
7. Lesser weight.
8. Reduced vibration
9. Ease of installation
10. Minimum maintenance

**Maintenance:**

Hydraulic hoist systems will operate well and can be easily serviced with careful planning and design of the system. Provision of manifolds in power packs will help in reducing the piping, couplings and space enabling for easy and better maintenance.

In Mechanical drives the lifting components such as gears, bushing etc. require constant maintenance and lubrication. While in Hydraulic drives the energy carrier at the same time acts as a lubricant. Maintenance work on oil hydraulic is minimal. It is usually restricted to routine checks. Comparable studies have shown that the extent maintenance is approximately 9 to 12% that required in Mechanical drives.

Oil selected for use in the systems should have additives to ensure anti-wear characteristics, must have proper viscosity to maintain sealing and lubricating quality at the expected operating temperature of the system. It should also have rust and oxidation inhibitors for satisfactory system operation.

The life of Hydraulic hoist system depends upon cleanliness of the fluid and the controls. The external cleaning, use of filters, oil substitution for every 2000 – 3000 hours of operation etc., with at frequency of monthly maintenance will help to maintain the system in good condition. The provision of isolating valve will help isolating a particular line for easy maintenance. Limit switches for monitoring the fully opened position and closed position of gates and also for monitoring oil level are necessary. A well planned power pack with indicating lamps and labels is valuable for effective maintenance.
Applications:

In view of the advantages as brought out above, the Hydraulic hoists find their applications in all most all types of gated installations. Fig-3 & Fig-4 shows the Hydraulic hoist for fixed wheel gates and intake gate respectively. Fig-5 shows the Hydraulic hoist for a slide type of gate. Fig-6 shows the Hydraulic hoist for a Radial gate with Flap. Fig-7 shows Hydraulic hoist for Sluice Radial gate. Fig-8 shows Hydraulic hoist for a Spillway Radial gate.
FIG. 8: HYDRAULIC HOIST FOR SPILLWAY RADIAL GATE
Chapter 5

Calculations for design of Vertical Lift Gate and Hoist capacity for Gates

1. Design of Vertical lift gate:

A vertical lift gate 4m wide by 6m high has six equally loaded horizontal girders and is subjected to a water head of 10m on the sill.

i) Draw the pressure diagram.

ii) Calculate maximum water thrust on the gate and its position?

iii) Determine the location of the horizontal girders?

iv) Give comments & suggestions if any on the positioning of the top most and bottom most girder.

2. Hoist capacity calculation:

Calculate the hoist capacity for operation of Vertical lift type fixed wheel gates designed for water head corresponding to FRL are provided on the spillway of the project. The gates are having U/S skin plate & sealing. Side seals are hollow bulb J-type rubber seals and flat type rubber seal (rectangular section) at bottom. The gates are designed as per IS 4622. The gates are operated by means of individual electrical operated Rope Drum Hoist under unbalanced head. Check also the requirement of ballast if any for self closing of the gate?

Technical details:

- Vent width (Span) :12000mm
- Sill level :EL 241.30 m
- FRL/MWL : EL 246.50 m
- Spill way crest level : EL 241.50 m
- Top of pier level : EL 251.00m
- Thickness of bottom seal : 14 mm
- Dia of hollow bulb Side seals : 44mm
- Thickness of seal clamp plate :10 mm
- Wheel outer dia : 200 mm
- Wheel pin outer dia : 100 mm
Assume suitable data if any required.

**Gate weight (G):**

\[ G = 0.735(B^2hH)^{0.697} \text{ for Fixed wheel gate with } B^2hH > 2000m^4 \]

\[ G = 0.886(B^2hH)^{0.654} \text{ for Fixed wheel gate with } B^2hH < 2000m^4 \]

\( G \) = weight of gate in kN, \( B \) = span of gate in m,
\( H \) = head on the sill in m & \( h \) = height of gate in m

**Hoist capacity calculations:-**

A. **VERTICAL LIFT GATES:**

**The downward forces acting on a gate when it is being raised are:**

i) Self weight;
ii) Weight of ballast, if any;
iii) Friction at the seal(s)
iv) Friction at slide blocks/wheels
v) Downpull

**Note:**
(i) Seal friction is common for all types of gates and is caused by the sliding of seals on the seal seat.
(ii) Frictional load in slide gate is the product of the total water thrust load on the gate and the co-efficient of friction.
(iii) Wheel friction load consists of rolling friction of wheel on track and the friction at the bearing of the wheel pin.

The capacity required for lifting would thus be the sum of the forces at i) to v) above. This would, of course, be slightly reduced because of buoyancy. In practice, however, no reduction is made in the capacity on this account.

**The upward forces acting on a gate when it is being lowered are:-**

i) Friction at the seal(s)
ii) Friction at slide blocks/wheels
iii) Uplift
iv) Buoyancy

The capacity required while lowering would be the sum of the self weight and weight of ballast, if any, less the sum of the forces at i) to iv) as applicable.
1. Radial Gate

Radial or tainter gate is in the form of a curved plate, storing water usually on convex side, having an arc of a circle as its main member which is supported on a system of steel framework which in turn transfers the thrust of water to concrete through another system of steel grillage or rods called anchorages. Fig. No. ‘1’ shows view of radial gate from downstream side.
Definitions of main component parts of a radial gate are given as under:

**Skin Plate:**
A membrane which transfers the water load on a radial gate to the other components.

**Horizontal Girders:**
The main structural members of a radial gate, spanning horizontally to transfer the water pressure from skin plate and vertical stiffeners to end arms of the gate.

**End Arms:**
Main structural members which carry the reactions from the horizontal girders to the gate trunnions.

**Trunnion Hub:**
A hub to which the converging end arms of a radial gate are rigidly connected. It houses the trunnion bushings/bearings and rotate about the trunnion pin.

**Trunnion Assembly:**
An assembly consisting of trunnion hub, trunnion bush or bearing, trunnion pin and trunnion bracket.

**Yoke/Trunnion Girder:**
A structural member supporting the trunnion bracket and held in place by load carrying anchors or tension members embedded in piers/abutments.

**Anchor Flats/Anchors:**
Structural tension members provided for transferring water load from the trunnion girder of a radial gate to the piers/abutments.

**Anchor Girder:**
An embedded structural member, transferring load from a radial gate to its surrounding structure.

**Thrust Block or Thrust Pad:**
A structural member designed to transfer to the pier or abutment that component of water thrust on a radial gate caused by lateral force induced due to inclination of end arms.

**Trunnion Tie:**
A structural tension member connecting two trunnion assemblies of a radial gate to cater to the effect of lateral force induced due to inclination of end arms.

**Wall Plate:**
A plate embedded flush in a pier/abutment to provide a track for the seal and guide rollers of a radial gate.
Sill Beam: A steel beam embedded in concrete supports the gate at bottom in closed position of gate. It also act as smooth surface for bottom seal.

Advantages of Radial Gate

Elimination of gate grooves, Less hoisting effort required, Self Closing, High Co-efficient of discharge, Large Size Possible and Less Vibrations are some of the advantages of radial gates over other type of gates.

However complicated design and requirement of extra civil structure restricts its application for many locations.

Uses

Spillways for storing and maintaining FRL

Top seal radial gate for increasing the spillway capacity

Under Sluices to discharge silt

Waterways to allow Ships to pass

Intake

Canal Regulator

Automatic Level Regulator

Design loads In general, the gate is designed for hydrostatic pressure acting on the gate and checked for occasional forces such as earthquake effect, wave effect and occasional overtopping. The maximum stresses in various parts of the gate under the action of occasional forces are restricted to 133% of the normal permissible stresses subject to a maximum of 85% of the yield stress of the material as per provisions of IS:4623 (Recommendations for structural design of radial gates). Ice load shall also be taken into account, if so specified. Load due to reaction from sill and due to rope tension shall be combined with hydrostatic pressure while carrying out the design analysis.

COMPONENT PARTS TO BE DESIGNED:

Following parts are required to be designed for a radial gate.

i) Skin plate
ii) Stiffeners (vertical or/and horizontal)
iii) Horizontal girders
iv) Diaphragms (if provided)
v) End arms and their bracings
vi) Trunnion assembly
vii) Thrust pad or Tie beam
viii) Seal assembly
ix) Guiding system
x) Anchorages
xi) Gate hoist connection

**Gate Geometry:**

**Gate Sill Location:**

Gate sill is located on downstream of crest and as close as possible to the crest of the dam to economise on height of gate and size of pier. From hydraulic standpoint, the location of gate sill should be such that the flow underneath the partly open gate continues to hug the spillway profile. As a general guideline sill may be placed at about 0.30 to 0.80 m below the crest.

**Radius of Gate:**

Radius of gate is normally reckoned from the inside surface of skin plate to centre of the trunnion. The radius of gate should be ideally between 1.00 H to 1.25 H, where ‘H’ is the vertical distance between the top of gate and gate sill.

**Gate Trunnion:**

Generally gate trunnions are located sufficiently above the upper nappe (along the pier) to prevent any submergence. It would be advantageous to place the trunnion centre at about one third the height of gate above the sill so that the resultant reaction is as close to horizontal as possible thereby avoiding any major vertical force on trunnion.

However, in case where tail water is very high, above criterion is not possible to be met and trunnions are required to be located far above the one third gate height.

**Location of Gate with respect to Stoplogs:**

The gate, if provided with stoplogs for isolation, should be placed sufficiently away from stoplog grooves. In general, a distance of 2.50 to 3.00 m is found satisfactory in most cases.
Location of Hoists:

Radial gates are usually operated either by rope drum hoists or hydraulic hoists. If hydraulic hoists are provided, they are required to be located on downstream only. In cases where rope drum type (or wire rope type hoists) are used, choice of suspension has to be a judicious one. Whereas upstream hoists offer lower hoisting capacities due to increased leverage lengths, they have a disadvantage of inaccessible suspension and gate connection. Downstream suspensions have advantage of accessibility but they result in higher hoisting efforts due to smaller leverage length.

Working Stresses:

Working stresses for radial gate components are as per IS:4623. The skin plate is designed for wet and inaccessible conditions while other components of gate like stiffeners, horizontal girders and arms are designed for dry and inaccessible conditions. Gate trunnion parts can be designed for dry and accessible conditions. Gate anchorages are required to be designed for wet and inaccessible conditions as these are permanently placed inside the concrete.

For end arms, stresses corresponding to respective slenderness ratios as given in IS:800 are generally. Hoist attachments for gates should be designed by considering permissible stresses for hoist components as contained in IS:6938. These connections should also be checked for rope tensions in wire ropes corresponding to the breakdown torque conditions of hoist motor.
SELECTION OF MATERIALS:

The types of materials recommended for gate components should have high yield strength and be ductile in nature. The steel used for fabrication should be weldable and should satisfy all the criteria regarding weld ability as laid down in the relevant Indian Standards. Following table shows the materials generally used for various gate components:

<table>
<thead>
<tr>
<th>Component Part</th>
<th>Recommended Material</th>
<th>Relevant IS Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin Plate, Stiffeners, Horizontal Girders, Arms, Bracings, Anchor Girder, Yoke Girder, Load carrying Anchors etc.</td>
<td>Structural Steel</td>
<td>2062</td>
</tr>
<tr>
<td>Guide Rollers</td>
<td>Cast Steel Structural Steel</td>
<td>1030 2062</td>
</tr>
<tr>
<td>Trunnion Hub and Bracket</td>
<td>Cast Steel Structural Steel</td>
<td>1030 2062</td>
</tr>
<tr>
<td>Trunnion Pins, Lifting Pin</td>
<td>Corrosion Resisting Steel</td>
<td>1570</td>
</tr>
<tr>
<td>Bushings</td>
<td>Self lubricating</td>
<td>305</td>
</tr>
<tr>
<td>Seal seats</td>
<td>Stainless steel</td>
<td>1570</td>
</tr>
<tr>
<td>Seal base, seal clamp and sill beam</td>
<td>Structural Steel</td>
<td>2062</td>
</tr>
</tbody>
</table>

DESIGN OF MAIN COMPONENTS:

Anchorages:

The anchorage system for a radial gate is provided for the transfer of water load through the gate trunnion to the piers and abutments. Anchorages are normally selected as bonded or of unbonded type depending on the size of gate. Smaller gate size say up to 12m x 12m may be provided a bonded type of anchorage while for bigger gates unbonded type of anchors may prove economical.

Bonded Anchorage:

In bonded type, the load transfer takes place in bond between the anchors and the concrete. Bonded anchors should be provided adequate anchorage length in concrete as per provisions contained in IS:456 subject to a minimum of two-thirds of the radius of the gate.

Unbonded Anchorage:
In unbonded type, the load transfer takes place in bearing as a bearing stress between the concrete and the embedded anchor girder at the upstream end of the anchors, which in this case are insulated from concrete, and the anchors are designed as pure tension members. The length of the anchors shall be such as to limit the shear stress in the 45\(^\circ\) planes at the anchor girder to a safe permissible value subject to a minimum of 0.60 of the radius of gate.

**Prestressed Anchorage :**

The anchorage for gates could also be provided in the system of prestressed anchorages. Large gates of size, say 15m x 15m and higher, should find prestressed anchorages an optimum alternative considering overall economics of gate as well as pier design.

**SEAL ASSEMBLIES:**

Radial gates provided on spillway generally have seals on sides and bottom. Top seals are necessary where breast walls are provided for spillways and also for outlets.

Bottom seals of radial gate are generally flat type and they seal against bottom seal seats by compression under the self-weight of gates to provide requisite sealing effect and stability. Angle-shaped seals (also called L-type) are commonly used as side seals for spillway radial gates because of their superior flexibility and resilience characteristics such that minor dimensional changes in the leaf structure due to thermal expansion and contraction can be accommodated without impairing sealing capability. The sealing effect is obtained partly due to initial interference (varying from 2 mm to 6 mm) and partly due to water load.

Outlet gates require sealing at top also, which is accomplished by providing two sets of seals, one attached to the embedded lintel beam to prevent leakage at the top when the gate is partially open, while the other is attached to the gate skin plate to ensure tight sealing when the gate is fully closed.

**GUIDING SYSTEM:**

The gate is provided with a guiding system consisting of guide rollers mounted on the gate, and wall plates embedded in concrete. Guide rollers are arranged on the sides to limit the lateral motion or side sway of the gate to not more than 6 mm in either direction by rolling contact.

**Gate Leaf Design**

Normally all members are analysed as having simple supports with due considerations for end restraints. Skin plates in middle panels (between the vertical stiffeners) are generally treated as continuously supported. The vertical stiffeners are also analysed as continuous beams spanning between horizontal girders. They will have skin plates as co-acting members. The horizontal girders are treated as simply supported beams spanning between end arms' centres as supports. In addition to normal bending and shear, they may be required to carry axial thrusts in case inclined end arms are provided. End arms are designed as compression members carrying thrust
from horizontal girders in addition to moments shared by them from horizontal girders, taking into consideration the type of fixity to the girder

**Trunnion Hubs:**

The trunnion hubs are treated as thick or thin cylinders subjected to internal pressure generated by the resultant load on trunnion, which is distributed over the entire bearing surface housed inside the hub. The trunnion hub shall have thickness of not less than 0.3 d, where ‘d’ is diameter of pin (outer diameter if hollow).

**Trunnion Bushings :**

Trunnion bushings shall be either aluminium bronze or self-lubricating types.

**Thrust Block:**

Thrust blocks transfer the lateral thrust induced due to the inclination of end arms to the piers supporting the gate. The thrust blocks are designed to withstand the bending and shear force caused by the side thrust which is ultimately transferred to the concrete as a bearing stress.

**References:**

- BIS codes
- Design manual of Radial Gate (CWC publication)
- Manual on design of Spillway Tainter Gate by US Army corps of Engineers
- Design & Drawings of projects
- Davis C.V, Handbook of Applied Hydraulics
Chapter 7
Radial Gate – a case study

1.0 General description:

The Radial Gates consists of curved skin plate of varied thickness supported on suitably spaced vertical stiffeners from ½ cut ISMB. The stiffener rest on 3 horizontal girders, which are supported by inclined arms at each end. These are braced and terminate on trunnion hub which rotated about the fixed trunnion pin mounted on trunnion bracket.

The trunnion bracket is connected to yoke girder. The water load from the gate is finally transferred to pier concrete through unbonded tie flats to anchor girder embedded in pier concrete.

The gate has been provided with ‘Z’ type molded rubber seals for sides and flat type seal for bottom. The rubber seals rests on stainless steel seal seats and create water tightness. Three numbers of guide rollers are provided on each side to arrest the lateral moment of gate and also to avoid compression of seals.

The gate is raised / lowered by 2 nos of Hydraulic hoist of adequate capacity connected to gate on Down stream.

2.0 Technical details: Ref. Clause 5A 3.1.2 design data of Radial Gates.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of gates</td>
<td>10 Nos.</td>
</tr>
<tr>
<td>Vent width</td>
<td>14.50 M</td>
</tr>
<tr>
<td>Vent height (above sill to FRL)</td>
<td>12.30 M</td>
</tr>
<tr>
<td>Radius to inside of skin plate</td>
<td>15.0 M</td>
</tr>
<tr>
<td>Sill level</td>
<td>EL 333.950 M</td>
</tr>
<tr>
<td>Spill way crest level</td>
<td>EL 334.250 M</td>
</tr>
<tr>
<td>Trunnion level</td>
<td>EL 338.300 M</td>
</tr>
<tr>
<td>Spill way ogee equation</td>
<td>$X^{1.65} = 18.53233Y$</td>
</tr>
<tr>
<td>Sill beam central line from center line of crest</td>
<td>2440mm</td>
</tr>
<tr>
<td>FRL</td>
<td>EL 346.250 M</td>
</tr>
<tr>
<td>MWL</td>
<td>EL 346.850 M</td>
</tr>
<tr>
<td>Top of gate</td>
<td>EL 346.400 M</td>
</tr>
<tr>
<td>Top of shield</td>
<td>EL 346.850 M</td>
</tr>
<tr>
<td>Top of pier</td>
<td>EL 349.750 M</td>
</tr>
<tr>
<td>Bottom of the gate when fully lifted position</td>
<td>EL 344.750 M</td>
</tr>
<tr>
<td>Hoisting Arrangement</td>
<td>Hydraulic hoist D/S suspension</td>
</tr>
<tr>
<td>Type of arms</td>
<td>Inclined Arms</td>
</tr>
<tr>
<td>Designed as per</td>
<td>Technical spn. and IS 4823-2000</td>
</tr>
<tr>
<td>Design head FRL &amp; MWL</td>
<td>12.30 M &amp; 12.800 M</td>
</tr>
</tbody>
</table>
It is proposed to design for FRL condition adopting the permissible stresses as specified in the Technical Specification and checked for MWL condition by increasing the stresses as per clause 6.4 of IS 4823.

**Material**: Ref: clause 5A.3.1.3 of Specification

<table>
<thead>
<tr>
<th>Part</th>
<th>Material</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin plate, Vertical stiffeners, horizontal girders, Arms, bracings, tie flats, anchor girder, Yoke girder, rest plate, Vertical rods, Sill beam, wall plate, trunnion bracket etc</td>
<td>Structural Steel</td>
<td>IS:2062</td>
</tr>
<tr>
<td>Guide rollers, trunnion hub</td>
<td>Cast Steel</td>
<td>IS:1030 Gr 280-520W</td>
</tr>
<tr>
<td>Trunnion pin, roller pins lifting pins etc</td>
<td>Corrosion resistance steel</td>
<td>IS:1570 Part V</td>
</tr>
<tr>
<td>Trunnion bearings</td>
<td>Self lubricating bearing</td>
<td>ASTM B22 or Eqt</td>
</tr>
<tr>
<td>Seal seals</td>
<td>Stainless steel</td>
<td>04Cr18Ni10 IS 1570 Part V</td>
</tr>
<tr>
<td>Gate Seals</td>
<td>Synthetic or Natural Rubber</td>
<td>IS:11655</td>
</tr>
<tr>
<td>Screws / Seal bolts</td>
<td>Stainless steel</td>
<td>04Cr18Ni10 IS1570 Part V</td>
</tr>
</tbody>
</table>
## 4.0 Permissible Stresses: IS 4623 - 2000

### A. Skin plate
(Wat and inaccessible)

<table>
<thead>
<tr>
<th></th>
<th>Structural Steel</th>
<th>Y.P: 2550 kg/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>UTS 4180 kg/cm²</td>
</tr>
<tr>
<td>a) Direct compression and compression in bending</td>
<td>0.40 YP</td>
<td>1020 kg/cm²</td>
</tr>
<tr>
<td>b) Direct tension and tension in bending</td>
<td>0.40 YP</td>
<td>1020 kg/cm²</td>
</tr>
<tr>
<td>c) Shear stress</td>
<td>0.30 YP</td>
<td>765 kg/cm²</td>
</tr>
<tr>
<td>d) Combined stress</td>
<td>0.60 YP</td>
<td>1276 kg/cm²</td>
</tr>
<tr>
<td>e) Bearing Stress</td>
<td>0.45 YP</td>
<td>1148 kg/cm²</td>
</tr>
</tbody>
</table>

### B. Vertical stiffeners, Horizontal Girders, End arms, Trunnion Bracket and Yoke girder
(Dry and Inaccessible)

<table>
<thead>
<tr>
<th></th>
<th>Structural Steel IS: 2062</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thk: 0 ≤ 20 mm</td>
</tr>
<tr>
<td></td>
<td>Y.P: 2550 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>UTS 4180 kg/cm²</td>
</tr>
<tr>
<td>a) Direct compression and compression in bending</td>
<td>0.45 YP</td>
</tr>
<tr>
<td>b) Direct tension and tension in bending</td>
<td>0.45 YP</td>
</tr>
<tr>
<td>c) Shear stress</td>
<td>0.35 YP</td>
</tr>
<tr>
<td>d) Combined stress</td>
<td>0.63 YP</td>
</tr>
<tr>
<td>e) Bearing Stress</td>
<td>0.65 YP</td>
</tr>
</tbody>
</table>
C. Anchor girder, Tie Flats
(Anchor Flats) Rect Beam etc., Wet and inaccessible

<table>
<thead>
<tr>
<th>Structural Steel IS: 2062</th>
<th>Thk : 0 ≤ 20 mm</th>
<th>Thk : 20 - 40 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y.P : 2500 kg/cm²</td>
<td>Y.P : 2440 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>UTS : 4180 kg/cm²</td>
<td>UTS : 4180 kg/cm²</td>
</tr>
</tbody>
</table>

| a) Direct compression and compression in bending | 0.40 YP 1020 kg/cm² | 979 kg/cm² |
| b) Direct tension and tension in bending | 0.40 YP 1020 kg/cm² | 979 kg/cm² |
| c) Shear stress | 0.30 YP 760 kg/cm² | 734 kg/cm² |
| d) Combined stress | 0.50 YP 1275kg/cm² | 1224 kg/cm² |
| e) Bearing Stress | 0.46 YP 1118 kg/cm² | 1102 kg/cm² |

D. Trunnion Pin: 6.10.3 of IS 4623:2000
Materials: Stainless Steel, Annealed Condition
20Cr13 IS:1573 part V
YP (360MPa) UTS (720MPa)
3572kg/cm² 7344kg/cm²

<table>
<thead>
<tr>
<th></th>
<th>YP (360MPa)</th>
<th>UTS (720MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3572kg/cm²</td>
<td>7344kg/cm²</td>
</tr>
</tbody>
</table>

| a) Bending Stress | 0.33YP | 1212 kg/cm² |
| b) Bearing Stress | 0.35UTS | 2570 kg/cm² |
| c) Shear Stress | 0.25YP | 918 kg/cm² |

E. Trunnion Bush:
Materials: AS1 M - B 505 Self lubricating bearing of high strength Brass Alloy
UTS 700Vpa (7140kg/cm²) 160 HDHN

F. Concrete:
Max. compressive stress in bearing = 61kg/cm²
Design of Gate Leaf

8.0 Design of Skin plate:
The Skin plate is proposed to be stiffened with vertical stiffeners at 480 mm centers at the middle and 440 mm at the starting point.
The skin plate is made out of the following plates:

1) Bottom part - 14 mm thick ........ 4.0 M (arc length)
2) 2nd part - 12 mm thick ........ 4.0 M (arc length)
3) 3rd part - 10 mm thick ........ Balance (arc length)
Design of skin plate for FRL condition:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Skin plate Thickness cm</th>
<th>Effective Thickness cm</th>
<th>Section Modulus cm³</th>
<th>Head M</th>
<th>End Span 44cm (bm/kg cm)</th>
<th>Mid Span 49cm (bm/kg cm)</th>
<th>Permissible Stress kg/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.4</td>
<td>1.25</td>
<td>0.2004</td>
<td>12.500</td>
<td>230.128</td>
<td>914</td>
<td>945</td>
</tr>
<tr>
<td>2</td>
<td>1.2</td>
<td>1.05</td>
<td>0.1937</td>
<td>8.333</td>
<td>101.908</td>
<td>961</td>
<td>911</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>0.85</td>
<td>0.1204</td>
<td>4.397</td>
<td>85.128</td>
<td>707</td>
<td>731</td>
</tr>
</tbody>
</table>

Design of skin plate for MWL condition:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Skin plate Thickness cm</th>
<th>Effective Thickness cm</th>
<th>Section Modulus cm³</th>
<th>Head M</th>
<th>End Span 44cm (Dm/kg cm)</th>
<th>Mid Span 49cm (Dm/kg cm)</th>
<th>Permissible Stress kg/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.4</td>
<td>1.25</td>
<td>0.2004</td>
<td>12.500</td>
<td>219.744</td>
<td>959</td>
<td>1360</td>
</tr>
<tr>
<td>2</td>
<td>1.2</td>
<td>1.05</td>
<td>0.1827</td>
<td>8.963</td>
<td>173.524</td>
<td>945</td>
<td>1360</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>0.85</td>
<td>0.1204</td>
<td>4.997</td>
<td>95.742</td>
<td>814</td>
<td>1360</td>
</tr>
</tbody>
</table>
8.1 Design of Vertical Stiffeners:

The vertical stiffeners are designed as a beam supported at Horizontal Girders. The section proposed for vertical stiffener is Tee-Section cut out of ISMB-480. The loading is taken for 1m width of gate. The horizontal girders are located at spacing as shown with 3Nos. as specified in the specification drawing.

The reaction at supports and bending moments in the verticals are calculated for the following condition for FRL loading:

i) When the gate is resting on sill and considering the sill reaction on the gate due to self weight of gate

ii) When the gate is just lifted condition and water is up to FRL.
8.1.1 Case I: Gate resting on the sill and water load is up to FRL

Loads are considered for 1m width of the gate.

![Diagram with calculations and tables]

<table>
<thead>
<tr>
<th>Joint</th>
<th>Member</th>
<th>D.F.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Balance</td>
<td></td>
<td>1.021</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carry Over</td>
<td></td>
<td>0.511</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carry Over</td>
<td></td>
<td>-0.335</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shear Force in t</td>
<td></td>
<td>31.858 t</td>
<td>30.623 t</td>
<td>16.471 t</td>
<td></td>
</tr>
</tbody>
</table>
### Case II: When gate is just lifted condition & water is up to FRL:

![Diagram showing a structural analysis for Case II with water levels and forces applied.]

<table>
<thead>
<tr>
<th>Joint member U.H</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>1</td>
<td>0.503</td>
<td>0.437</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Fixed end moments in Balance Carry Over**
  - Fixed end moments: +7.228
  - Balance carry over: +2.825
    - +1.413
    - -0.383
  - Total distribution: +7.228
  - Balance carry over: +10.757
    - -0.146
    - -0.114
  - Net moments: +7.228
- **S.F. due to Reactions (t)**
  - +12.946
  - +17.640
  - -15.612
  - +14.149
  - +10.831
  - +6.164
- **Shear Force (t)**
  - +12.046
  - +10.070
  - +10.578
  - -14.701
  - -10.219
  - +16.283

### Table:

<table>
<thead>
<tr>
<th>Joint member U.H.</th>
<th>0</th>
<th>1</th>
<th>0.503</th>
<th>0.437</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed end moments</td>
<td>+7.228</td>
<td>-10.053</td>
<td>+9.344</td>
<td>-10.114</td>
<td>+8.62</td>
<td>-7.856</td>
</tr>
<tr>
<td>Balance carry over</td>
<td>+2.825</td>
<td></td>
<td>+1.413</td>
<td>-0.383</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total distribution</td>
<td>+7.228</td>
<td>-7.228</td>
<td>+10.757</td>
<td>-10.497</td>
<td>+7.856</td>
<td>-7.856</td>
</tr>
<tr>
<td>Net moments</td>
<td>+7.228</td>
<td>-7.228</td>
<td>+10.611</td>
<td>-10.611</td>
<td>+7.856</td>
<td>-7.856</td>
</tr>
<tr>
<td>Shear Force (t)</td>
<td>+12.046</td>
<td>+10.070</td>
<td>+10.578</td>
<td>-14.701</td>
<td>-10.219</td>
<td>+16.283</td>
</tr>
</tbody>
</table>

---

Page 101
8.1.3 **Case III:**

When gate is resting on the sill & water is up to MW1:

![Diagram](image)

<table>
<thead>
<tr>
<th>Joint member</th>
<th>D.F</th>
<th>0</th>
<th>1</th>
<th>0.663</th>
<th>0.437</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carry Over</td>
<td></td>
<td>+ 1.270</td>
<td>+ 0.635</td>
<td>+ 1.489</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.F due to Moments (t)</td>
<td></td>
<td>0</td>
<td>-0.164</td>
<td>+ 0.164</td>
<td>+ 0.587</td>
<td>- 0.587</td>
<td>0</td>
</tr>
<tr>
<td>S.F due to Loads (t)</td>
<td></td>
<td>+15.246</td>
<td>+18.689</td>
<td>+16.062</td>
<td>+15.489</td>
<td>+12.151</td>
<td>+8.639</td>
</tr>
<tr>
<td>Shear Force (t)</td>
<td></td>
<td>+15.246</td>
<td>+18.525</td>
<td>+16.826</td>
<td>+14.912</td>
<td>+12.768</td>
<td>+8.639</td>
</tr>
</tbody>
</table>

| 33.771t | 31.738t | 21.407t |
### 8.1.4 Case IV:

When gate is just lifted & water is up to MWL:

![Diagram](image)

<table>
<thead>
<tr>
<th>Joint member</th>
<th>D.F</th>
<th>0</th>
<th>1</th>
<th>0.503</th>
<th>0.437</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed end moments ( \text{in} ) Balance Carry Over</td>
<td>+7.591</td>
<td>-10.665</td>
<td>+9.665</td>
<td>+3.074</td>
<td>+1.537</td>
<td>+2.977</td>
<td>-12.610</td>
</tr>
<tr>
<td>Total ( \text{in}) distribution</td>
<td>+7.591</td>
<td>-7.591</td>
<td>+11.493</td>
<td>-1.044</td>
<td>-0.811</td>
<td>+12.610</td>
<td>-12.610</td>
</tr>
<tr>
<td>Net moments ( \text{in} )</td>
<td>+7.591</td>
<td>-7.591</td>
<td>+10.449</td>
<td>-10.449</td>
<td>+12.610</td>
<td>-12.610</td>
<td></td>
</tr>
<tr>
<td>S.F due to Moments (t)</td>
<td>0</td>
<td>-0.816</td>
<td>+0.816</td>
<td>-0.486</td>
<td>+0.486</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Shear Force (t)</td>
<td>+13.606</td>
<td>+17.872</td>
<td>+17.478</td>
<td>+15.019</td>
<td>+12.661</td>
<td>+8.630</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.479t</td>
<td>32.493t</td>
<td>21.300t</td>
</tr>
</tbody>
</table>
### 8.1.5 Abstract showing the bending moment, shear force and reaction of all horizontal girders:

<table>
<thead>
<tr>
<th>Water level</th>
<th>Case &amp; condition</th>
<th>Bottom H.G.</th>
<th>Middle H.G.</th>
<th>Top H.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bending moment</td>
<td>S.F</td>
<td>Reaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tm</td>
<td>t</td>
<td>t</td>
</tr>
<tr>
<td></td>
<td>Gate resting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>On sill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gate is just</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lifted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gate resting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>On sill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gate is just</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lifted</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Bottom H.G.:** % of increase in load in case of MWL over FRL  
\[(33.771 - 31.888) \times 100 / 31.888 = 5.9\% < 33.333\%\]

**Middle H.G.:** % of increase in load in case of MWL over FRL  
\[(32.497 - 31.340) \times 100 / 31.340 = 3.7\% < 33.333\%\]

**Top H.G.:** % of increase in load in case of MWL over FRL  
\[(21.407 - 10.471) \times 100 / 10.471 = 198.6\% < 33.333\%\]

Since the increase in loads are less than 33.333% in case of MWL, the girders are proposed to design for FRL condition.
8.1.5 Design of vertical stiffeners at bottom horizontal girder (at point 'A'):

The stiffener is tee cut out of ISMB 450 X 150

a) Gate resting on the sill
i) S.F. = 17.302 X 0.490 = 8.478 t
ii) B.M. = 0.032 X 0.490 = 0.429 kNm
iii) Skin plate stress = \( \frac{(11.237 \times 49.0^2)}{(12 \times 0.2604)} \approx 883.42 \text{kg/cm}^2 < 1020 \text{kg/cm}^2 \)
iv) Coacting width of skin plate is min of the following.

40t + B = 40 \times 1.25 + 0.94 = 51 cm

C/C of spacing of stiffeners = 49.0 cm

0.11 of span = 0.11 \times 350 = 38.5 cm

The sectional properties are as follows:

Area = 92.93 cm²

\( I_{xx} = 6093 \text{ cm}^4 \)

\( Z_1 = 984 \text{ cm}^3 \)

\( Z_2 = 1152 \text{ cm}^3 \)

\( Z_3 = 52 \text{ cm}^3 \)

Bending stress on U/S of skin plate = \( \frac{442563 \times 904}{92.93} = 446 \text{ kg/cm}^2 < 1020 \text{ kg/cm}^2 \).

Bending stress on D/S of skin plate = \( \frac{442563 \times 1152}{92.93} = 384 \text{ kg/cm}^2 < 1020 \text{ kg/cm}^2 \).

Bending stress on D/S of flange = \( \frac{442563 \times 525}{92.93} = 718 \text{ kg/cm}^2 < 1020 \text{ kg/cm}^2 \).

Shear stresses = \( 4478 \times (22.30 \times 0.04) = 40.4 \text{ kg/cm}^2 < 765 \text{ kg/cm}^2 \).

Check for combined stress: Max combined stress on D/S skin plate

\( \sigma_c = \sqrt{443.42^2 + 384^2 + 883.42 \times 384} = 1106.6 \text{ kg/cm}^2 < 1275 \text{ kg/cm}^2 \)

Weld strength required at 1.

F = \( \frac{SAY}{2} \times (4478 \times 36 \times 1.25 \times 0.405) / (2 \times 9535) = 100 \text{ kg/cm} \).

Proposed 6 mm fillet weld having strength of 0.8 \times 0.7 \times 765 = 321 \text{ kg/cm length}.
8.1.7 Design of vertical stiffeners at middle H.G (at point 'B'):

The gate is just lifted condition and water is up to PRL:

i) S.F = 15.300 X 0.49 = 7.49t

ii) B.M = 10.611 X 0.49 = 5.1909tm

iii) Skin plate stress = (0.7763 X 49.0²) / (12 X 0.1837) = 640kg/cm² < 1020 kg/cm²

iv) Co-acting width of skin plate is min of the following:

- 40t + B = 40 X 1.05 + 0.04 = 43cm
- C/G of spacing of stiffeners = 49.0cm
- 0.11 of span = 0.11 X 350 = 38.5cm

The sectional properties are as follows:

\[ \text{Area} = 85.33 \text{cm}^2 \]
\[ I_{xx} = 8354 \text{ cm}^4 \]
\[ Z_1 = 883 \text{cm}^3 \]
\[ Z_2 = 988 \text{cm}^3 \]
\[ Z_3 = 812 \text{cm}^3 \]

Bending stress on U/G of skin plate = 519939 / 803 = 646kg/cm² < 1020kg/cm².

Bending stress on D/S of skin plate = 519939 / 988 = 537kg/cm² < 1020kg/cm².

Bending stress on D/S of flange = 519939 / 612 = 850kg/cm² < 1020kg/cm².

Shear stresses = (7497 X 36 X 1.05 X 9.015) / (2 X 8354) = 164kg/cm² < 857kg/cm².

Check for combined stress:

Max combined stress on D/S skin plate.

\[ \sigma_c = \frac{\sqrt{848^2 + 537^2 + 846 \times 537}}{1 \times 537} = 1208kg/cm^2 < 1275kg/cm^2 \]

Weld strength required at 1.

\[ F = \frac{S_A Y}{2L} = (7497 X 36 X 1.05 X 9.165) / (2 X 0364) = 104kg/cm\text{ length} \]

Proposed 6mm fillet weld having strength of 321kg/cm length.
8.1.8 **Design of vertical stiffeners at top horizontal girder** (at point 'c'):

**Case:** When gate is resting on the sill and water is up to MWL.

i) \( S.F = 12.783 \times 0.49 = 6.256 \)

ii) \( B.M = 12.610 \times 0.40 = 6.178 \text{bm} \)

iii) Skin plate stress = \((0.3533 \times 49.0^2) / (12 \times 0.1204) = 655 \text{kg/cm}^2 < 1360 \text{ kg/cm}^2 \)

iv) Co-acting width of skin plate is min of the following:

- \( 40t + B = 40 \times 0.85 + 0.94 = 35 \text{cm} \)
- C/C of spacing of stiffeners = 42.0 \text{cm} \\
- 0.11 of span = 0.11 \times 450 = 49.5 \text{cm} \\

The sectional properties as follows:

\[
\begin{align*}
\text{Area} & = 75.19 \text{cm}^2 \\
I_{xx} & = 7333 \text{ cm}^4 \\
Z_1 & = 682 \text{ cm}^3 \\
Z_2 & = 740 \text{ cm}^3 \\
Z_3 & = 592 \text{ cm}^3 \\
\end{align*}
\]

Bending stress on J/S of skin plate = \( 817890 / 682 = 906 \text{kg/cm}^2 < 1360 \text{kg/cm}^2 \).

Bending stress on D/S of skin plate = \( 817890 / 740 = 835 \text{kg/cm}^2 < 1360 \text{kg/cm}^2 \).

Bending stress on D/S of flange = \( 817390 / 592 = 1044 \text{kg/cm}^2 < 1360 \text{kg/cm}^2 \).

Shear stresses = \( 6256 / (22.3 \times 0.84) = 29.8 \text{kg/cm}^2 < 1017 \text{kg/cm}^2 \).

Check for combined stress:

Max combined stress on D/S skin plate:

\[
c_c = \sqrt{655^2 + 835^2 + 655 \times 835} = 1293 \text{kg/cm}^2 < 1600 \text{kg/cm}^2 \\
\]

Weld strength required at 1.

\[
F = S_A Y / I = (6256 \times 35 \times 0.85 \times 10 \times 533) / (2 \times 7333) = 134 \text{kg/cm length} \\
\]

Proposed 6mm fillet weld having strength of 321 kg/cm length.
### Design of Horizontal Girders

The loads on horizontal girders are tabulated for all cases for 1m width of gate.

<table>
<thead>
<tr>
<th>Water Level</th>
<th>Case &amp; Condition</th>
<th>Bottom H.G (in t)</th>
<th>Middle H.G (in t)</th>
<th>Top H.G (in t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRL</td>
<td>Case - i Gate resting On sill</td>
<td>31.888</td>
<td>30.623</td>
<td>15.471</td>
</tr>
<tr>
<td></td>
<td>Case - ii Gate is just Lifted</td>
<td>29.619</td>
<td>31.340</td>
<td>16.283</td>
</tr>
<tr>
<td>MNWL</td>
<td>Case - iii Gate resting On sill</td>
<td>33.771</td>
<td>31.731</td>
<td>21.407</td>
</tr>
<tr>
<td></td>
<td>Case - iv Gate is just Lifted</td>
<td>31.479</td>
<td>32.497</td>
<td>21.300</td>
</tr>
</tbody>
</table>

As already calculated in 0.1.5 the MNWL load is less than 33.333% of when compared to FRL. Hence, the horizontal girders are designed for max. load of FRL loading with normal stresses.

1. The bottom horizontal girder 31.888/M when resting on the sill. Also checked for just lifted condition considering hoist reaction.

2. The middle horizontal girder is designed for max. load of 31.340 per meter for just lifted condition.

3. The top horizontal girder is designed for 15.471/Meter width, for condition gate resting on the sill.
3.2.1 The Layout of Bottom And Second Horizontal Girder With Arms
8.2.2 The Formula Arrived For Calculating The Shear Force And Bending Moments At Various Points Are As Follows:

\[ \text{EM at A} = 142P_1 + 98P_2 + 45P_3 \]
\[ \text{EM at B} = (1029R_3 - 343P_2 + 387P_1) \]
\[ \text{EM at C} = (4140P_3 + 661.5P_2 + 705.5P_1) \]
8.2.3 The Bending Moment and Shear forces are tabulated for Horizontal girders as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Bottom H.G</th>
<th>Middle H.G</th>
<th>Top H.G</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.G reaction per meter width</td>
<td>31.888t</td>
<td>31.34t</td>
<td>16.471t</td>
</tr>
<tr>
<td>$P_1 = (0.195 + 0.22)w$</td>
<td>13.234t</td>
<td>13.008t</td>
<td>6.835t</td>
</tr>
<tr>
<td>$P_2 = (0.220 + 0.246)w$</td>
<td>14.928t</td>
<td>14.573t</td>
<td>7.656t</td>
</tr>
<tr>
<td>$P_3 = 0.246w$</td>
<td>16.826t</td>
<td>16.807t</td>
<td>8.571t</td>
</tr>
</tbody>
</table>

Shear force

| $R_A = P_1 + P_2 + 2P_3$ | 59.312t | 58.293t | 30.635t |
| $R_C = (P_1 + P_2 + 4P_3) + 9P_3$ | (60.562+ 140.625)t | (99.009+138.213)t | (46.779+72.639)t |

Bending moment

| $BM @ A$ | $142P_1 + 98P_2 + 46P_3$ | $+4097.997$cm | $+1027.469$cm | $+2116.631$cm |
| $BM @ B$ | $270.5P_1 + 226.5P_2 + 418P_3$ | $+13438.339$cm | $+13207.419$cm | $+6941.583$cm |
| $BM @ C$ | $435P_1 - (502P_3 + 343P_3 + 387P_3)$ | $+647.683$cm | $+648.235$cm | $+334.840$cm |

8.2.4 Design of Bottom Horizontal Girder:

The section adopted for bottom horizontal girder is as follows. The bending stress and shear stress is calculated at various sections.

At point 'C':

Max $BM = 16725725 \times 0.01$cm
SF = 0
Area = 310cm$^2$
$I_M = 133.1645cm^4$
$Z_{of} = 16141cm^3$

Bending stress $= 16725725 / 16141 = 1035kN/cm^2 < 1102kN/cm^2$
At point 'B':
Max Bending moment = 647588kg-cm
Max Shear force = 1093/5kg

The section proposed is as follows:

Area = 310cm²
$I_{xx} = 1331846cm^4$
$Z_1 = 16141cm^3$

Bending stress = \( \frac{647588}{16141} = 40\text{kg/cm}^2 > 1102\text{kg/cm}^2 \)
Shear stress = \( \frac{1093}{(100 \times 1.4)} = 0.944\text{kg/cm}^2 < 1102\text{kg/cm}^2 \)

At point 'G':
Max Bending moment = 15438335kg-cm
Max Shear force = 140625kg

The section proposed is as follows:

Area = 451.5cm²
$I_{xx} = 1085692cm^4$
$Z_1 = 7090cm^3$
$Z_2 = 20437cm^3$

Bending stress on U/S of flange = \( \frac{13438359}{19680} = 672\text{kg/cm}^2 < 1102\text{kg/cm}^2 \)
Bending stress on D/S of flange = \( \frac{13438359}{28437} = 4.72\text{kg/cm}^2 < 1102\text{kg/cm}^2 \)
Shear stress = \( \frac{140625}{(100 \times 1.4)} = 0.822\text{kg/cm}^2 < 1102\text{kg/cm}^2 \)

At point 'A':
Max bending moment = 4067007kg-cm
Shear force = 59312kg

The section proposed is as follows:

Area = 265cm²
$I_{xx} = 445052cm^4$
$Z_1 = Z_2 = 8477cm^3$

Bending stress = \( \frac{4067007}{8477} = 483\text{kg/cm}^2 > 1102\text{kg/cm}^2 \)
Shear stress = \( \frac{59312}{(100 \times 1.4)} = 4.24\text{kg/cm}^2 < 1102\text{kg/cm}^2 \)
Checking the girder for just lifted condition with Hoist reaction.

It is proposed to provide lifting bracket between the bottom and middle horizontal girder.

Load shared by bottom horizontal girder = 48 X (2.75 / 3.5) = 37.71t = 38.0t

Max. load = 29.9t / width of girders

$P_1 = 12.292t$
$P_2 = 13.773t$
$P_3 = 14.513t$

Hoist reaction = $w = 38t$ acting at central line of 2nd stiffener in $P_2$.

$R_0 = [P_1 + (P_2 + w) + 4P_3] + 9P_3$

$= 12.292 + (13.773 + 38) + 4 \times 14.513 + 9 \times 14.513 = 252.734t$

$W_S = 270.5 \times 12.292 + 226.5 (13.773 + 38) + 416 \times 14.513 = 21088.79It$

The section proposed is as follows:

$A_{geo} = 464.6cm^2$

$I_{xx} = 198550cm^4$

$Z_t = 18980cm^3$

$Z_1 = 28437cm^3$

Bending stress on U/S of flange = $21088.706 / 19980$

= 1055kg/cm^2 < 1102kg/cm^2

Bending stress on D/S of flange = $21088.706 / 29437$

= 722kg/cm^2 < 1102kg/cm^2

Shear stresses = $130617 / (160 \times 1.4)$

= 563kg/cm^2 < 592kg/cm^2
Checking D/S flange at support 'S':

At point 'D' there is a compressive force due to inclination of arms.

Direct compressive load = 252734 x tan 15.0106° = 67770 kg

$I_{po}$ of D/S flange = 14667 cm$^4$

Area = 162.5 cm$^2$

$f_{ck} = 14557 / 162.5 = 9.5$ cm

$L / r_{sh} = 122 / 9.5 = 12.8$ cm

Permissible stress = [(0.45 / 0.68) x 143 x 10.2] = 994 kg/cm$^2$

Direct compressive stress = $67770 / 162.5 = 417$ kg/cm$^2 < 994$ kg/cm$^2$

Check for unity = (533 / 1102) + (417 / 994) = 0.946 < 1.0

Design of Web Stiffeners:

$
u'$ ratio for 1.0 cm web thick is $160 / 1.0 = 160 > 85 < 160$ and for 1.4 cm web thickness is $160 / 1.4 = 114 > 85 < 160$

Hence vertical stiffeners are proposed.

Max $I_{sw}$ required = $1.5 \times t^4 / c^3$

Where $d = 160$ cm

$t = 1.0$ cm

$c = 1.5 \times 160 = 240$ cm

$I_{sw} = (1.5 \times 160^3 \times 1.0^3) / 240^3 = 107$ cm$^4$

Proposed 2 Nos of 110 X 10 mm stiffeners

$I_{sw} = [(2 / 12) \times 1 \times 11^3] + (2 \times 11 \times 1 \times 6.0^3) = 1014$ cm$^4 > 107$ cm$^4
**Design of Bearing stiffeners:**
Proposed 8 Nos of 140 X 25mm Bearing stiffeners as shown

\[ A = (6 \times 14 \times 2.5) + (75 \times 1.4) = 315 \text{ cm}^2 \]
\[ I_{xx} = 15898 \text{ cm}^4 \]
\[ I_{xx} = \frac{15898}{315} = 7.1 \text{ cm} \]
\[ l = 168 \text{ cm} \]
\[ \frac{l}{I_{xx}} = \frac{168}{7.1} = 23.3 \]

Permissible stress = \((0.45/0.66) \times 141 \times 10.2 = 980 \text{ kg/cm}^2\)
Actual compressive stress = \(\frac{252734}{315} = 802 \text{ kg/cm}^2 < 980 \text{ kg/cm}^2\)

**Design of Weld at S1:**
\(I_{xx} = 1565592 \text{ cm}^4\)
It is proposed to design weld size at support S where Max. shear force acting and adopt the same for all sections Max shear force = 140625 kg
\[ F_1 = S \times A \times 21 = (140625 \times 30 \times 2.5 \times 97.13) / (2 \times 1565592) = 2811 \text{ kg/cm length} \]
Proposed 6mm fillet weld having strength of 360 kg/cm length.
\[ F_2 = S \times A \times 21 = (140625 \times (30 \times 2.5) \times (35 \times 2.5) \times 564.52) / (2 \times 1565592) = 376 \text{ kg/cm length} \]
Proposed 8mm fillet weld having strength of 460 kg/cm length.
8.2.5 Design of Middle Horizontal Girder:

The section adopted for middle horizontal girder is as follows. The bending stress and shear stress are calculated at various sections.

**At point 'C':**

Max Bending moment = 16487.11 kNm
SF = 0
Area = 300 cm²
$I_{xx} = 1265025 cm^4$
$Z_1 = Z_2 = 15341 cm^3$
Bending stress = $16487.11/15341 = 1075 kg/cm² < 1102 kg/cm²$

**At point 'D':**

Max Bending moment = 846238 kNm
Max Shear force = 107498 kN
The section proposed is as follows:

Area = 200 cm²
$I_{xx} = 139/2 sqcm$
$Z_1 = 14038 cm³$
$Z_2 = 15632 cm³$
Bending stress on U/S side of flange = 646238 / 14038 = 46 kg/cm² < 1102 kg/cm².
Shear stresses = 107498 / (160 X 1) = 675 kg/cm² < 882 kg/cm².

**At point 'S':**

Max Bending moment = 13207419 kNm
Max Shear force = 199213 kN
The section proposed is as follows:

Area = 397 cm²
$I_{xx} = 1861211 cm^4$
$Z_1 = 15610 cm³$
$Z_2 = 24836 cm³$
Bending stress on U/S of flange = 13207419 / 166110 = 795 kg/cm² < 1102 kg/cm²
Bending stress on D/S of flange = 13207419 / 24836 = 532 kg/cm² < 1102 kg/cm²
Shear stress = 199213 / (160 X 1) = 120 kg/cm² < 882 kg/cm².
Checking the girder for Initial Tied Condition:

Considering hoist capacity reaction of 10t at second Horizontal Girder:

Max. Bending moment at support S:

\[ M = 270.5 \times 13.008 + 226.5 \times (14.573 + 10) + 416 \times 15.357 \]

\[ = 16472.420 \text{cm} \times \text{m} \]

The section proposed is as follows:

Area = 357 cm²

\( l_{xx} = 1647711 \text{cm}^4 \)

\( Z_1 = 16611 \text{cm}^3 \)

\( Z_2 = 24836 \text{cm}^3 \)

Bending stress on U/S flange = \[ \frac{16472420}{16611} = 531 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]

Bending stress on D/S flange = \[ \frac{16472420}{24836} = 670 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]

Shear stress = \[ \frac{58293}{100 \times 1} = 583 \text{kg/cm}^2 < 892 \text{kg/cm}^2 \]

At point 'A':

Max. bending moment = 4027498 + 10000 \times 98 = 5007498 \text{kg/cm}

Shear force = \[ \frac{5007498}{10000} = 5027 \text{kg} \]

The section proposed is as follows:

Area = 320 cm²

\( l_{xx} = 398583 \text{cm}^4 \)

\( Z_1 = Z_2 = 7502 \text{cm}^3 \)

Bending stress = \[ \frac{5007498}{7502} = 666 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]

Shear stress = \[ \frac{68293}{100 \times 1} = 683 \text{kg/cm}^2 < 892 \text{kg/cm}^2 \]
Checking DISS flange at support 'S':
At point 'S' there is a compressive force due to inclination of arms.
Direct compressive load = 227330 x tan 15.0101° = 50958 kg
I_{xx} of DISS flange = 10148 cm^4

Area = 145 cm^2
r_{xx} = 8.4 cm
I / r_{xx} = 124 / 8.4 = 15

Permissible stress = (0.45 / 0.66) x 143 x 10.2 = 99 kg/cm^2
Direct compressive stress = 50958 / 145 = 420 kg/cm^2 < 99 kg/cm^2
Check for unity = (532 / 1102) + (420 / 994) = 0.806 < 1.0

Design of Web Stiffeners:
d/t ratio for 1.0 cm web thick is 150 / 1.0 = 150 > 85 < 150 and for 1.2 cm web thickness is 160 / 1.2 = 133 > 85 < 150
Hence  vertical stiffeners are proposed

\[ \text{Max } |\alpha| \text{ required } = 1.5 \frac{d^2 t}{c^2} \]

Where \( d = 150 \text{ cm} \)
\( t = 1.0 \text{ cm} \)
\( c = 1.5 \times 160 = 240 \text{ cm} \)
\( l \text{ required } = (1.5 \times 160^3 \times 1.0^3) / 240^2 = 107 \text{ cm}^4 \)

Proposed 2 Nos of 110 X 10 mm stiffeners
\( l_{xx} = (3.14 \times 1 \times 11^3) + (2 \times 11 \times 1 \times 6.0^3) = 1014 \text{ cm}^4 > 107 \text{ cm}^4 \)
Design of Bearing stiffeners:
Proposed 6 Nos of 130 X 25mm Bearing stiffeners as shown

\[ A = 285 \, \text{cm}^2 \quad I_{xx} = 12587 \, \text{cm}^4 \]

\[ \gamma_{xx} = \frac{12587}{285} = 6.65 \, \text{cm} \]

\[ l = 100 \, \text{cm} \]

\[ l / \gamma_{xx} = 166 / 6.65 = 25 \]

Permissible stress = \((0.45 / 0.66) \times 145 \times 10.2 = 1008 \, \text{kg/cm}^2\)

Actual compressive stress = \(227330 / 285 = 795 \, \text{kg/cm}^2 < 1008 \, \text{kg/cm}^2\)

Design of Weld:

\[ I_{xx} = 1667211 \, \text{cm}^4 \]

Max shear force = 138213kg

\[ F_1 = \text{SAY} / 2l = (138213 \times 24 \times 2.5 \times 60.12) / (2 \times 1667211) = 24.6 \, \text{kg/cm length} \]

Proposed 8mm fillet weld having strength of 350kg/cm length.

\[ F_2 = \text{SAY} / 2l = (138213 \times 23 \times 2.5 \times 60.12) / (2 \times 1667211) = 368 \, \text{kg/cm length} \]

Proposed 8mm fillet weld having strength of 400kg/cm length.

\[ F_3 = \text{SAY} / 2l = (138213 \times 23 \times 2.5 \times 65.28) / (2 \times 1667211) = 190 \, \text{kg/cm length} \]

Proposed 8mm fillet weld having strength of 360kg/cm length.
8.2.6 Design of Top Horizontal Girder:

The lay out of top horizontal girder and top arm is as follows:

The section adopted for top horizontal girder is as follows. The bending stress and shear stress are calculated at various sections.
At point 'C':
Max BM = 8839899 kgc/m

5" = 0
Area = 190 cm²
\( b_0 = 515208 \text{cm}^4 \)
\( Z_1 - Z_2 = 6507 \text{cm}^3 \)

Bending stress = \( \frac{8839899}{8307} / \frac{8307}{1040 \text{kg/cm}^2} = 1102 \text{kg/cm}^2 \)

At point 'B':
Max Bending moment = 334840 kgc/m
Max Shear force = 56497 kg

The section proposed is as follows:

Area = 190 cm²
\( b_0 = 0 \text{cm}^3 \)
\( Z_1 - Z_2 = 8307 \text{cm}^3 \)

Bending stress = \( \frac{334840}{8307} / \frac{8307}{4102 \text{kg/cm}^2} = 1102 \text{kg/cm}^2 \)
Shear stresses = \( \frac{56497}{125 \times 1} = 452 \text{kg/cm}^2 = 803 \text{kg/cm}^2 \).

At point 'S':
Max Bending moment = 6941583 kgc/m
Max Shear force = 72639 kg

The section proposed is as follows:

Area = 275 cm²
\( b_0 = 0 \text{cm}^3 \)
\( Z_1 = 8270 \text{cm}^3 \)
\( Z_2 = 13396 \text{cm}^3 \)

Bending stress on U/S of flange = \( \frac{6941583}{748 \text{kg/cm}^2} = 1102 \text{kg/cm}^2 \)
Bending stress on D/S of flange = \( \frac{6941583}{520 \text{kg/cm}^2} = 1102 \text{kg/cm}^2 \)
Shear stress = \( \frac{72639}{120 \times 1} = 454 \text{kg/cm}^2 = 592 \text{kg/cm}^2 \).
At point 'A':
Max bending moment = 2116631kgcm
Shear force = 30636kg

The section proposed is as follows:
Area = 200cm²
I_xx = 349042cm⁴
Z_x = Z_y = 8551cm³

Bending stress = 2116631 / 6591 = 321kg/cm² < 1102kg/cm²
Shear stress = 30636 / (100 x 1) = 306kg/cm² < 892kg/cm²

Checking D/S flange at support 'S':
At point 'S' there is a compressive force due to inclination of arms.
Direct compressive load = 113417 x ten 15.0105³ = 32021kg
I_xx = 3885cm⁴
Area = 105cm²
γ_xx = 3885 / 105 = 36.1 cm
I / γ_xx = 123 / 0 = 20.6 cm
Permissible stress = [0.4 x 5 / 0.66] x 142 x 10² = 986kg/cm²
Actual compressive stress = 32021 / 105 = 305kg/cm² < 986kg/cm²
Check for unity: = (305 / 986) + (520 / 1102) = 0.78 < 1.0

Design of web stiffeners:
d/t ratio for 1.0cm web thick is 120 / 1.0 = 120 > 85 < 180
Hence vertical stiffeners are proposed
Max I_xx required = 1.5 d²f² / σ²
I required = (1.5 x 120² x 1.0²) / 160² = 101cm⁴
 Proposed 2 Nos of 90 x 10mm stiffeners
I = 571.5cm⁴ > 101cm⁴
Design of bearing stiffeners:

Compressive load = 119417kg

Protruded 90 x 25mm Bearing stiffeners as shown

\[ A = 210 \text{ cm}^2 \]
\[ t_{xx} = 3.33 \text{ cm}^4 \]
\[ t_{xx} = \frac{4233}{210} = 4.5 \text{ cm} \]
\[ l = 124 \text{ cm} \]
\[ l / t_{xx} = 124 / 4.5 = 27.5 \]

Permissible stress = (0.45 / 0.66) \times 1141 \times 10.2 = 660 \text{ kg/cm}^2

Actual compressive stress = 119417 / 210 = 569 \text{ kg/cm}^2 < 960 \text{ kg/cm}^2

3.3.0 Design of arms:
Inclination of arm to horizontal \( \theta = 15.0105^\circ \)
The horizontal girder reactions and axial loads on the arms are as follows:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Horizontal girder</th>
<th>Axial load on arms ( \Gamma_x )</th>
<th>Length of arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bottom arm</td>
<td>231.187 Sec 15.0105 = 236.354</td>
<td>1207 cm</td>
</tr>
<tr>
<td>2</td>
<td>Middle arm</td>
<td>237.330 Sec 15.0105 = 235.360</td>
<td>1207 cm</td>
</tr>
<tr>
<td>3</td>
<td>Top arm</td>
<td>119.417 Sec 15.0105 = 123.635</td>
<td>1247 cm</td>
</tr>
</tbody>
</table>
8.3.1 Design of Bottom arm:

It is proposed to design bottom arm for max. load of 239.354t.

\[ P_1 = 13.334t \quad P_2 = 14.828t \quad P_3 = 15.625t \]

Cantilever moment = 13433.830t cm

\[ FEM = P_3 \frac{L_2}{L} \left( \sum (10.5 \times 351.5^2) / 670^2 + (95.15 \times 18.5^2) / 870^2 \right) \]

\[ = 15.625 \times 1289 = 20140.625t \text{cm} \]

The following section is proposed:

- Area = 370 cm²
- \( I_{xx} = 17991 \text{cm}^4 \)
- \( I_{yy} = 19362 \text{cm}^4 \)
- \( Z_{xx} = 6426 \text{cm}^3 \)
- \( r_{xx} = 17504.1 / 370 = 22.05 \text{cm} \)
- \( r_{xy} = 7.207 \text{cm} \)
- \( \frac{r_{xy}}{r_{xx}} = 22.05 / 22.05 = 54.7 \)
- \( \frac{r}{r_{yy}} = 355 / 7.2 = 54.86 \)

Permissible stress = 123 X 10.2 X (0.45 / 0.65) = 856 kg/cm²

\[ K_1 = (3 \times 17991) / 1207 = 447.2 \]

Mean Ixx of bottom Horizontal circle

\[ I_{mean} = \left( \frac{1}{870} \right) \left( 1331648 \times 600 + 1965592 \times 270 \right) = 1528388 \text{cm}^4 \]

\[ \cdot K_2 = 4 \times 1528388 / 870 = 70.27 \]
<table>
<thead>
<tr>
<th>0.940</th>
<th>0.940</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantilever moment</td>
<td>13438.339</td>
</tr>
<tr>
<td>- 402.137</td>
<td>- 6000.149</td>
</tr>
<tr>
<td>- 189.004</td>
<td>+ 3150.074</td>
</tr>
<tr>
<td>- 88.832</td>
<td>+ 1480.535</td>
</tr>
<tr>
<td>- 45.752</td>
<td>+ 895.852</td>
</tr>
<tr>
<td>- 19.023</td>
<td>+ 327.650</td>
</tr>
<tr>
<td>- 9.223</td>
<td>+ 753.714</td>
</tr>
<tr>
<td>- 6.335</td>
<td>+ 144.491</td>
</tr>
<tr>
<td>- 2.037</td>
<td>+ 72.245</td>
</tr>
<tr>
<td>- 1.047</td>
<td>+ 56.910</td>
</tr>
<tr>
<td>- 0.567</td>
<td>+ 33.665</td>
</tr>
<tr>
<td>- 0.283</td>
<td>+ 31.618</td>
</tr>
<tr>
<td>- 0.750</td>
<td>+ 760.943 cm^3</td>
</tr>
</tbody>
</table>

Moment in the arm = 760.943 cm^3

Actual bending stress = 750943 / 6426 = 118 kg/cm^2 < 1102 kg/cm^2

Actual compressive stress = 238354 / 317 = 647 kg/cm^2 < 855 kg/cm^2

Check for unity = (118 / 1102) + (647 / 855) = 0.863 < 1
Check the arm for just lifted condition and considering hoist component on the girder:

Load on the arm = 252.734660 x 6 = 252.734660 x 15.01066 x 261.682
Girder movement = 4186.8 / 10000 cm
P_s = 14.513 t
Fixed end moment = 14.513 x 1289 = 18707.257 cm

<table>
<thead>
<tr>
<th>Arm</th>
<th>H.G</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06</td>
<td>0.040</td>
</tr>
<tr>
<td>-21088.708</td>
<td>+18707.257</td>
</tr>
<tr>
<td>+142.887</td>
<td>+2235.564</td>
</tr>
<tr>
<td>+89.542</td>
<td>-1119.282</td>
</tr>
<tr>
<td>+30.822</td>
<td>+1028.740</td>
</tr>
<tr>
<td>+14.519</td>
<td>-514.870</td>
</tr>
<tr>
<td>+6.824</td>
<td>+483.978</td>
</tr>
<tr>
<td>+3.208</td>
<td>-241.980</td>
</tr>
<tr>
<td>+1.507</td>
<td>+227.470</td>
</tr>
<tr>
<td>+280.370 m</td>
<td>-280.370 cm</td>
</tr>
</tbody>
</table>

Moment in the arm = 289379 kN cm

Actual bending stress = 289379 / 3426 = 45 kg/cm² = 1102 kg/cm²

Actual compressive stress = 261662 / 370 = 707 kg/cm² = 855 kg/cm²

Check for unity = (45 / 1102) + (707 / 855) = 0.867 < 1
### 8.3.2 Design of Middle Arm

- **Inclination of arm** = 15.0, 10, 15
- **Length of arm** = 1207 cm
- **Max. compressive load** = 235.360 t
- **PEW** = 15.397 \* 1289 = 19795.173 cm
- **Gantleve moment** = 13207.419 tcm

The sectional properties are as follows:
- **Area** = 337.922 cm$^2$
- **I_{xx}** = 155667 cm$^4$
- **I_{yy}** = 15427 cm$^4$
- **Z_{xx}** = 5640 cm$^3$
- **Z_{yy}** = 21.46 cm$^3$
- **T_{yy}** = 6.75 cm

It is proposed to trace the arms on $I_{xx}$ direction
- **l_{xx}** = 1207 cm
- **l_{yy}** = 395 cm

**Permissible stress** = 110 \* 10.2 \* (0.45 / 0.30) = 628 kg/cm$^2$

**K_r** = (3 \* 155667) / 1207 = 387

Mean I_{xx} of Middle + G = (1 / 670) \* (1266626 \* 650 + 168721 \* 279) = 1300256 cm$^4$

**K_T** = (4 \* 1390256) / 870 = 6392

<table>
<thead>
<tr>
<th>DF</th>
<th>0.052</th>
<th>0.048</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantleve moment</td>
<td>–13207.419</td>
<td>+19795.173 fixed end moments</td>
</tr>
<tr>
<td>- 375.542</td>
<td>- 6212.252</td>
<td></td>
</tr>
<tr>
<td>- 177.049</td>
<td>- 2926.077</td>
<td></td>
</tr>
<tr>
<td>- 53.479</td>
<td>+ 1484.539</td>
<td></td>
</tr>
<tr>
<td>- 39.359</td>
<td>+ 1381.050</td>
<td></td>
</tr>
<tr>
<td>- 18.558</td>
<td>+ 690.530</td>
<td></td>
</tr>
<tr>
<td>- 8.750</td>
<td>+ 607.727</td>
<td></td>
</tr>
<tr>
<td>- 4.126</td>
<td>+ 525.555</td>
<td></td>
</tr>
<tr>
<td>- 1.945</td>
<td>+ 458.614</td>
<td></td>
</tr>
<tr>
<td>- 0.917</td>
<td>+ 396.610</td>
<td></td>
</tr>
<tr>
<td>- 709.888 tcm</td>
<td>+ 709.685 tcm</td>
<td></td>
</tr>
</tbody>
</table>

**Arm moment** = /U/Ojs x 0.1 cm

**Actual bending stress** = 709686 / 5640 = 125.83 kg/cm$^2$ < 1100 kg/cm$^2$

**Actual compressive stress** = 235360 / 337.92 = 698 kg/cm$^2$ < 848 kg/cm$^2$

**Check for unity** = (126.93 / 100) + (698 / 848) = 0.03 + 0.82 = 1.0
Check the arm for just lifted condition and considering hoist component on the girder:

Load on the arm = 245.36kN
Counterover movement = 15473.42cm
Fixed end moment = 18795.173kNcm

<table>
<thead>
<tr>
<th>DF</th>
<th>0.057</th>
<th>0.043</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counterover moment -</td>
<td>15473.42</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>246.340</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>116.149</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>54.784</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>25.821</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>12.176</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>5.740</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>2.707</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>1.276</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>0.002</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>485.573kNcm</td>
<td>+</td>
</tr>
</tbody>
</table>

Arm moment = 485.573kNcm
Actual bending stress = 465573 / 5540 = 82.55kg/cm² < 110.2kg/cm²
Actual compressive stress = 245300 / 337.32 = 726kg/cm² < 848kg/cm²
Check for unity = (82.55 / 110.2) + (726 / 848) = 0.75 < 1.0
8.3.3 Design of Top Arm:

Inclination of arm = 71°10′

Max. compressive force = 123,638t

Cantilever moment = 894.1,583 cm

FEM = 8.071 X 1238 = 104,03.519 kN/mm

The sectional properties are as follows:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>181.8 cm²</td>
</tr>
<tr>
<td>Ixx</td>
<td>83400 cm⁴</td>
</tr>
<tr>
<td>Iyy</td>
<td>8755 cm⁴</td>
</tr>
<tr>
<td>Zxx</td>
<td>3199 cm⁴</td>
</tr>
<tr>
<td>mxx</td>
<td>21.4 cm</td>
</tr>
<tr>
<td>myy</td>
<td>6.94 cm</td>
</tr>
</tbody>
</table>

It is proposed to brace the arm on YY direction.

\[
\frac{m}{m_{yy}} = 4.14 / 6.9 = 0.61
\]

Permissible stress = 122 X 10.2 X (0.61 / 0.80) = 84.6 kpsi/cm²

K₁ = [3 X 85400] / 1207 = 207

Mean Ixx of Top Horizontal girder = \(\frac{1}{870}(516020 \times 800 + 668050 \times 270) = 574713 cm^4\)

\(\frac{1}{K₂} = 4 X 574713 / 870 = 26.2\)

<table>
<thead>
<tr>
<th>DF</th>
<th>0.072</th>
<th>0.927</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantilever moment</td>
<td>8941.583</td>
<td>+ 10403.519 FEM</td>
</tr>
<tr>
<td>- 246.259</td>
<td>- 3211.577 balance</td>
<td></td>
</tr>
<tr>
<td>- 115.820</td>
<td>+ 1505.639</td>
<td></td>
</tr>
<tr>
<td>- 53.648</td>
<td>- 691.461</td>
<td></td>
</tr>
<tr>
<td>- 24.863</td>
<td>+ 345.731</td>
<td></td>
</tr>
<tr>
<td>- 11.560</td>
<td>- 148.865</td>
<td></td>
</tr>
<tr>
<td>- 5.359</td>
<td>+ 74.434</td>
<td></td>
</tr>
<tr>
<td>- 2.467</td>
<td>- 99.925</td>
<td></td>
</tr>
<tr>
<td>- 1.154</td>
<td>+ 18.805</td>
<td></td>
</tr>
<tr>
<td>0.635</td>
<td>+ 7.436</td>
<td></td>
</tr>
<tr>
<td>463.505</td>
<td>+ 463.505</td>
<td></td>
</tr>
</tbody>
</table>

Arm moment = 463,505 kN-mm

Actual bending stress = 463,505 / 3156 = 147 kN/cm² < 1102 kN/cm²

Actual compressive stress = 123,638 / 10.2 = 12,000 kN/cm² < 3400 kN/cm²

Check for unity = (147 / 1102) + (6800 / 3400) = 0.035 < 1.0
8.4 Design of Trunnion pin, Bush & Trunnion hub:

8.4.1 Design of Trunnion pin:

Material: corrosion resistance steel
Annealed condition IS 1570 Part V.2 20 Cr 13
$Y' = 900$ Mpa
UTS = 720 Mpa
Hardness = 250 HN
$R_u = R_y = 200$ kN
Bending Moment = $(586 \times 10^3 / 8)(2 \times 66.2 - 50) = 5010300$ kNcm
Proposed 40 cm long pin
$Z_k = 628.3$ cm$^3$, Area = 1257 cm$^2$
Bending stress = $5010000 / 6283 = 797.1$ N/cm$^2$ < 1212 kN/cm$^2$
Shear stress = $293000 / 1257 = 233$ kN/cm$^2$ < 916 kN/cm$^2$
Cheek plate thickness at support: 52 mm
Bearing stress = $293000 / (40 	imes 5.2) = 1400$ kN/cm$^2$ < 2570 kN/cm$^2$

8.4.2 Design of Trunnion Bush:

Material: Self lubricated bearing ASTM B636 or equivalent.
UTS = 700 N/mm$^2$
Hardness = 160 BHN
Proposed Bush bearing as per Manufacturer catalogue ID: 400 OD = 440, 500 long
Bearing stress = $586000 / (40 \times 50) = 283$ kN/cm$^2$ < 400 kN/cm$^2$

8.4.3 Trunnion Hub:

Material: Cast steel IS 1030 Grade 280 - 520 W
Thickness of hub = 0.3 X 400 = 120 mm
Size Hub OD = 440 + 2 X 120 = 680 mm
8.4.4 Design of Trunnion Bracket:

The trunnion bracket is checked for bending between cheek plates and also for bearing stress of the cheek plate.

Load on each trunnion = 536000 kg

Area of bearing plate provided = 650 \times 650

Pressure intensity = \frac{536000}{650 \times 650} = 139 \text{ kg/cm}^2

R_a = R_b = 230000 kg

BM @ A = \frac{(536000 / 65) \times (3.9 / 2)}{2} = 17580 \text{ kg-cm}
BM @ center = 203000 \times (28.5 - 16.26) = 3618550 \text{ kg-cm}
The section proposed is as follows:

<table>
<thead>
<tr>
<th>Section</th>
<th>Area cm²</th>
<th>X cm</th>
<th>Ax</th>
<th>I self</th>
<th>I about NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>63 X 5</td>
<td>325</td>
<td>2.5</td>
<td>812.5</td>
<td>577</td>
<td>20119</td>
</tr>
<tr>
<td>16 X 3.2</td>
<td>51.2</td>
<td>13</td>
<td>665.6</td>
<td>1002</td>
<td>355</td>
</tr>
<tr>
<td>2 X 16 X 3.2</td>
<td>115.2</td>
<td>14</td>
<td>1012.8</td>
<td>3110</td>
<td>1520</td>
</tr>
<tr>
<td>2 X 22 X 3.2</td>
<td>140.8</td>
<td>24.6</td>
<td>3463.7</td>
<td>120</td>
<td>28519</td>
</tr>
</tbody>
</table>

\[ \Sigma A = 632.2 \text{ cm}^2 \]  
\[ \Sigma\text{Ax} = 6554.5 \]  
Total \[ 55512 \text{cm}^4 \]

\[ x = \frac{6554.6}{632.2} = 10.305 \text{cm} \]  
\[ Z_x = \frac{55512}{10.305} = 5354 \text{cm}^3 \]  
\[ Z_y = \frac{55512}{16.332} = 3366 \text{cm}^3 \]  

Bending stress on D/S of flange = \[ \frac{3618550}{5354} = 676 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]  
Bending stress on U/S of flange = \[ \frac{3618550}{3366} = 1082 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]  
Bearing stress in cheek plate = \[ \frac{283000}{(40 \times 5.2)} = 1409 \text{kg/cm}^2 < 1581 \text{kg/cm}^2 \]

**Checking of Local Buckling of D/S Flange:**

\[ p = 136 \text{kg/cm}^2 \]  
\[ S = 5 \text{cm} \]  
\[ b / a = 29.8 / 19 = 1.58 \]

**K value for b / a = 1.58 is**

\[ \sigma_{x1} = 23.0, \quad \sigma_{y1} = 11.0 \]
\[ \tau_{xy1} = 46.0, \quad \sigma_{xy1} = 13.6 \]
\[ \sigma_{x2} = 10.23, \quad \sigma_{y2} = 34.3 \]

**Bending stress in flange**

\[ \sigma = \left( \frac{[K / 100] X ((p \cdot a^2 / S)^2)}{[K / 100] X ((139 \times 19)^2 / 5^2)} \right) \]
\[ = 20.070 \text{kg/cm}^2 \]

\[ \sigma_{xx} = 462 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]
\[ \sigma_{yy} = 933 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]
\[ \sigma_{xx} = 270 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]

\[ \sigma_{xy} = 221 \text{kg/cm}^2 < 1102 \text{kg/cm}^2 \]
8.5 Design of Joints:

8.5.1 Design of Joints between Arms and Horizontal Girder:

The design of joints between arms and horizontal girder are designed to withstand the self weight of skin plate and the self weight of horizontal girder and shear load of water thrust.

- Weight of skin plate assembly
  - i) Drg. No. 201 Skin plate = 2236.00
  - ii) Drg. No. 202 Details of Hood = 2101.00
  - iii) Drg. No. 203 Seal Assembly = 221.00
  - iv) Drg. No. 204 Side guide assembly = 132.00 = 2490.00

- Drg. No. 205 Bottom horizontal girder = 4904.00
- Drg. No. 206 Middle horizontal girder = 4282.00
- Drg. No. 207 Top horizontal girder = 2948.09

i) Dead load on each joint = 47124 / 8 = 7394.0kg
   Proposed 8NOS of M 38 X 4 hex. bolts having
   Shank area of 10.16cm² each
   Shear stress due to dead weight = 7352 / (8 x 10.18) = 96kg/cm²

ii) Shear stress due to water thrust:
   Max load on bottom joint = 262.734 tan 16.0109° = 67.770t
   Shear stress = 67770 / (8 x 10.18) = 832kg/cm²
   Resultant stress = √(96² + 832²) = 838kg/cm² < 960kg/cm²

8.5.2 Connection between Arms and Trunnion Arms:

The self weight shared by the joints of bolts where gate is being lifted is about 1/3rd of self weight of gate.

Self weight of gate on each side = 76 / 2 = 38t
Weight of joints on each side = 38 / 3 = 12.667t
It is proposed to provide 8NOS M 36 X 4 bolts on each joint.
Area of each bolt is 10.16cm²
Shear stress due to self weight
= 12667 / (8 x 10.18) = 155kg/cm²
Shear load due to water thrust on the three joints
= 500 tan 15.9605° = 157.13t
Shear stress = 157133 / (8 x 9 x 10.18) = 643kg/cm²
Resultant thrust = √(155² + 643²) = 681kg/cm² < 960kg/cm²
3.5 Design of Horizontal Girder Bracings:

The bracings for the down stream flange of horizontal girder is designed for the following:
I. ½ of the weight of horizontal girder.
II. 2½% of axial force in down stream flange of girder.

Design of bracings between Bottom and 2nd Horizontal Girder:

A. Self weight:
   ½ the weight of Bottom H.G = \( \frac{4504}{2} \) = 2452 kg
   ½ the weight of Middle H.G = \( \frac{4252}{2} \) = 2126 kg

B. Axial force in D/S flange of bottom & middle H.G
   Axial force in Bottom H.G D/S flange = 252.734 \( \tan 15.0105^\circ \) = 67.770
   Axial force in Middle H.G D/S flange = 217.843 \( \tan 15.0105^\circ \) = 58.440
   2 ½% of cross shear = \( \frac{2.5}{100} (67.770 + 58.440) / 2 \) = 2.429
Max. shear forces in panel BB = 2.425 + 1.2 = 3.625
θ = tan⁻¹(1.9 / 3.06) = 31.83°
Length of AB = 306² + 190² = 360cm
Adopt: 2L100 X 100 X 6
Area = 2 x 100 x 100 x 6 = 23.34cm²
t_m = 3.09cm
I / t_m² = 0.89 x 300 / 3.09 = 69
Permissible stress = 80 x 10.2 (2.45 / 0.89) = 550kg/cm²
Actual compressive stress = 5625 / 23.31 = 156 kg/cm² < 550kg/cm²

8.6.2 Design of bracings between middle and top horizontal girder:

Since the self weight & axial force are on rection side, it is proposed to use same section as above that is 2L100 X 100 X 6 for bracings between middle & the top horizontal girder.
8.7 Design of Arm Bracings:

It is proposed to brace the bottom arm, middle arm and top arm as shown in the sketch. The section adopted are indicated in the tabular form:

\[
\begin{align*}
\text{Axial load on the bottom arm} &= 239.354t \\
\text{Axial load on the middle arm} &= 225.642t \\
\text{Axial load on the top arm} &= 123.036t
\end{align*}
\]

8.7.1 Design of Bracings between Bottom and Second arm:
Considering the water thrust in the arm.
Force on the bracings = \((2.5 / 100) \left( (239.354 + (225.642 / 2)) \right) = 8.805t\)

8.7.2 Design of Bracings between Middle and Top arm:
Force on the bracings = \((2.5 / 100) \left( (225.642 / 2) + 123.036 \right) = 5.911t\)
### Spillway Radial Gates - Madikanea

#### 2.7.1 Design of bracing between bottom and middle arms:

<table>
<thead>
<tr>
<th>Member</th>
<th>Force in kgs due to water thrust (kmp)</th>
<th>Force in kgs due to Self weight of arms</th>
<th>Net force compression kgs</th>
<th>Section</th>
<th>Length L for Allowable stress</th>
<th>Actual stress kg/sq.cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>B - H</td>
<td>8805</td>
<td>2200</td>
<td>11005</td>
<td>2 No. L 100 X 100 X 10</td>
<td>Area = 38.06 sq cm, ( r_{xx} = 3.85 ) cm</td>
<td></td>
</tr>
<tr>
<td>H - I</td>
<td>8805</td>
<td>200</td>
<td>8605</td>
<td>Built in section</td>
<td>Area = 60.06 sq cm, ( r_{xx} = 16.2 ) cm</td>
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</tr>
<tr>
<td>I - J</td>
<td>8805</td>
<td>200</td>
<td>15006</td>
<td>2 No. ISMO 128 X 66</td>
<td>Area = 33.4 sq cm, ( r_{xx} = 5.08 )</td>
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</tr>
<tr>
<td>J - K</td>
<td>8805</td>
<td>600</td>
<td>8205</td>
<td>do</td>
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<td></td>
</tr>
<tr>
<td>K - L</td>
<td>8805</td>
<td>2100</td>
<td>10905</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L - M</td>
<td>8805</td>
<td>600</td>
<td>8305</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G - H</td>
<td>8805</td>
<td>2000</td>
<td>8405</td>
<td>2 No. L 100 X 100 X 10</td>
<td>Area = 38.06 sq cm, ( r_{xx} = 3.85 ) cm</td>
<td></td>
</tr>
</tbody>
</table>
### Spillway Radial Gate - Madikheda

#### Design of bracings between middle and top arm:

<table>
<thead>
<tr>
<th>Member</th>
<th>Force in kgs due to water thrust (comp)</th>
<th>Force in kgs due to self weight of arms</th>
<th>Net force compression kgs</th>
<th>Section Proposed</th>
<th>Length in cms</th>
<th>f/r Allowable stress kgs/cm²</th>
<th>Actual stress kgs/cm²</th>
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<tr>
<td>B - H</td>
<td>5911</td>
<td>1000</td>
<td>7511</td>
<td>2 Nos. L 100 X 100 X 10</td>
<td>250</td>
<td>58</td>
<td>763</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Area = 20.00 sqcm</td>
<td>f/k = 3.85 cm</td>
<td></td>
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<tr>
<td>M - I</td>
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<td>790</td>
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<td>Built in section</td>
<td>354</td>
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<td>Area = 98.0 sqcm</td>
<td>f/k = 18.2 cm</td>
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</tr>
<tr>
<td>I - J</td>
<td>5911</td>
<td>2450</td>
<td>3461</td>
<td>2 Nos. ISMB 125 X 65</td>
<td>530</td>
<td>104</td>
<td>542</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Area = 53.4 sqcm</td>
<td>f/k = 3.03</td>
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<td>J - K</td>
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<td>7611</td>
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<td>240</td>
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<td></td>
</tr>
<tr>
<td>K - L</td>
<td>5911</td>
<td>2150</td>
<td>3761</td>
<td>do</td>
<td>480</td>
<td>98</td>
<td>550</td>
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<td></td>
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<tr>
<td>L - M</td>
<td>5911</td>
<td>1190</td>
<td>7011</td>
<td>do</td>
<td>130</td>
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<td></td>
</tr>
<tr>
<td>G - H</td>
<td>5911</td>
<td>1000</td>
<td>4911</td>
<td>2 Nos. L 100 X 100 X 10</td>
<td>260</td>
<td>68</td>
<td>763</td>
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<tr>
<td></td>
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<td></td>
<td>Area = 38.06 sqcm</td>
<td>f/k = 3.85 cm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.8 Deflection Calculation:

C/C tees = 45cm

\[ W_1 = 0.057 \text{kg} \]
\[ W_2 = 286 \text{kg} \]

Moment of inertia of the section = 9033 cm²

\[ \delta_2 = \frac{11 \times W_2 \times a^2}{60EI} \text{ (Page 362 of steel designer manual 4th edition)} \]
\[ = \frac{(11 \times 236 \times 110^2)}{(60 \times 2047000 \times 9033)} = 0.0038 \text{cm} \]

\[ S_2 = \frac{1 \times W_2 \times a^2}{FFI} = \frac{(1 \times 236 \times 110^2)}{(9 \times 2047000 \times 0.033)} = 0.004 \text{cm} \]

Total deflection = 0.054 + 0.0038 = 0.0464 cm

Permissible deflection = 110 / 800 = 0.1375 cm > 0.046 cm

Deflection at the top of the gate:

It is proposed to provide a prop at the top of gates and C/S flange at top horizontal girdler to limit the deflection in cantilever portion.

Max. spacing of props provided is 1900 at hood and 1515 at shield.

Considering 1000 mm the design is checked,

\[ W = \frac{3}{4} \times 0.4307 \times 441 \times 100 = 1842.1 \text{kg} \]

Load on prop = 1842.1 / 5 = 368.4 kg

Effective length = 425 cm
Proposed L 100 X 100 X 8 = 2 kg.

Area = 2 X 11.7 = 23.4 cm²
Iₓx = 7325 cm⁴
Iᵧx = 4.29 cm

Allowable stress = 53 X 10.2 X 0.45 = 29.68 = 368 kg/cm²
Actual stress = 3684 / 29.4 = 157 kg/cm² < 368 kg/cm²
Permissible deflection = 829 / 900 = 0.09 cm

δ max. = 0.0047 WL/El (as per steel designer's manual)
= (0.0047 X 18421 X 423) / (2047000 X 7.333)
= 0.84 cm < 0.94 cm

8.9 Design of Side Guide Assembly

It is proposed to provide a pair of side guide rollers at all horizontal guides points.

As per IS 4523, a minimum load of 5% of the total weight of gate is recommended for the design of each guide roller.

Max. weight of moving parts = 70 kg
Load on each guide roller = 1.6 X [5 / 100] = 36 kg
Size of the guide roller provided = 150mm X 50mm tread width.

Material: Wheel - Cast steel IS 1030 Grade 250 - 320W
YS = 285 kg/cm²
UTS = 530 kg/cm²

Allowable contact stress = 1.6 X 5.334 = 8.488 kg/cm²
Contact stress 10 = 0.416 (PE/10) = 0.416 (13.8 X 20 ft) / (7.5 X 5)
= 5.02 ft/cm² < 8.488 kg/cm²

Bush bearing:
Material: Al. Bronze grade AB2
Permissible stress = 26 kg/cm²

Proposed bush bearing size: ID 50 OD 70 L = 25 mm

Bearing pressure, [3800 / (5 X 5)] = 127 kg/cm² < 261 kg/cm²

Design of Pin:
Material: BS 20Cr13 IS 1570 Part V
R₀ = R₂ = 11000 kg
SM = (3800 / 6) [(2 X 8)/6 - 6] = 52,532 kg/cm

m = 3 cm
Z₂ = 12 cm
loading = 6320 / 12 = 443 kg/cm² < 162 kg/cm²
8.10 **Design Tie between Trunnions:**

Max. Load on the trunnion (on each side) = 664t
Inclination of the arm = 15.0105°

Tensile load on the tie between trunnion = 664000 tan 15.0105° = 157133 kg

The tie between trunnion is designed for 157133 kg of tensile load and self weight of slider 216 kg/m

The arrangement is shown in the Drawing.
OMML / MADIKHEDA / RG / GP / 213

The sectional properties are as follows:

Area = 2 x 111 + 2 x 38 x 1.6 = 343.0 cm²
Iy = 2 x 45200 + (2 x 38 x 1.6² / 12) + 2 x 38 x 1.6 x 25.8² = 171359 cm⁴
Zyy = 94420 cm³

Direct tensile stress = f = 157133 / 343.0 = 239 kg/cm² < 1102 kg/cm²

Bending stress due to self weight:

Rₐ = Rₜ = 2160 kg
Bending moment = 864000 kgm
Bending stress = 864000 / 6442 = 134 kg/cm² < 1102 kg/cm²
Total stress = 239 + 134 = 423 kg/cm² < 1102 kg/cm²

Check for eccentricity:
The load acting at 220 mm eccentricity.
Moment = 157133 x 22 = 3456926 kgm
Zₜ = 94420 cm³
Bending stress = 3456926 / 6442 = 537 kg/cm² < 1102 kg/cm²
Total stress = 423 + 537 = 960 kg/cm² < 1102 kg/cm²
Check for Temperature effect:

Compressive stress $P$ induced in the section due to temperature variation of 20° C. The tie is free to shorten due to fall in the temperature:

$$\Delta = \alpha \Delta T = 0.000011 \times 20 \times 1000 = 0.22 \text{ mm}$$

$$P = \frac{8 \Delta E}{E} = 0.394 \times \frac{1600 \times 2047000}{2451 \text{ kg/m}^2} = 491 \text{ kg/cm}^2$$

Max total stress = 560 + 491 = 1451 kg/cm$^2$ < 1.33 x 1102 = 1466 kg/cm$^2$

3.11 Design of Trunnion Level Platform:

- Yaw width = 14.5 M
- Span of the platform = 15.0 M
- Loads on the bridge = Self weight 3800 kg, 500 kg/m
  - Live load 500 kg/m, 745 kg/m

$$R_x = R_y = 5774 \text{ kg}$$

Bending moment = 745 x 15.5 x 15.5 / 8 = 2237328 kgm

Section proposed 2 Nos., ISMB 450 x 150 is as follows:

- Area = 2 x 92.2 = 184.4 cm$^2$
- $I_{xx} = 2 \times 30400 = 60800$ cm$^4$
- $Z_{xx} = 2 \times 1350 = 2700$ cm$^3$

Bending stress = $2237328 / 2700 = 828 \text{ kg/cm}^2 < 1200 \text{ kg/cm}^2$

Shear stress = $5774 / (2 \times 45 \times 0.84) = 85 \text{ kg/cm}^2 < 1200 \text{ kg/cm}^2$

Check for Deflection:

Permissible deflection = $L / 325$
- 1660 / 325 = 4.77 cm

Actual deflection = $5 / [384 \times WL^3 / EI]$
- $(5 \times 11547.5 \times 1550^3) / (384 \times 2047000 \times 60800) = 4.5 \text{ cm} = 4.77 \text{ cm}$

Proposed 20 mm anchor bolts 6 Nuts per side.
## 8.12 Gate Weight:

![Diagram](image)

<table>
<thead>
<tr>
<th>S.No</th>
<th>Org. No.</th>
<th>Description</th>
<th>WL in T</th>
<th>X</th>
<th>Wk</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>OMML-MADIKEDA-RG-GP-201R1</td>
<td>Skin plate assembly</td>
<td>32.536</td>
<td>14.80</td>
<td>451.533</td>
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<tr>
<td>2</td>
<td>OMML-MADIKEDA-RG-GP-202R2</td>
<td>Hood</td>
<td>2.254</td>
<td>13.65</td>
<td>30.789</td>
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<tr>
<td>3</td>
<td>OMML-MADIKEDA-RG-GP-203R1</td>
<td>Seal Details</td>
<td>0.221</td>
<td>15.08</td>
<td>3.332</td>
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<tr>
<td>4</td>
<td>OMML-MADIKEDA-RG-GP-204R1</td>
<td>Side Guide</td>
<td>0.150</td>
<td>14.90</td>
<td>2.335</td>
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<td>5</td>
<td>OMML-MADIKEDA-RG-GP-205R2</td>
<td>Bottom Horizontal Girder</td>
<td>4.528</td>
<td>13.50</td>
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<td>6</td>
<td>OMML-MADIKEDA-RG-GP-206R3</td>
<td>Middle Horizontal girder</td>
<td>4.422</td>
<td>13.95</td>
<td>61.966</td>
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<td>OMML-MADIKEDA-RG-GP-207R4</td>
<td>Top Horizontal girder</td>
<td>3.154</td>
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<td>8</td>
<td>OMML-MADIKEDA-RG-GP-208R5</td>
<td>Horizontal girder bracings</td>
<td>2.519</td>
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<td>OMML-MADIKEDA-RG-GP-209R6</td>
<td>Arm assembly</td>
<td>21.240</td>
<td>7.35</td>
<td>168.114</td>
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<td>11</td>
<td>OMML-MADIKEDA-RG-GP-211R8</td>
<td>Trunnion Bush</td>
<td>0.218</td>
<td>0.21</td>
<td>0.045</td>
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<td>12</td>
<td>OMML-MADIKEDA-RG-GP-213R9</td>
<td>Tie between Trunnions</td>
<td>4.165</td>
<td>0.56</td>
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<td>13</td>
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<td>Lifting arrangement</td>
<td>1.650</td>
<td>14.00</td>
<td>23.100</td>
</tr>
</tbody>
</table>

\[x = \frac{0.3133}{82.055} = \boxed{1.360}\]
8.13 Hoist Capacity Calculations:

1. Moving weight of gate = 82.055t
   C.G. of the gate = 11.350m
   Moment due to self weight of gate = 931.324tm -- (1)

2. Moment due to trunnion friction:
   Load on the trunnions = 130t
   Friction factor = 0.2
   Diameter of the pin = 0.40m
   Moment due to trunnion friction = 130t X 0.2 X 0.2 = 52.320tm -- (2)

3. Moment due to seal friction:

   \[ R = \left( \pi \times 5.7 \times 3.8 \right) / 5.7 = 3.8 \]  \[ \text{Seal friction} = 2\mu R \]
   \[ = 2 \times 1.5 \times 133.4 \times 3.6 \times 0.636 \times 0.672 \]
   \[ = 141.602tm -- (3) \]
   \[ \text{Total moments} = (1) + (2) + (3) = 1124.710tm \]
   \[ \text{Lever arm of the hoist} = 9.657m \]
   \[ \text{Hoist capacity required} = 1084.618 \div 0.657 = 165.466t \]
   
   \[ \text{Add 20\% reserve} = 23.290t \]
   
   \[ = 188.756t \]

Proposed 140t rope drum hoist.

*****
Chapter 8

Design of Rope Drum Hoists for Hydraulic Gates

**Rope Drum Hoist:**

Hoists commonly used with vertical gates can broadly be divided into two types namely rope drum hoists and screw hoists.

Rope Drum Hoists are the simplest and most widely used motorized hoists, where the entire load is supported by the hoist, without the use of counterweights. These are very popular due to their indigenous manufacture and easy maintenance. Rope drum hoists are suitable only for gates that would close under their own weight, with sufficient force to effectively press the bottom seal to prevent leakage. This restricts their use to the fixed wheel gates only as pad friction in slide gates is rather high and the gates usually do not close under their own weight.

IS: 6938 –1989 DESIGN OF ROPE RUM AND CHAIN HOISTS FOR HYDRAULIC GATES – CODE OF PRACTICE lays down the broad requirements and has been largely followed in the design. Use of bought out components for mechanical transmission and electric control is preferred as that ensures reliability of operation. Rope drum hoists should be so designed that they can be operated manually without excessive effort.

**COMPONENTS OF THE ROPE DRUM HOIST**

Each hoist shall comprise following components:-

- **Central Drive Unit**
  
  Central drive unit shall comprise of an electric motor, 1st stage reduction gearbox, electro -magnetic brakes, gate position indicator and manual drive unit, couplings etc.

- **End Gear Reduction Unit**

  The end gear reduction unit shall comprise of gears, pinions, plummer blocks, Shafts, pedestals, rope drums, bearings, couplings and all other such accessories which may form in-separable components for the satisfactory operations.

- **Control Equipment**

  The control equipment shall comprise of electric motor, switchgears, and limit switches, control panel, and various electrical relays required for satisfactory operation of motors and brakes etc.

- **Miscellaneous Parts**

  Miscellaneous parts like wire ropes, rope sockets, equalizers, turn buckles, pulleys/sheaves, hoist base frames, cover boxes and hoist supporting structure etc.
Concept of Rope Drum Hoist:
- Flexible rope of special steel wound on a grooved drum of steel
- One end connected with gate and other with drum
- Winding effected with rotation of drum
- Rotation of drum through a source such as electrical motor and gearing arrangement

Types of Hoisting Equipment
- Rope drum hoist
- Chain hoist
- Rack & pinion hoist
- Gantry cranes
- EOT cranes
- Mono rail cranes

Most Commonly adopted Hoisting Equipment
- Rope drum hoist —for self closures
- Screw hoist—for positive thrust
- Hydraulic hoist—for higher capacity
Advantages of Rope Drum Hoist:

- Simple in design, fabrication & erection
- Low cost for moderate capacities
- Easy maintenance and component replacement
- Convenient for high lifts for gates located under wells or duct
- Can result in optimum capacities due to gate connection in radial gates

Limitations:

- Absence of positive thrust complexity in rope layout
- Higher capacities
- Danger of rope snapping
- Larger space requirement
- Limited operating speeds
- Expensive for higher capacities

Criteria for Adopting Rope Drum Hoists:

- Used only in case of self closing gates
- It is used for moderate capacities
- In India used conveniently up to 200t.
- Beyond 200t only few examples are available
- Economics should be considered before adopting them
- Capability of manufacturer

Components

1. Hoisting Components

- Steel wire ropes
- Grooved or plain drum
- Pulleys
- Sets of open gear reduction
- Shafts
- Couplings, bearings, Plummer blocks, etc

2. Central drive unit

- Reducer
- Motor
- Shafts
- Couplings, bearings, Plummer blocks etc.
- Brakes
3. Structure

- Structural parts
- Gear box chair
- Drive units tools/base frames
- Hoist bridge
- Trestles
- Gate hoist connection

4. Other Miscellaneous Components

- Gate position indicator
- Hand operation
- Covers for drive units and hoist
- Ladders, walkways and gratings

AC Motors:

TEFC motors are most commonly used for hydro mechanical equipments.

- 3 phase induction motor is most widely used for modern industrial applications.
- Starting torque: starting torque, also referred to as locked rotor torque, is the torque that the motor develops each time.
- It is started at rated voltage and frequency.
- Pull-up torque: as the motor picks up speed, torque decreases slightly until point b on the graph is reached.
- Break-down torque: as speed continues to increase from point b to point c, torque increases up to a maximum value at approximately 200% of full-load torque. This maximum value of torque is referred to as breakdown torque.

AC Motor:
AC Motors: torque rating

Types of AC Motors:

1. Squirrel cage induction motor
   - Not having rotor winding
   - Low starting torque
   - Cannot add external resistance
   - Not having slip ring brush
   - Self starting

2. Slip ring motor
   - Having rotor winding
   - High starting torque
   - Add some external resistance

Advantages of Squirrel Cage Induction Motor:

- Squirrel cage induction motors are cheaper in cost compared to slip ring induction motors.
- Squirrel cage induction motors requires less conducting material than slip ring motor
- Squirrel cage motors are better cooled compared to slipping induction motors
- Squirrel cage motors operate at nearly constant speed, high overload
- Capacity, and operates at better power factor.

Electromagnetic Brakes:

- In operation when power goes off
- Designed for 150% of full load torque
- Electrically released when current is applied.
Typical arrangement of rope drum hoist for vertical lift gate
Materials for Various Components:

1. **Motors, reducers & brakes:**
   - Standard and replaceable makes
   - Available from standard catalogues

2. **Shafts:**
   - Mild steel, forged/rolled steel

3. **Couplings:**
   - Cast/forged steel

4. **Ropes:**
   - Improved plough steel IS:2266

5. **Drums:**
   - Cast steel IS: 1030
   - Mild steel IS: 2062
   - Cast iron IS: 210 (for small capacity hoists only)
6. Open gears:
   • Cast steel IS: 1030
   • Forged steel, carbon steel, surface hardened steel or mild steel

7. Bearings:
   • Running shafts : spherical roller bearings
   • Drum shaft: spherical roller bearings or bush
   • Plummer blocks : cast steel or cast iron

8. Bearings:
   • standard and reputed makes

9. Bushing:
   • IS:305(generally), IS:318
   • Form in or applications

10. Gears:
    • Cast steel IS : 1030
    • Forged steel: IS: 2004, 1875 and 1570 etc.

11. Pinions:
    • Similar to gears but one grade higher

Design Standard:
   • Designed in accordance with IS: 6938.
   • This standard covers detailed guide lines applicable for the design of
     Rope drum hoists for gates in WRD projects

Steps for the Design of Rope Drum Hoists:

1. Computation of hoist capacity
   • Gate weight (including ballast, if any)
   • Frictional forces (wheel, guide, seal etc)
   • Hydrodynamic forces (down pull/uplift)
   • Silt/ice loads, if any
   • Weight of appurtenant structures
   • Seating loads

2. Finding the Rope Tension
   • Consider no. of “rope falls” per drum
   • Consider no. of pulleys over which the rope is passing
   • Consider pulley efficiencies over which the rope is passing

3. Rope Tension is given by:
   \[ T = w \left\{ (1-n) / (1-n^f) \right\} \]
   Where,
W=hoist load per drum
n=efficiency of pulley
f= number of rope falls per drum

4. **Select Rope Diameter from IS : 2266 for FOS**

The minimum factor of safety based on breaking strength and safe working load of the wire ropes shall not be less than 6 (six) under normal conditions and not less than 3 (three) under breakdown torque condition of electric motor selected.

Find out overall running efficiency

(Multiplication of individual efficiencies)

5. **Determine Motor H.P.**

Consider hoist capacity
Lifting/lowering speed

Overall efficiency by following relationship:

\[
Hp = \frac{(h \times V)}{(4.5 \times E)}
\]

Where h= hoist capacity in t.
V=lifting speed in m/min.
E=running efficiency

**Efficiency of the Hoisting System**

- **Starting and running efficiencies**
- Drum/ sheave/pulley
- Spur gears
- Helical gears
- Worm reducer
- Motor

<table>
<thead>
<tr>
<th>Ratios of overall running and starting efficiency</th>
<th>&lt; Ratio of starting to running</th>
</tr>
</thead>
</table>

**Torque of the Motor**

- Select motor giving suitable horse power and adopt characteristics in design of reduction etc.
- Determine braking torque for brakes:

\[
Bt = \frac{(71620 \times hpx1.5)}{\text{RPM of motor}}
\]

**Design of Drum:**

1. Find PCD > 20 x rope dia.
2. Find circumference: \( c = \varnothing \times \text{PCD} \)
3. No. of grooves :=( Lift of gate x no. of falls)/\( \Box \) *d+3
4. Pitch of grooves = Rope dia. + n
   \( n=1.5\) mm up to 12 mm dia.
   = 2.5 mm from 12 to 30 mm dia.
   = 3.0 mm above 30 mm dia.
5. Depth of groove = 0.35 x rope dia.
6. Radius of groove = 0.53 x rope dia.
7. Find length of drum by accounting turns
8. Find crushing strength by:
   \[ c = (kT / pt) \]
   Where \( k=\) a factor as per IS: 6938
   \( T=\) rope tension in kg
   \( p=\) pitch in cm
   \( t=\) thickness of shell in cm
   \( c=\) stress in kg/cm\(^2\)
   ➢ Determine bending stress \( \sigma \) by considering self weight and rope tension at critical location
   ➢ Combine crushing and bending stresses
     \[ =\sqrt{(c^2+\sigma^2+c*\sigma)}, \text{ which should be within permissible limits} \]

**Design of Reduction Unit:**

- Inputs required as under:
  Hoisting speed (v)
  Drum circumference
  Drum speed= no. of falls per drum x v/circumference
- Total reduction required (r)
  = Motor rpm/Drum rpm
- Distribute ‘r’ in reducer and open reductions
- Select no. of open reduction sets and adjust teeth to suit desired reduction

**Open Gear Reduction**

- Designed as per IS:6938
- Find tooth load on drum gear= (RT x PCD of drum) / (drum gear PCD x eff.)
Or through torque on the drum
  ➢ Root stress=p x q/f x m where , ‘p’ is tooth load , ‘q ‘is strength factor,’ f’ is face width and ‘m’ is module
  ➢ Repeat above procedure for subsequent reductions
Reducer Selection

• Generally worm or helical type
• Should have input hp sufficiently higher than motor hp
• Ascertain starting and running efficiencies from catalogue supplied by manufacturer

Pulleys and Shafts:

Pulleys

• Fitted with bush or roller bearings
• Preferably of cast steel
• Conforming to standard features
• PCD more than 20 x rope dia.

Shafts

• Designed for moments and torques transmitted
• Checked for bending and shear due to loads and torques
• Checked for equivalent bending and torque

Design for Shafts

• Bending stress = \( \frac{M}{z_{xx}} \)
• Shear stress = \( SF/\text{cross sectional area} \)
• Eq. torque, \( Te=\sqrt{(M^2+T^2)} \)
• Eq. B.M.=\( \frac{1}{2}(Te+M) \)
• Torsional shear = \( Te/\text{polar moment of Inertia} \)
• Bearings for shafts
• Select standard roller bearings of reputed make as far as possible having sufficient static and dynamic load capacities.

Design of Hoist Supporting Structure

The hoist supporting structure and trestle shall be made of structural steel (weldable) conforming to I.S: 2062-1992 and shall be designed to withstand the dead weight of the hoist, hoisting load as well as vibrations coming on the hoist, while in operation. Suitable anchorages for the hoist frame shall be provided to take the worst combinations of all loads under which the gates and hoists are under operation. The hoist supporting structure and trestle shall be either in riveted or welded construction. The frame shall be of the box type. Field welding will not be accepted. Diaphragms shall be provided to distribute the loads to the sides properly. Shop connection in the frame shall be either riveted or welded so that the surface of the hoist includes the outside of the frame, case and hoist housing and viewed along with the intake structure will be a plane surface except for projections of rivet heads. The hoist bridge shall be provided with hand railing, uncovered stairs. The structure shall be designed for each of the following combinations.

i) Dead loads plus live load, impact load, wind load @ 50 kg / sq. m and crowed load @ 500 kg/ sq. m on entire area of walkway.

ii) Dead load with no hoisting load plus effect of storm wind load @ 150 kg/sq. m.

iii) Breakdown torque of the motor as specified in the manufacturer's catalogue. The permissible stresses as specified in IS: 800-1984 for normal operation shall be increased by 33-1/3 %.
Check for breakdown torque:

All hoist components are checked for the loading resulting from BDT

Condition of the hoist motor as under

\[(\text{Motor torque})_{\text{BDT}} = \text{hp} \times 71620 \times (T_b/T_r) \times (1/\text{RPM})\]

\(T_b\) and \(T_r\) are values specified by the manufacturer of motor

- Torque at drum=(motor torque) BDT x R x Nst. ,where ‘R’ is reduction and ‘Nst’ is starting efficiency
- BDT rope tension=torque at drum/(2xdrum radius)
  
  (Divided by 2 for symmetrical drive)

Check all hoist components as before for this value of rope tension

Other miscellaneous components

Shafts

- Bearings/Plummer blocks
- Connection of drum and drum gear
- Computation of graduations for position indicator and its reduction
- Manual operation

Shafts

- Drum shaft, drum gear (w1) pinion shaft (p1), w2 p2 shaft etc.
- Floating shaft straight from the worm reducer on both the sides
- Usual design practice for equivalent bending and torsion.
- \(L/d>50\), angle of twist to be checked (limited to 0.25 to 0.33 degrees/metre)
- Linear deflection limited to 1mm/m

Bearings

- Ball roller or bush bearings are usually provided on all the Running shafts
- Manufacturer’s catalogue is referred for calculating the life of a bearing
- Individual lubrication for all the bearings

Gate position indicator

- Graduated dial calibrated with the lift of the gate
- Made of non rusting metal enameled plate/thick plastic sheet
- Generally circular in shape
- Installed in a manner such that easily readable by the gate operator

Manual operation of the gates

- Emergency provision in case of power failure
- Inter locks provided to delink electrical power with manual operation
- Maximum no. of persons deployed for manual operation: four
- Ratchet and pawl arrangement.
Chapter 9

35t Rope Drum Hoist Case Study

1.0.0: GENERAL DESCRIPTION:

An electrically rope drum hoist of 35.0 t capacity is provided for operation of SPILLWAY GATE. The hoisting mechanism mainly comprises of central drive unit having an electric motor, an electro-magnetic brake and a worm reducer. Two end gear boxes, each with 2 sets of spur gear-pinion & a rope drum are connected to gate by rope, one end of which is fixed to the drum & the other end, after passing over gate pulley is connected to hoist bridge structure. The hoist mechanism is operated through a local control panel mounted on Hoist Bridge. All relays, contactors & fuses etc are located in control panel. Provision is also made for manual operation of hoist in the event of power failure.

2.0.0: DESIGN DATA & ALLOWABLE STRESSES:

(A) DESIGN DATA

1. Hoist capacity = 35.0 t
2. Type of hoist = Electrically operated rope drum.
3. Life of the gate = 10.5 M.
4. Lifting speed = 0.5 M/Min ± 10%

(B) ALLOWABLE STRESSES:

The allowable stresses for various components of hoist machinery are taken as given IS-6938-1989 for normal operation as well as under break down torque condition of motor. Exception is made for drum stress in drum which is to be 0.35 of U.T.S or 0.65 Y.P. of material of drum, whichever is smaller.

3.0.0: WIRE ROPE : IS 2226-1977

Load to be lifted = 35000 kgf
Nos. of drums = 2
Nos. of rope fall/drum = 2

Since the rope is passing over the gate pulley to the drum. Rope tension is given by

\[ T = \frac{35000}{2(1+0.95)} = \text{Say 8975 Kgf} \]

(where 0.95 is the efficiency of gate pulley)

Adopt 32 mm dia, 6 x 37 construction, fibre core, ordinary lay ungalvanized wire rope with wire designation 1960 and & having normal braking load of 592 KN

Factor of safety Normal condition = \[ \frac{592 \times 102}{8975} = 6.728 > 6.0 \]

Rope tension under B.D.T condition (see para 9.1.0)

\[ T = \frac{531706.8}{35.0 \text{ (drum radius)}} \]

= say 15192
F.O.S = \frac{592 \times 102}{15192} = 3.974 > 3.0 \text{ O.K.}

4-0-0: **RODE DRUM : Material : Cast Steel IS-1030 Gr 280 - 520 N**

Rope Tension \quad N \quad T = 8975 \text{ Kgf}

\begin{align*}
\text{(B.D.T)} & = (15192.0) \\
\text{Rope dia} & = d = 32 \text{ mm} \\
\text{Drum p.c.d} & = D = 700 \text{ mm} > 20 \times d \\
\text{Pitch of scouring} & = p = 35 \text{ mm} \\
\text{Drum shell thickness below rope groove} & = t = 30 \text{ mm} \\
\text{Radius of groove} & = 0.53 \times 32 = \text{say 17 mm} \\
\text{Depth of groove} & = 0.35 \times 32 = \text{say 11.5 mm} \\
\text{Crushing Stress} Cr & = KXT \quad (IS:6938 = CI.4.3-3) \\
\text{Normal crushing Stress} & = 1 \times 8950 = 852.38 \text{ Kgf/cm}^2 \\
& = 3.5 \times 3.0 < 0.2 \text{ UTS} \\
\text{B. D.T. crushing Stress} & = 15192 = 1446.86 \text{ Kgf/cm}^2 \\
& = 3.5 \times 3.0 < 0.35 \text{ UTS}
\end{align*}

4-1-0: **LENGTH OF DRUM**

1. Length of rope to be wound on drum = 2 \times 10.5 = 21 \text{ M}
2. Drum p.c.d = 700 \text{ mm}
   
   Number of groove for the lift = 21 = \text{say 10 grooves}
   
   0 \times 0.7

Total number of grooves i/c fixing and idle grooves = 10 + 3 = 13 Nos

Grooved length od drum = 13 \times 35 = 455 \text{ mm}

Adopt over all length od drum as say = 705 \text{ mm}
Core dia of drum = 608 \text{ mm}
Turn dia of drum = 691 \text{ mm}
4-2-0: **LENGTH OF DRUM**

B. M. in drum, due to rope load in centre

\[ \text{B. M} = \frac{8975 \times 71}{4} = 159306.25 \text{ kgcm} \]

B. M. due to self wt of drum at centre

\[ \text{B.M} = 600 \times \frac{71}{8} = 5325 \text{ kgcm} \]

Total B.M. = 159306.25 + 5325 = 164631.25 Kgcm

\[ Z \text{ to drum} = \pi \left( \frac{(66.8)^4 - (Q0.8)^4}{32} \right) \times 1 = 9180.28 \text{ cm}^3 \]

Bending stress = 164631.25 - 9180.28 = 17.93 Kgf/Cm³

Combined stress = \[(852.38)^2 + (17.93)^2 + 852.38 \times 17.93\]^{1/2} = 861.48 Kgf/Cm²

5-0-0: **GEAR REDUCTION & LIFTING SPEED**

Adopt gear ratio as under:

1. Worm reducer ratio = 60 : 1 Size -700
2. Drum gear / pinion = 115 : 20
3. 2²nd Gear/Pinion = 121 : 20
4. Rated speed of motor = 960 rpm

Total reduction = \[60 \times 115 \times 121\] = 2087.25
\[1 \times 20 \times 20\]

Drum rpm = \[960 / 2087.25\] = 0.4599353

Lifting speed = \[0.45993 \times \pi \times 0.7\] = 0.5057 M/Min
\[2\]

6-0-0: **EFFICIENCY OF SYSTEM**

From the table of IS-6938 - 1987, the starting and running efficiencies for drum, gear, pinion & pulleys are as under:
<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Item</th>
<th>Starting Efficiency</th>
<th>Running Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Drum &amp; Pulley</td>
<td>0.93(^2)</td>
<td>0.95(^2)</td>
</tr>
<tr>
<td>02</td>
<td>2 sets spur gear / pinion</td>
<td>0.93(^2)</td>
<td>0.95(^2)</td>
</tr>
<tr>
<td>03</td>
<td>Worm reducer 60:1 Size 7 or (700)</td>
<td>0.42</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Overall efficiency</td>
<td>0.314</td>
<td>0.6109</td>
</tr>
</tbody>
</table>

\[
\text{Ratio of efficiencies} = \frac{0.6109}{0.314} = 1.945 < 2.20
\]

7-0-0: **ELECTRIC MOTOR : IS-325 - NGEF, GEC CROMPTION**

Hoisting Load - P = 35000 KN
Lifting Speed \(S\) = 0.5057 M/Min
Overall efficiency \(n\) = 0.6109

\[
\text{HP Motor} = \frac{P \times S}{4500 \times n} = \frac{35000 \times 0.5057}{4500 \times 0.6109} = 6.438
\]

Adopt 7.5 HP, 060 rpm, TEFC, squirrel case reversing service with shaft extension, class E insulation induction motor working on 415 - 440 V, 3 Phase, 50 cycles, A.C. Electric-Supply.

Frame size - AM 132 - M-6 of NGEF or equivalent GEC / Crompton Make

8-0-0: **ELECTRO MAGNETIC BRAKE**

Rated torque of motor = \(\frac{71620 \times 7.5}{960} = 559.3\text{Kg cm}\)

Brake torque required = \(1.5 \times 559.5 = 839.3\text{ Kg cm}\)

Adopt 200 mm dia brake drum, solenoid operated, spring set with hand release lever, single phase. A.C electromagnetic brake having braking torque of 1550 Kg cm @ 100% coil rating of reputed make 'like Strom kraft / sterling / electro-Mag etc.
9-0-0: **ELECTRIC MOTOR**

The torque transmission under normal condition & under B.D.T condition, is as under:

<table>
<thead>
<tr>
<th>Set</th>
<th>TORQUE IN Kgcm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Output</td>
</tr>
<tr>
<td>01</td>
<td>Drum Gear/ Pinion N B.D.T</td>
</tr>
<tr>
<td>02</td>
<td>2nd shaft N B.D.T</td>
</tr>
<tr>
<td>03</td>
<td>3rd shaft N B.D.T</td>
</tr>
</tbody>
</table>

9-1-0: **B.D.T. CONDITION**

B D torque of motor = 2.9 x 559.5 = 1622.55 Kgcm
Total reduction = 2087.25
Starting efficiency = 0.314
Torque on drum under B.D.T = \[
\frac{1622.55 \times 2087.25 \times 0.314}{2} = 531706.8 \text{ Kgcm}
\]

10-0-0: **WORM REDUCER - ELECON / SHANTHI**

Adopt 60 : 1 ratio, size 700 F.U (under driven) type single stage worm reducer with output shaft on both sides, having input Hp of 9.0 at nominal r.p.m of 1000 & output torque of 288 da NM: of SHANTHI or ELECON MAKE

Torque at 7.5 HP = \[
\frac{288 \times 1000 \times 7.5}{9 \times 960} = 250 \text{ daNM > 21063.8 Kgcm}
\]

11-0-0: **GEAR PINIONS**

The root stress in tooth of gear or pinion is given by

\[
\sigma_{root} = \frac{p \times q}{F \times m}
\]
(IS:6938, Cl - 4.5.2)

The table below gives the details of gears and pinions and the stress developed in normal & B. D.T condition.
<table>
<thead>
<tr>
<th>Part</th>
<th>No of teeth N</th>
<th>Module M mm</th>
<th>P.CD N x m Mm</th>
<th>Face width F mm</th>
<th>Strength Factor q</th>
<th>Torque N / B.D.T Kgcm</th>
<th>Tooth load P = N BDT</th>
<th>Stress = pxq F.m Kgf/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drum Gear W₁</td>
<td>115</td>
<td>10</td>
<td>1150</td>
<td>155</td>
<td>2.50</td>
<td>330657.9</td>
<td>571727.7</td>
<td>5750.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9943.09</td>
<td></td>
<td>1603.7</td>
</tr>
<tr>
<td>Pinion P₁</td>
<td>20</td>
<td>10</td>
<td>200</td>
<td>165</td>
<td>3.367</td>
<td>57505.7</td>
<td>99430.9</td>
<td>5750.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2029.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Gear W₂</td>
<td>121</td>
<td>6</td>
<td>726</td>
<td>80</td>
<td>2.50</td>
<td>60532.3</td>
<td>106944.95</td>
<td>1667.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2946.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Pinion P₂</td>
<td>20</td>
<td>6</td>
<td>120</td>
<td>90</td>
<td>3.367</td>
<td>10005.3</td>
<td>17671.9</td>
<td>1667.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2946.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11-1-0: MATERIAL FOR GEARS & PINIONS - ALLOWABLE STRESS:

(A) FOR GEARS : Cast steel to IS-1030, Gr. 280-520 N
   (1) Stress under Normal Condition = 0.2 X 520 X 10.2 = 1060.8 Kgf/cm²
   (2) Stress under B.D.T. Condition = 0.8 X 280 X 10.2 = 2284.8 Kgf/cm²

(B) FOR PINIONS I.S.1875: Class4 -45 C8
   UTS = 620 N/mm² = YP = 320 N/mm
   (1) Stress under Normal Condition = 0.2 X 620 X 10.2 = 1264.8 Kgf/cm²
   (2) Stress under B.D.T Condition = 0.3 X320 X 10.2 = 2611.2 Kgf/cm²

The stress in the gears & pinions are within the above permissible limits.

12-0-0: DRUM SHAFT : MATERIAL 1S-1570 40 C8 or EN8 :
   UTS = 580 Mpa, yp = 320 MPa

The arrangement of drum shaft w.r.t. drum and drum gear is shown in Fig.1. The drum shaft is fixed shaft.
VERITCAL LOAD

(A) At point "A"
(1) Due to rope load = 8975 x 491/705
(2) Due to 1/2 self Wt. of drum ...

At point "B"

(1) Due to rope load
(2) Due to self wt of drum & Gear (350+450)
(3) Due to tooth load of drum Gear

HORIZONTAL LOAD

At Point B :

Due to tooth profile = 5750.6 tan 20° = \[ \frac{2093.0 \text{ Kgf}}{3621.0 \text{ Kgf}} \]

Schematic loading of drum shaft in both cases is shown in Fig 2
VERTICAL REACTIONS :-

<table>
<thead>
<tr>
<th>Rope position</th>
<th>RCV</th>
<th>Kgf</th>
<th>RCV</th>
<th>Kgf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>5589.95 ▲</td>
<td>9044.8 ▲</td>
<td>1215.95 ▼</td>
<td>2645.8 ▼</td>
</tr>
<tr>
<td>B.D.T</td>
<td>2558.4 ▲</td>
<td>3913.9 ▲</td>
<td>1816.61 ▲</td>
<td>2487.1 ▲</td>
</tr>
</tbody>
</table>

HORIZONTAL REACTIONS :-

<table>
<thead>
<tr>
<th></th>
<th>RCH</th>
<th>Kgf</th>
<th>RDH</th>
<th>Kgf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>523.3</td>
<td>908.7</td>
<td>1567.70</td>
<td>2712.3</td>
</tr>
</tbody>
</table>

RESULTANT REACTIONS :-

<table>
<thead>
<tr>
<th>Rope position</th>
<th>RC</th>
<th>Kgf</th>
<th>RD</th>
<th>Kgf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>5614.6</td>
<td>9090.3</td>
<td>1984.0</td>
<td>3789.04</td>
</tr>
<tr>
<td>B.D.T</td>
<td>2611.8</td>
<td>4018.0</td>
<td>2399.6</td>
<td>3680.0</td>
</tr>
</tbody>
</table>

Max. B. M. @ B (Normal) = 2399.6 x 26.0 = 62389.6 Kgcm
Max. B. M @ B (B.D.T) = 3789.04 x 26.0 = 98515.04 Kgcm

Adopt 90 mm dia shaft in hub zone & 87 mm dia in centre

Z min = π x (8.7)^3/32 = 64.648 cm³
Max. bending stress = 62389.6/64.048 = 965.07 Kgf/cm²
< 0.2 UTS

Max. bending stress B.D.T. = 98515.04-64.648 = 1532.9 Kgf/cm²
<0.8 yp

Normal bearing stress on 20 thick plate = 5614.6
9.0 x 2.0 = 311.9 Kgf/cm²

Shear Stress (Normal) = 5614.6 x 4
55 x 9² = 88.26 Kgf/cm²
12-1-0  **BRONZE BUSH : IS: 305 GR AB-1**

(A) **DRUM HUB BUSH**

Max load on drum hub = 6592 Kgf  
Shaft dia at hub = 90 mm  
Bush length = 90 mm  
Bronze bush bearing stress = \( \frac{6592}{9.0 \times 9.0} \) = 81.38 Kgf/cm²  
Provide bronze bush having id = 90 mm, od = 115 mm & length = 90 mm

(B) **DRUM GEAR HUB BUSH**

Neglecting all downward loads max upward load = 5751 Kgf (Tooth load)  
Bush length = 140 mm  
Bearing stress = \( \frac{5751}{9.0 \times 14} \) = 45.64 Kgf/Cm²  
Provide bronze bush with id = 90 mm, od = 115 mm and length 2 x 70 mm

13-0-0:  **2nd SHAFT**:  
Material : IS-1570-40 C8 or EN8  
UTS = 580 Mpa  YP = 320 Mpa  

**VERTICAL LOADS**

<table>
<thead>
<tr>
<th>Point</th>
<th>Normal</th>
<th>BDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Due to tooth load</td>
<td>5751</td>
<td>9943</td>
</tr>
<tr>
<td>(2) Due to self Wt. of P₁</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Total load @ P₁ Say</td>
<td>5800</td>
<td>9990</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Point</th>
<th>Normal</th>
<th>BDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>W₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Due to tooth load</td>
<td>1667.55</td>
<td>2946.1</td>
</tr>
<tr>
<td>(2) Due to self Wt of P₁</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>Total load @ W₂ Say</td>
<td>1900</td>
<td>3180</td>
</tr>
</tbody>
</table>
HORIZONTAL LOADS

At point W2  - Due to tooth profile 1667.5 \( \tan 20^\circ = 607 \) kqf (1073 Kgf)

At point P1  - Due to tooth profile as before 2093 (3621 Kgf)

Schematic loading of shaft is shown in Fig – 3

VERTICAL REACTIONS

RAV = 1285 86 Kgf (7353.03 Kgf)

RBV = 3414.14 Kgf (5816.97 Kgf)

HORIZONTAL REACTIONS

RAH = 1521.98 Km (2640.20 Kgf)

RBH = 1178.02 Kgf (2053.74 Kgf)

RESULTANT REACTIONS

RA = \( \sqrt{(4285.86^2 + 1521.98^2)} \) = 4548.08 Kgf (7812.7 Kgf)

RB = 3611.66 Kgf (6168.87 Kgf)

Max. moment @ P1 = 4548.08 x 18.0 = 81865.44 Kqcm (140628.6 Kgcm)

Torque = 57505.7 Kgcm (99430.9 Kgcm)
Equivalent torque = \( \sqrt{(81865.44)^2 + (57505.7)^2} \) Kgcm

\[ 100044.3 \quad 172229.2 \text{ Kgcm} \]

Equivalent B.M = \( 0.5 (100044.3 + 81865.44) = 99954.87 \text{ Kgcm} \)

(156428.9 Kgcm)

Adopt 100 mm dia shaft

\( Z_b = 98.17 \text{ cm}^3 \) and \( z_p = 196.349 \text{ cm}^3 \)

Bending stress = \( 81865.44 / 98.17 \text{ Kgcm}^2 = 833.92 \text{ Kgcm}^2 \)

(1432.5 Kgcm^2)

Torsional stress = \( 57505.7 / 196.349 = 292.87 \text{ Kg/cm}^2 \)

(506.4 Kgcm^2)

Combined stress = \( \sqrt{(833.92)^2 + 3(292.87)^2} \)

\[ 976.08 \text{ Kg/cm}^2 \]

\( \text{B.D.T.} = (1679.7 \text{ Kgf}/\text{Cm}^2) \)

\( \text{Combined stress} < 1958.4 \text{ Kgf}/\text{Cm}^2 \)

Equivalent bending stress = \( 90954.87 / 98.17 = 926.5 \text{ Kgf/cm}^2 \)

(1.2 x 887.4 kgf/Cm^2)

B.D.T. equivalent bending stress = 1593.45 Kgf/cm^2

\( \text{B.D.T.} < 1958.4 \text{ Kg/cm}^2 \)

Equivalent torsional stress (N) = \( 100044.3 / 196.349 = 509.5 \text{ Kgf/cm}^2 \)

B.D.T. = (877.15 Kgf/cm^2)

**13-1-0: BEARING FOR SHAFT**

Provide SNA 520 type plummer block with bearing No. 2220 KK + Adapter sleeve H 320 + locating rings 2 Nos FRB 12/180. P

Static / dynamic capacity of bearing = 53 / 97.5 KN

2nd shaft r.p.m. = 0.4599353 X 115/20 = 2.644

Max reaction = 4548.08Kgf = Say 45600 N

Life of bearing = \( (97.5/456)^3 \times 10^6 \) HRS

\[ \frac{60 \times 2.644}{60 \times 2.644} \]

> 20,000 HRS
Total tooth load of P₂ = \( \frac{1667.55}{\cos 20^0} \) = say 1775 Kgf (3138 Kgf)

Loading on shaft is as shown in Fig – 4

\( R_A = 555.81 \text{ Kgf} \) (982.6 Kgf)

\( R_B = 1219.19 \text{ Kgf} \) (2155.4 Kgf)

\( \text{B.M.P}_2 = 18897.4 \text{ Kgcm} \) (33400.7 Kgcm)

Torque = 10005.3 Kgcm (17671.9 Kgcm)

Equivalent torque = \( \{(10005.3)^2 + (18897.4)^2\}^{1/2} \)

= 21382.7 Kgcm (37794.7 Kgcm)

Equivalent B. M = 0.5 \( (18897.4 + 21382.7) \)

= 20140.05 Kgcm (35601.7 Kgcm)

Adopt 65 mm dia shaft -\( Z_b = 26.96 \text{ Cm}^3 \) & \( Z_p = 53.92 \text{ Cm}^3 \)

Bending stress = \( \frac{18897.4}{26.96} = 700.94 \text{ Kg/cm}^2 \) (<887.4 Kgcm²)

B.D.T bending stress = 1239.2 Kgf/cm² (<1958.4)

Torsional stress = \( \frac{10005.3}{53.92} = 185.56 \text{ Kgcm}^2 \)

Combined stress = \( \{(700.94)^2 + 3(185.56)^2\}^{1/2} \)

= 7711 Kg/cm²

\( \text{Equivalent bending stress} = \frac{20140.05}{26.96} \)

= 747.03 Kgf/cm² (1363.03 Kgf/cm²)

\( \text{Equivalent torsional stress} = \frac{21382.7}{53.82} \)

= 396.56 Kgf/cm² (700.94 Kgf/cm²)

All the stresses are within permissible limits.

14-1-0: BEARING FOR SHAFT
Provide SNA 513 type plummer block with bearing No. 2213k +
Adaptor sleeve H 313 and locking ring = 2 Nos FRB 10/120 P
Static/dynamic capacity = 21.6/43.6 KN
Max reaction ................. = 1219.19 Kgf= Say 12.0 KN
R.P.M. of 2nd. shaft = 2.644 x 121/20 = Say 16 rpm
Life of bearing in hours = \( (43.6/121)^3 \times 10^6 \)
\[ \frac{60 \times 16}{59762 \text{ Hrs}} \]
> 20,000 Hrs

15-0-0: **KEY FOR SHAFT**

(A) **FOR 2\textsuperscript{nd} SHAFT**
Shaft dia.........................\( d \) = 100 mm
Torque on shaft .......... \( T \) = 57505.7 Kgc
Adopt Key ............ 28 x 16..... 120 mm (min)
Shear stress in key = \( \frac{2 \times T}{d \times w \times l} \) = \( \frac{2 \times 57505.7}{10 \times 2.8 \times 12} \) < 0.3 x YP

Bearing/compressive stress = \( \frac{4t}{d \times h \times l} \) = \( \frac{4 \times 57505.7}{10 \times 1.6 \times 12} \)
\[ 1198.04 \text{ Kgf/Cm}^2 \]
< 0.5 YP

(B) **FOR 3\textsuperscript{rd} SHAFT**
Shaft dia ......................... = 65 mm
Torque.......................... = 10005.3 Kgc
Adopt Key ............. = 20 x 12..... 90 mm
Shear stress = \( 2 \times 10005.3 \) = 171.03 Kgf/Cm\(^2\)
\( 6.5 \times 2.0 \times 9.0 \)

Bearing stress = \( 4 \times 10005.3 \) = 570.08 Kgf/ Cm\(^2\)
\( 6.5 \times 1.2 \times 9.0 \)

16-0-0: **FLOATING SHAFT : (IS-1570 - 20 CS)**
1) Torque say .......t ......... 10532 Kgcm (Para 9-0-0)
2) Shift dia ............. d = 70 mm
3) Length ............. l = 100 Cm
4) Modulus of rigidity G = 8.1 x 10^5.
5) Angle of twist = \( \frac{15842 \times 10532 \times 100}{8.1 \times 10^5 \times 7^4} \)

= 0.316°/m - 1/3° /M

17-0-0: MANUAL OPERATION:

Motor speed = 960 rpm
Handle radius = 0.4 M (i.e 400 mm)
Handle r.p.m = 24
Lifting speed with motor = 0.5057 M/min
Sprocket ratio provided = \( \frac{0.5057 \times 24 \times 3 \times 100}{960} \)

= 3.79275 Cm/Min

Taking efficiency of sprocket ratio as 0.95

Handle effort required = \( \frac{35000 \times 0.037925}{(2 \times \pi \times 24 \times 0.4) \times (0.6109 \times 0.95)} \)

= 37.53 Kgt/Cm²

Four persons are required to operate the gate manually.

18-0-0: GATE LIFTING LUG

The arrangement is as shown in Fig below

Load on lifting lug = 21.0
Provide 2 plates = 600 x 16 - 650
Load on each plate = 10500 kgf
Tearing along x-y = 10500 = 452.6 Kgf/cm²
(19-4.5) x 1.6
Bearing shaft on plate = 10500 = 729.17 Kgf/cm²
9.0 x 1.6
Weld length available for this plate = 2x60 = 120 Cm
Weld stress (6 mm fillet) = 10500 = 206.3 Kgf/cm²
120x0.6 x767
However, additional Welds are available with the vertical plate stiffener attached to these plates.

19-0-0: GATE PULLEY – BUSH & PIN

Rope dia ................. = 32 mm
P.C.D of pulley = 650 mm
Load on one pulley = \( \frac{35000}{2} = 17500 \) say 18000 kgf

20-1-0: PULLEY PIN - IS 1570 - 12 or 13 /20 or 13

Load on pin is
RA = RB = 9000 kgf
Say = 9000( 10.2 – 4.5 ) = 56700 kgcm
Adopt 90 Ø Pin, Zb = 71.569 cm³
Bending Stress = \( \frac{56700}{71.569} \) = 792.24 Kgf/Cm²
Shear stress = \( \frac{9000 \times 4}{\pi \times 9^2} \) = 141.47 Kgf/Cm²

Bearing stress as 16 mm thick plate = \( \frac{9000}{9.0 \times 1.6} \) = 625 Kgf/Cm²

20-2-0 PULLEY BUSH-IS - 305 OR AB-1
Load on pulley = 18000 kgf
Pin dia = 90 mm
Bush length = 180 mm
Bush bearing stress = \frac{18000}{9 \times 18} = 111.11 \text{ kgf/cm}^2

Provide bronze bush id = 90 mm, od = 112 mm & length = 180 mm

**21-0-0: DRUM / DRUM GEAR CONNECTION**

Tooth load of drum gear = 5750.6 kgf
PCD of drum gear = 1150 mm

PCD of both circle = 790 mm

No & dia of bolts = 6 Nos - 24 Ø shank (40 C8)

Effective area of bolt = 3.53 cm^2

Shear stress in bolt = \frac{5750.6 \times 1150}{790 \times 6 \times 3.53} = 395.24 \text{ Kgf/cm}^2

**22-0-0: DIAL INDICATOR**

Dial indicator box is connected to 2nd shaft
Total lift of gate = 10.5 mm
No of revolutions of drum for the lift = \frac{10.5 \times 2}{\pi \times 0.7} = 9.5492966
No of revolutions of second shaft = 54.908455
Adopt state of 3 stage gear box = 64 : 1
And sprocket ratio of = 18 : 16
Total reduction = 64 \times 18 = 72
16

Pointer movement for total lift = \( \frac{54.908455}{72.5} \times 0.7626174 \)
= 274.54228

Angle / M travel = 26.146883
Mark dial with meter. 1/2 meter & 1/10 m marking of suitable colour combination

**********
Chapter 10
Flow Characteristics and Design
Considerations for Hydraulic Gates

INTRODUCTION

The control of rivers, canals and reservoirs requires weirs or appurtenances. The fixed weir is the preferred control structure from consideration of reliability and maintenance. Similarly, the fixed-crest, free-overflow spillway is the most advantageous arrangement for reservoirs. Many a time to provide for additional volume of water in the reservoir and release when flooding, control gates are very much a necessity for the weirs or the spillways. Gates and valves are therefore an essential and critical part of many flood control schemes, or reservoir management and control of water in river courses.

The computation and design of hydraulic structures is a major activity of engineers concerned with water. The building and maintenance of such works involves very high costs. It is therefore particularly important that individual works which are part of such installations should be optimized functionally and economically.

The engineering works in and along the water course are comparatively very little standardized. It is mainly because of the nature of hydraulic engineering, each construction requires individual design / solution to take account of the local conditions.

Though many of the flow processes can be adequately understood at a theoretical level, there are many complex situations which cannot be solved with the computers available today. It is not mainly the solution of differential equations, but the boundary conditions which arise from the shape of an individual structure. In such cases, the design must be based on principles derived from model investigations. One can certainly apply the experience gained from one construction to another, if it is similar. But the designer must be very much careful to understand the modifications, though very small, can induce significant change in flow pattern.

The flow through many hydraulic structures is governed by gravity and slightly affected by viscosity and other influences. These kinds of flow normally defy the set of rules understood till date by hydraulicians. It is strongly recommended by the hydraulicians to study the flow conditions using models to arrive at an optimal design shape for these structures.
Gates and valves control the flow of water. The hydraulic conditions are therefore basic to the success of the installation. This comprises not only the flow under or over a gate but also the upstream and the downstream hydraulics.

Since gates are designed for extreme events, personal experience of their performance under these conditions is limited. Some gate installations have met with serious difficulties in service. The subsequent research and published papers have sometimes been presented at a specialist congress and have not been disseminated to prevent the repeat of flawed design features. Systematic understanding of the gates and valves is essential for the engineers involved in the development of water resources.

**TYPES OF GATES**

Broadly various gates can be classified as free surface gates and closed conduit gates. Similar type of gates exists in both the groups. But the design of gates in high head submerged outlets is more demanding and requires special attention.

While there are many types of gates designed to suit individual structures, few among them are predominantly used because of there simplicity, reliability and versatile features while operating. In open channels, at spillways and barrages, radial gates are the first choice. The bottom hinged flap gate is sometimes preferred because of less visual obstruction than radial gate. It also discharges debris easily.

Vertical lift gates are more often used in conduits than radial gates because of greater flexibility. Radial gates require large chamber to retract. But the vertical lift gate slots pose hydraulic problem at high velocity.

Table 1 lists the main applications and the advantages of the various types of gates.

**Table 1. Main applications, advantages and disadvantages of various types of hydraulic gate**

<table>
<thead>
<tr>
<th>Type</th>
<th>Main Applications</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gates in open channels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>River control.</td>
<td>Low hoisting force. Mechanically simple.</td>
<td>Increased fabrication complexity.</td>
</tr>
<tr>
<td></td>
<td>Spillways.</td>
<td>Bearings out of the water.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barrages.</td>
<td>Can be fitted with overflow</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------</td>
<td>-------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2. Radial automatic gates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Main Applications</td>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>

**GATES IN FREE SURFACE FLOW**

**Radial gates**

Radial gates are the most frequently used movable water control structures. They consist of a skin plate formed into a segment with a radius about the pivot. The skin plate is stiffened by vertical and horizontal members who act compositely with the skin plate. The skin plate assembly is supported by two or more radial struts, which converge downstream to the pivot assemblies, which are anchored to the piers and carry the entire thrust of the water load. The resultant of the water load passes through the pivot pins and there is no unbalanced moment.
to be overcome when hoisting the gate. The hoisting load consists of the weight of the gate, the friction force between the side seals and the seal contact plates embedded in the piers and the moment of the frictional resistance at the pivots. Usual size of radial gates is 12 m span and 15 m high. Following table provides the sizes of radial gates adopted by few projects in India.

<table>
<thead>
<tr>
<th>Project name</th>
<th>Span in meter</th>
<th>Height in meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pandoh Dam</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Bhakra Dam</td>
<td>15.25</td>
<td>14.5</td>
</tr>
<tr>
<td>Pong Dam</td>
<td>14.5</td>
<td>12.35</td>
</tr>
<tr>
<td>Ranjit Sagar</td>
<td>15.6</td>
<td>17.3</td>
</tr>
<tr>
<td>Chamera St-II</td>
<td>15</td>
<td>21.8</td>
</tr>
</tbody>
</table>

Radial gates are under most conditions the simplest, most reliable and least expensive type of gate for the passage of large floods. Their advantages are:

- Absence of gate slots. (This benefits pier structural design and hydraulic flow. Pier slots can produce cavitation and at low flows collect silt.)
- Gate thrust is transmitted to two bearings only.
- Less hoisting capacity is required than for a vertical-lift gate.
- Mechanically it is simpler and mechanical equipment usually costs less.
- Location of the bearings protects from damage by debris, simplifies corrosion protection and permits some degree of inspection while in service.
- The superstructure required for the gate lifting gear is generally much lower, and in the case where a roadway spans the sluiceway no additional structure is usually required.
- Stiffer structurally.
- Better appearance.
- No possibility of trash getting jammed in the wheels.

The disadvantages of radial gates are:

- The flume walls are required to extend downstream at a sufficient height to provide attachment for the gate pivot bearings.
- The gate water load is taken by the piers as concentrated loads at the gate anchorages.
- Increased fabrication complexity.
Radial gates will not pass floating material until they are at least 75% open. This can be overcome by adding a flap or overflow section to the top of the gate. These are usually operated by an independent motor and hoist gear or separate hydraulic cylinders. The overflow discharge section is curtailed on this type of gate for the nappe to clear the gate arms. Tilting crests may be required when ice has to be discharged in spring or where the river carries an abnormal amount of debris during part of the year.

The shape of the tilting crest has to be checked so that flow separation does not take place in any position when the crest section is lowered. If the crest section is curtailed the nappe will be vented and problems due to nappe collapse will not occur.

Radial gates have been designed to be submersible to provide overflow.

**VERTICAL-LIFT GATES**

This type of gates can be sliding, fixed wheeled, caterpillar etc, depending on the type of wheel provided. These could be used up to a span of 25 m. Practically, span times (in meter) head is usually 105, i.e. Span (m) X head (m) = 105. The advantages of vertical lift gates are:

- A short length of flume walls.
- Distribution of the gate water load.

The disadvantages are:

- The requirement of gate slots.
- Possibility of trash getting jammed in the wheels.
- Overhead structure.
- Wheels which have to rotate under water.

The majority of vertical-lift gates are counterbalanced to reduce the hoisting load. To prevent the counterbalance from entering the water when the gate is lifted, the counterbalance is reeved 2:1 so that it travels for only half the distance. This results in an additional load on the superstructure of the order of 2.7 times the mass of the gate, and requires a substantial support structure, adding to the cost of the gate installation.

The various types of vertical gates are explained below
Needle control
Needles, vertical stop logs are difficult to set in place in fast-flowing water and once in place and a differential head develops; it is difficult to move them closer together to stop leakage between the members.

Stop logs
Stop logs, which span openings between concrete walls or piers that have recess grooves to support them, are still in use. However, most of the larger sizes are now formed of a framework of structural steel covered with a skin plate of sheet steel. The purpose of these structures is mainly to shut off flow for inspection and repair of control gates rather than control the flow, as did the wooden timbers of the past. As the need arose for large and more manageable gates for larger and higher head hydraulic structures, the old designs gave way to newer and improved designs such as bear trap gates, flap gates, vertical lift gates (fixed wheel and roller gates), drum gates, rolling gates and radial gates.

Flap gates
A flap gate usually consists of a relatively long leaf of flap hinged along the upstream edge. The operating mechanism may be by power applied by rods from a super structure or from rods and hydraulic cylinders from a recess in the structure under the gates. These gates are suitable for long lengths and low heads.

Vertical lift Gates
The term “Vertical lift” is a general term applied to gates of square or rectangle shapes that are raised or lowered in guide grooves in end walls or piers. In general, this type of gate is not conducive to passing floating debris from the reservoir to the downstream river channel.

Slide gates
The slide gates slides directly on seal strips in the sides of the grooves that support it at the ends. Sizes of this type of gates are limited because of the usually high friction between the sliding contact surfaces, which necessitates high-powered operating equipment. Wheel and rollers were added to the structural gates to overcome this disadvantage.

Stoney gates
This vertical-lift gate was named for its developer, F. G. M. Stoney. The gates make use of a train of rollers. The rollers bear on tracks in the downstream sides of a train of rollers. The rollers bear on tracks in the downstream sides of the guide grooves in the walls of piers at the ends of the gates. The sliding friction is eliminated in this design since the rollers are not attached to either the gate or the groove. Wear corrosion and debris can interfere with smooth operation and large capacity hoist equipment becomes a deterrent.
Fixed wheel gates

This type of vertical-lift gate utilizes wheels fixed at each end to roll on vertical tracks in the grooves to minimize friction forces. The gate has most of the advantage of the stoney gate but does offer more flexibility when it is sectionalized into two or more sections.

All vertical-lift gates, because of their guide groove supports at the ends, are cavitation prone at small openings and heads in excess of approximately 12 m. The gate itself is not usually damaged by cavitation but the supporting structures at the ends can be severely eroded. Also, the wheels and rollers used to reduce friction forces are subject to violent hydraulic action within the gate slots and can be subject to damage by silty water and other debris. Although the cavitation problem has been minimized in various ways, other types have pushed the vertical-lift design into the background; particularly drum gates and radial gates. Excessive hydraulic down pull on these gates was a factor that was considered in improving the designs.

The gate slot (groove) designs were altered principally by changing the shape of the downstream corner of the groove. In general the changes included an offset of the downstream corner of the groove outward from the flow and then flaring the wall back to the initial width at some point downstream. Some of the tested designs used a slope with a point of intersection of the downstream end while others used an offset with a curve in the wall that became tangent to the initial width at some point downstream.

The excessive down pull forces caused by the old square or flat bottom shapes were minimized by sloping the upstream face near the bottom or adding a lip extension to the upstream side.

Drum Gates

The drum gate is a three-sided structural frame covered with a steel skin plate. The hollow structure is made water-tight so as to make it a floating vessel when subjected to water pressure in a recess in the top of the supporting structure. A hinge along the top upstream edge allows the water pressure under the gate to move the gate while in the raised position. The top surface of the gate approximates the curve of an ogee or other shape crest, the downstream surface of the gate is usually an arc with its center at the hinge and the shape of the third side, although not critically important, is usually straight. The gate requires a large quantity of structural steel and steel plate making it a relatively heavy structure. However, it has the advantage of being cavitation free and can be lowered to easily release floating debris. Also, lengths can be long. Structures up to 40 m long have been used and there are installations 34 m long.

The application and use of various types of gates in relation to the outlet and their details are
explained in the plates 1 to 12 presented at the end of these notes (USBR).

For the purpose of repairs and maintenance of hydraulic gates used in the control structures, the flow of water through the vents of the gates is often required to be stopped so that the gates can be isolated or taken out of the vent without causing wastage of water. This is achieved by inserting in the vents on the upstream side, additional gates known as emergency gates, stoplogs, bulk-head gates or emergency stoplogs. The differences between various guard gates are in respect of operating conditions and the number of pieces the gate leaf is made of. Classification is explained in Table 2. Normally a sluice outlet is provided with service gate, emergency gate and stoplog or bulkhead gate on upstream. The emergency gate is usually in the conduit bonnet and cannot be easily taken out for maintenance. This necessitates the upstream stoplogs.

<table>
<thead>
<tr>
<th>Type</th>
<th>Lowering operation under</th>
<th>Raising operation under</th>
<th>No. of pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency gate</td>
<td>Unbalanced conditions</td>
<td>Balanced conditions</td>
<td>One</td>
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<tr>
<td>Emergency stoplogs</td>
<td>Do</td>
<td>Do</td>
<td>More than one</td>
</tr>
<tr>
<td>Bulk-head gate</td>
<td>Balanced conditions</td>
<td>Do</td>
<td>One</td>
</tr>
<tr>
<td>Stoplogs</td>
<td>Do</td>
<td>Do</td>
<td>More than one</td>
</tr>
</tbody>
</table>

**Location**

The location of vertical lift gate groove with respect to the spillway is important as it plays important role in the hydrodynamic force exerted by the flowing water. The stoplog gate is generally operated under balanced condition, but usually as a precaution it is required to be designed for lowering in flowing water with under and over flow. Hydraulic model studies conducted on spillway stoplog gates indicated that the hydrodynamic force acting on the gate is dependent on the location of the stoplog groove. Few case studies are presented below to enlighten the importance of the position of the gate groove.

**Case study 1: Spillway stoplog gate for Mahanadi**

Spillway for Mahanadi dam in Madhya Pradesh consisted of 14 spans each of 15 m width. Stoplog consisting of six elements was proposed to be lowered on the upstream side of the regulating gate for the spillway, under the maximum operating head of about 10.4 m. Stoplog gate consisted of skin plate on downstream side and vertical plates forming open truss type girder on its upstream side. This gate design with projected area of 6.30 sq. m. when model tested, experienced a maximum downpull force of about 32 tonne at an intermediate location.
and a maximum uplift force of 50 tonne when the gate was about to sit on its sill on the spillway. Stoplog groove in this case was provided on the upstream sharp curved profile of the spillway, making an angle of about 35 degrees with horizontal. Studies were conducted to investigate the effect of slope of spillway profile on the hydrodynamic uplift forces by shifting the stoplog groove position on the flatter portion of the spillway. Studies indicated that the gate would experience maximum uplift forces of 29 tonne and 10 tonne when the groove is located such that slope at its sill seat makes an angle of 10 degrees and zero degrees respectively, with the horizontal. Thus it can be seen that uplift force on the stoplog gate got reduced by shifting the gate groove from steeper to flatter portion of the spillway.

Case study 2: Stoplog Gate for Malaprabha Dam Spillway.

Malaprabha dam in Karnataka consists of four spillway bays each of 15.24 m width. Flow over the spillway is controlled by radial gate, under maximum head of about 12.5 m. Stoplog gate consisting of seven elements with skin plate on upstream side and girders on downstream, were proposed to be lowered one above the other in the flowing water condition. Bottom unit of the stoplog gate with projected area of about 12.45 sq. m, when tested in model experienced a maximum downpull force of about 36 tonne at an intermediate gate opening and a maximum uplift force of about 15 tonne near closure. Stoplog groove in this case was located at a point on spillway surface, making an angle of about 16 degrees with the horizontal. Studies were conducted by shifting location of stoplog groove towards the spillway crest, to a point at which the spillway slope made an angle of 10 degrees with the horizontal. Bottom stoplog gate element in such a case, experienced a maximum uplift force of only 12 tonne.

Thus it can be concluded that bottom stoplog gate element, when operated over the spillway would experience a higher uplift force, if stoplog groove is located on the upstream steeper profile of the spillway. In such a situation, self weight of the stoplog element will have to be increased proportionately, so as to make the gate close under its own weight. Excessive increase in the weight of stoplog gate element would lead to a necessity of using gantry crane of very high capacity, for safe operation of stoplog over the spillway. Shifting of stoplog gate groove towards the spillway crest or placing it on the flatter surface of the spillway would reduce uplift force considerably which in turn would enable choice of a stoplog gate with lesser self weight to make it self closing.
Practical aspects of providing stoplog groove very close to the spillway crest may be a matter of debate in regard to practicability and other considerations. However, the above discussion would help the design engineers understand the effect of various hydraulic/structural parameters on the stoplog operation, and choose the best shape of the stoplog gate with minimum self weight and suitable location of its groove over the spillway.

**Location of Bulkhead Groove for Sluice Outlet.**

The regulating gates used for controlled release of water from sluices are generally located within the conduit, some distance downstream from the upstream face of the dam. The guard gate or a bulkhead gate is located either upstream of the service and emergency gates or at the upstream face of the dam. The bulkhead gate is generally designed for its operation under balanced condition.

**Bulkhead Groove Upstream of Sluice Entrance.**

The bulkhead gate when located at the upstream face of the dam can be in the form of a single unit usually operated, by a gantry crane moving over the bridge, from the top of the dam. The guides for the gate are embedded on the face of the dam and the gate has a special spring loaded system to hold itself to the guides. The gate seal for such a bulkhead gate is on the downstream side. With this location, the size of gate and consequently its self weight would be large due to flaring of the bell mouth entrance.

While deciding the layout of the sluice for a dam, the following aspects are considered;

i) If the bulkhead gate is to be located on the upstream face of the sluice, it is preferable to locate the sluice in the non-overflow section of the dam or within the portion of spillway piers. This would enable use of pier for locating hoist or gantry crane for the bulkhead gate operation.

ii) If the sluice is located in the overflow section of the spillway, with the bulkhead gate at its upstream face, the gate guides have to be terminated at the crest level since guides cannot be provided above the crest level and hence it would not be possible to operate the gate from top of dam when the spillway is overflowing. Also when the gate is lowered with the help of a gantry crane from top of the bridge, the gate ropes would be affected by drag of overflowing spillway water.
iii) In such a choice of sluice and bulkhead gate combination, the upstream face of the spillway or dam should be uniformly sloping. Preferably, it should be vertical to enable easy lowering of bulkhead gate from top of the dam.

**Bulkhead Gate Groove Located Downstream of Bellmouth Entrance**

When the upstream face of the dam or spillway (where the sluice is located) consists of two or more slopes, it would-not be possible to lower the bulkhead gate in the groove along the changing slopes, because the gate would not be able to align itself with changing slopes. Under such a situation, bulkhead groove may have to be provided downstream of the bellmouth. In one of the project, two river sluices of 2.14 m x 3.20 m size, were proposed in the body of the spillway below the piers. Sluices were designed for their operation under the maximum head of 70 m. From structural considerations the bulkhead gate groove of about 1.0 m width was located downstream of the bellmouth entrance and it was kept open in the reservoir water (as shown in Fig. 1). Studies were conducted at CWPRS to understand the effect of location of bulkhead gate groove, downstream of bellmouth entrance, on the flow conditions in the sluice. Piezometric pressures - indicated existence of negative pressures of high magnitude in the roof portion of the sluice in the downstream vicinity of the bulkhead gate groove. It was also seen that this was mainly due to typical flow situation that existed at the junction of the bulkhead groove and roof of sluice, due to interaction of vertical flow through the gate groove and horizontal flow of sluice. Negative pressures of high magnitude indicated a possibility of cavitation damage at the roof of the sluice, when the sluice would be operated under higher heads. In a similar situation, cavitation damage was noticed on the roof portion of low level conduit of Kinzua Dam, Allegheny project (USA), where stoplog groove was located downstream of bellmouth entrance and opening in to reservoir waters. Hence such a location of bulkhead groove was not considered hydraulically satisfactory and was not recommended for adoption.
In order to eliminate this effect, studies were also conducted by extending the bulkhead gate well, upto the top of dam and not allowing the water to enter and flow downward through the gate groove portion. Piezometric pressures on the roof of the sluice, with this modification indicated that there were no negative pressures in the sluice portion, downstream of the bulkhead groove and hence the sluice was safe from operation point of view.

Thus it can be concluded that bulkhead gate grooves may preferably be provided on upstream face of sluice entrance. If due to structural problems, the groove has to be located downstream of the bellmouth entrance, then the gate well must be extended upto the top of the dam, in the form of wet well gate shaft or provide a slot cover frame to stop the slot flow.

**Seals**

Seals are required to prevent loss of water. While in many cases due to inadequate sealing, jets emitting at inadequately sealed sills, sides or soffits are major source of gate vibration and gate noise. In addition, seal leakage in gates subjected to high-head can cause long-term damage to downstream concrete works. The selection of seals and the design of their mountings are therefore important. Modern seals are extruded or moulded from an elastomer. Block seals of timber or lignum vitae which were fitted to older installations are not suitable. The usual materials are natural rubber or polychloroprene, commercially known as Neoprene.
The elastomers are compounded to attain the required properties for seal application such as tensile strength, tear resistance, low water absorption, compression set and be ultraviolet resistant and contain anti-oxidants. Seals are normally specified to have a Shore A hardness of 65 with a tolerance of ±5. High-head gates often have seals of greater hardness. At hardness significantly lower than 65, the coefficient of friction between a seal and a stainless steel sliding surface increases. The coefficient is also affected by the surface finish of the seal contact face.

The typical forms of seals that are in use are presented in Fig. 2. For perfect sealing, installing the embedded parts in true alignment is absolutely essential.

![Figure 2. Types of seals](image)

Typical sealing arrangement for vertical lift gate with u/s sealing and downstream sealing are presented in Fig. 3. Fig. 4 presents the sill and lintel sealing for vertical lift gates.
Figure 3. Sealing arrangement of vertical lift gates.

Figure 4. Sill sealing
**Intake gates: upstream or downstream seals**
In most recent hydropower projects, the emergency intake gates have been provided with upstream seals. The main reason given for this preference is the lower initial cost when compared with downstream sealing gates. In general, upstream sealing gates are not subjected to downpull forces. This allows the use of lower hoist capacity than those required for gates with downstream seals. Lower capacity means lower cost. Nevertheless this is not the only requirement to govern the selection of seal arrangement.

**Sloped sill**
In some cases, only gates with upstream seals can be used. In heavy sloped intake sills (Fig. 5), the use of a gate with downstream seals may restrain the design of the lower horizontal girder. Since this element is subjected to a greater load, it requires a larger inertia. A high girder depth may interfere with the sill face. On the other hand, the bottom girder of a gate with upstream seals is located on the downstream side of the skin plate and, theoretically, can be set in any position without causing trouble.

Upstream sealing gates are also used in spillways in cases when there is a strong occurrence of debris or ice. Downstream sealing gates are not adequate for this type of structure, as debris and ice may accumulate between the girders turned to the upstream side, increasing the weight of the movable parts and, consequently, the lifting forces.

**Aeration**
During part-gate operation when the conduit is full at the downstream portal and partly full near the gate, a vent admits air so that the pressure near the gate is not reduced substantially below atmospheric pressure. This action reduces the tendency for cavitation.

An air vent built into the concrete structure connects the downstream conduit to the external air. For upstream sealing gates, aeration can be provided through the gate shaft itself.

![Figure 5. Intake of Tucurai power plant, Brazil.](image)
unless a watertight cover is installed in the shaft (see Fig. 5).

**Gate inspection in the closed position**

The leaf of upstream sealing gates can be inspected in dry conditions, in the closed position. In this case, the access to the penstock is vertically through the gate shaft or bulkhead doors installed in the intake walls. Nevertheless, this inspection is seldom done, since it does not allow for the inspection of the main items which are subjected to damage (seals, main wheels and wheel track).

The inspection of downstream sealing gates is done under the protection of intake stoplogs.

**Top seal leakage**

Special measures are taken in the design of the top seal of gates with upstream seals to reduce the deflection of the top horizontal girder when the gate is closed and subjected to the maximum hydraulic load. The deflection of the top girder in the downstream direction may cause leakage in the centre of the top seal. In a 12 m span gate with upstream seals, for example, a top girder deflection equivalent to 1/1000 of the support length will cause a gap of about: 12 - 5 = 7 mm, assuming a maximum seal compression of 5 mm.

The problem of leakage in the top seals does not occur with downstream sealing gates, as the deflection of the girder increases the seal compression.

**Failure of gates with upstream seals**

When an intake gate with upstream skin plate and seals is used for filling the penstock, forces large enough to catapult the gate can develop. Several failures in installations of this type have occurred. At the Mossyrock dam, USA, an intake gate weighing 654 kN was catapulted approximately 12 m up the gate slot. At Dworshak dam, a gate 124.6 kN catapulted 76 m to the top of the gate slot. At the Uvac power plant in Yugoslavia, an intake gate with a width of 2.6 m, a height of 4.6 m and a weight of 174.6 kN was catapulted when the tunnel filling was completed and the filling of vent and the gate shaft started.

**Comparison of gates with u/s or d/s seal.**

The intake gate is the ultimate safety device for the turbine and its main function is to close in an emergency and in any conditions of flow and water levels. From the point of view of safety, the most reliable equipment for emergency closure of intake structures is a gate with downstream seals, as it is not subjected to catapulting forces.
Simulated studies show that the additional cost of the initial investment using gates with downstream seals instead of those with upstream seals as emergency devices for intake structures is very low, and should not be considered as the main factor in the selection of the seal arrangement.

Intake gates with upstream seals are susceptible to catapulting during filling of the penstock. This type of failures does not occur with downstream sealing gates. So, a small cost reduction in the purchase of the hydraulic cylinders does not compensate for the reduction in operational reliability.

The reliability of the equipment in closure operations should be the most important criterion in the selection of the type of emergency intake gates. However, gates with upstream seals have been preferred by engineers only in relation to requiring a hydraulic cylinder of reduced capacity when compared with downstream sealing gates. This capacity is defined as a function of the forces acting on the gate during opening operations. In other words, the seal arrangement of intake gates is defined solely by the requirement of lifting capacity of the hydraulic cylinder for the opening operations, while the main function of this type of gate is to close in emergency conditions.

**Forces acting on the vertical lift gates**

The various forces acting on the vertical lift gates are:

1. Submerged self weight of the gate and lifting beam
2. Friction forces
3. Hydrodynamic uplift and downpull forces

Out of these three forces computation of 1 and 2 is theoretically possible. The third one is very complex and depends on flow conditions around the gate. Hydraulic models have been used successfully to evaluate the magnitude of the hydraulic downpull forces during the placing of the logs under various assumed conditions.

When stop logs are lowered in flowing water, the velocities beneath and over the logs influence the pressures on the bottom and top surfaces. When the resultant force is downward (the usual case) the force is termed hydraulic downpull. Conversely, when the force is upward it is termed hydraulic uplift. Both can be of large magnitude depending on the log shapes, the flow velocities, and water depths.
Hydraulic downpull on a stop log or gate is controlled primarily by the velocity of the water and the shape of the stop log or gate. Other factors such as the geometry of the channel, the distribution of the approaching flow and the presence of a nearby partially opened gate can also influence the downpull.

The main variable that the designer can control is the shape of the stop logs. Past experience and research has documented that even minor changes in design can result in a major influence in the magnitude of the downpull and on the tendency of the log or gate to vibrate. The major geometric factors influencing downpull and vibration are:

1. Shape of the bottom and top surfaces,
2. Width of top and bottom surfaces,
3. End effects,
4. Position of stop log or gate in the flow,
5. Ventilation of the cavity downstream from the log or gate.

Of these five items the greatest flexibility in design and the greatest influence on downpull is the shape of the top and bottom surfaces.

**Shape of Top and Bottom Surfaces**

Consider the most elementary shape of a stop log; one having a simple rectangular cross section. For such a stop log in a flowing stream away from the influence of the free surface and other logs previously installed, the flow divides above and below the log. The division will depend on the nearness of the stop log to the water surface or the seating surface. Separation occurs at the leading edges of both top and bottom surfaces resulting in relatively low pressures on both surfaces. Consequently, little net hydraulic downpull is generated and the log must depend on its submerged weight for lowering.

When a rectangular log approaches another log, or the bottom of the channel, the gap between the logs decreases and the flow passage approaches that of a short tube. The flow still separates at the leading edge but reattaches to the bottom of the log causing a decrease in downpull and possibly an uplift force. This change in uplift force may cause the log to rise slightly and may cause a shift in the reattachment point. Movement of the reattachment point causes large variations in the vertical force which can be sufficient to cause vibrations. If the uplift force is sufficiently high it may prevent final closure.
It is desirable to have relatively large downpull forces to insure that the logs will seat and to avoid conditions that cause rapid variations in the downpull as the log is lowered as these can be a primary source of vibration.

**Influence of Top and Bottom Surface Shapes**

To maximize downpull, it is necessary to have high pressures on the top of the log and low pressures on the bottom. There are two configurations commonly used to produce high pressures on the top (or bottom) of the stop log: a sloping surface or a lip projection.

Several examples of gates having sloping surfaces designed to minimize or eliminate separation at the upstream edge are shown in Fig. 6. These shapes have been investigated for use as the bottom shape of high-head slide and roller gates. The results are applicable to stop logs.

Laboratory results show that the slope of the bottom, e, has a measurable influence on the pressure distribution and consequently, on the downpull. As the angle $\theta$ increases, the pressures on the bottom increase. $\theta = 45^\circ$ is about the limit for structural and practical reasons.

Since large downpull forces are required for stop logs it would be desirable to use the dependence of downpull on $e$ to advantage. For the top surface, using the maximum slope would provide maximum downward pressure. For the bottom surface one would take advantage of the negative forces associated with $\theta = 0$. A typical shape (based only on this criterion) is shown in Fig. 6a.

To make a shape like that shown in Fig. 7a practical, one modification would be to provide a horizontal sealing surface on the top of the log. This is identified in Fig. 7b by the variable $d'$. This minor structural change can cause significant modifications to the pressure distribution and can change the net force. Its influence on downpull and vibrations should be carefully considered.
If the change between the sloping and horizontal surfaces is abrupt, separation will occur and the pressures on surface d' will be low, and possibly sub atmospheric. If d' is large, the downpull will be significantly reduced. The separation associated with the d' surface can also cause vibrations if there is a shift of control as the upper log is seated.

Another factor that will reduce the total downpull is the stream lining (or lack of it) at the upstream side of the top surface. If an abrupt change of boundary is used at the leading edge, Fig. 7c, separation will occur and the downpull will be reduced.
A variation of the sloping surface which is effective in modifying the downpull is the lip extension shown in Fig. 6d. Varying the length of the projection can result in major changes in downpull just as was noted for variations in $e$. If this shape were to be used for the top of a stop log, as depicted in Fig. 7d, a large value of $e$ would be desirable. However, such an extension can cause other problems when subsequent logs are placed.

The radius $r$ for the fairing on the top and bottom surfaces is also an important variable. The main factor on the upper surface is that $r$ must be sufficiently large to eliminate separation. Increasing $r$ beyond this minimum value will continue to increase the downward force on the log. The limit of $r$ will normally be controlled by structural and fabrication criteria.

On the bottom surface it may be desirable to eliminate the radius completely. This will normally decrease the total pressure on the bottom and increase the downpull. However, one must be concerned about where the control is and how the pressure distribution varies as the log is lowered. Minor changes, such as in the design or location of the seal can cause a shift in the separation point during seating. This may cause large variations in the downpull and prevent seating or cause vibrations.

As a stop log is lowered and approaches a previously placed log, the flow passage formed by the top surface of the lower log and the bottom surface of the upper log is extremely important. For example, consider stop logs of the shape shown in Fig. 7b. When in a flowing stream, away from a second stop log the pressure on the top surface is considerably greater than that on the lower surface and large hydraulic downpull forces are created. As it is lowered and approaches a log previously placed, a converging flow passage is formed with the control point at the downstream edge of the log. High pressures will result on the bottom which may be sufficient to prevent seating.

The potential for vibrations can be demonstrated by discussing a stop log similar to the one shown in Fig. 7b but with $r = 0$. For this case separation occurs at the leading edge. The pressure on the bottom, which is controlled by the separation, is relatively low. As the log approaches another log, a point will be reached where control of flow through the converging passage will shift suddenly to the narrow constriction at the back of the log. This causes a large and sudden increase in the pressure on the bottom of the log, decreases the downpull and may cause the log to surge slightly upward. If this occurs the point of control may shift
back to the leading edge. If the point of control oscillates between the leading and trailing edges the log may vibrate violently. One should carefully examine the log design including the design and location of the seal to insure that no shift of control occurs.

One variation of stop log design which is effective in increasing downpull is to make the top of the log wider than the bottom as shown in Fig. 7e. The idea is that on the sloping upper surface, the pressure increases substantially from the trailing edge to the leading edge. On the bottom surface where the velocity is relatively high, the pressure is lower and more constant. By adding width to the log the net result is a substantial increase in the downpull force.

**Influence of End Effects**

Another factor that should be considered in estimating total downpull is the end effect. The disturbance to the flow caused by the stop log slots modifies the pressure on the bottom of the gates near the wall. The magnitude of the change is dependent on the size and shape of the slots and on the design and length of the log.

**HYDRAULIC DESIGN GUIDELINES**

Based on extensive hydraulic model studies and prototype experience, certain design features have been adopted to minimize hydraulic problems and are briefly described as follows.

**Cavitation**

To avoid or minimize cavitation damage the following features have been developed.

1. Streamline the slide and wheeled gate slots. This is usually achieved by providing an outward offset between the upstream slot corner and the downstream corner. The width of conduit at the downstream corner of the gate slot is wider than at the upstream corner, usually by an amount equal 0.1 to 0.2 times the length of the gate slot. A transition usually of 1:12 slope is provided from the downstream corner of the gate slot to the conduit normal width.

2. A flat bottom gate leaf is prone to cavitation and must be avoided. A 45° sloping bottom is used for slide and fixed wheel gates with downstream skin plates wherever practical with sharp vertical bottom seal strip at the downstream end of the gate leaf.
With an upstream skin plate, a vertical lip gate leaf is used and the downstream flange of the bottom beam of the leaf is kept about 0.6 times beam depth above the gate leaf bottom especially for penstock and submerged installations. The intention is to prevent the water jet from hitting the bottom horizontal beam during partial gate leaf openings, which is often the cause of either low pressure or turbulent roller zones under the gate leaf with consequent potential for cavitation damage, vibration or excessive downpull in tree discharge conditions. Provision should be made for openings in the web of the bottom beam of the gate leaf to allow air to be admitted to the space under the beam.

3. Provide steel or stainless-steel lining in the gate slots including the downstream corner. This is advisable under high velocity flows to avoid erosion and cavitation damage within the gate slots and downstream of the slots.

4. The conduit downstream of the gate leaf should be smooth without offsets and protrusions. Any offsets and protrusions should be ground smooth to a suitable slope depending on the velocity of flow.

5. Adequate aeration should be provided in the vicinity of the gate leaf, in the frame, and in the conduit downstream of the gate leaf. The size of air vent and extent of aeration should be in accordance with published literature or accepted practices.

6. Hydraulic model studies may be needed in individual cases for high-head gates if published literature is not applicable. The designer should use judgment to decide when hydraulic model study is essential.

7. Water-operated needle valves should not be used as they are prone to costly maintenance and are dangerous if improperly operated. Jet-flow gates are cavitation-free if properly designed. Slide gates should not be used for prolonged operation for gate openings less than 75 mm or 50% of gate thickness, whichever is more. Off-the-shelf commercial slide gates should not be used for high-head regulation unless they are specifically designed for such application.
Vibration of Gates

Vibration of gates can lead to structural failure of not only the gate components but the surrounding structure. Vibrations may be caused by several factors. Some causes of gate vibrations are:

- Shear flow under the gate leaf.
- Shifting of flow control point under the gate leaf.
- Excessive changes in the magnitude of hydraulic down pull for small vertical movements of the gate.
- Lack of adequate aeration and consequent pressure fluctuations in the zones under the gate leaf or immediately downstream of the leaf.
- Impingement of high velocity jets on downstream gate components.

The designer should refer to various publications on the subject; however, the following recommendations for elimination or minimizing vibration of gates are useful.

1. Do not use flat bottom gate leaves for high heads, as these will cause shifting of flow control points from the upstream bottom corner of the gate leaf to the downstream corner and, thus, induce vibrations. Gate leafs also suffer from excessive cavitation damage, excessive variation of downpull for small leaf movements due to excessive pressure fluctuations under the gate leaf and downstream fluid way. Use 45° sloping bottom gate leaf with downstream skin plate and downstream bottom seal or a vertical lip gate leaf with upstream skin plate with upstream bottom seal that are suitable for slide and fixed wheel gates, respectively.

2. Provide adequate aeration by means of liberally sized air vents located immediately downstream of gate leaf. Ensure that the inlets of air vents remain free at all times without submergence or obstructions by water jets issuing from the gate. The air vents should be preferably separate and independent of gate shafts. With upstream sealed fixed wheel gates, the shaft can be used as air vent only if the sealing is effective at partial gate opening. Otherwise, the ensuing water jets obstruct efficient aeration.

3. In the case of regulating gates, ensure that sealing is effectively watertight throughout gate leaf travel, to avoid vertical water jets which may induce vibrations and cavitation damage.
4. Hydraulic model study may be needed in which published literature is not applicable. Model studies are intended to develop special design features to avoid vibrations and cavitation damage.

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### Tower Intakes (Rectangular Gate)

- **Reservoir W.S.**
- **Curtain Wall**
- **Trashrack**
- **Bulkhead Gate**
- **Wheel or Roller-Mounted Gate**

**Bridge to Dam or Abutment**

"Air inlet for upstream seal gate. See Vertical intake, Type B, for air vent on downstream seal gate."

**Hoist Stem Sections**

**Transition**

**Pipe**

**NOTES AND COMMENTS**

Tower intakes are used principally on earth dams where abutments are not suitable for intake structures. Also used for concrete dams where intakes must be located on abutments and other types are not suitable. Basic arrangement is similar to vertical abutment intake. Bridge is usually provided to dam or abutment.

### Tower Intake (Cylinder Gate)

- **Reservoir W.S.**
- **Hoist**
- **Air Vents**
- **Trashrack**
- **Bulkhead Gates**
- **Radial Entrances**
- **Cylinder Gate**
- **Bellmouth**

**Bridge to Dam or Abutment**

**NOTES AND COMMENTS**

Tower intake used primarily where intake entrance is vertical. Other selection factors are similar to those stated above for vertical towers for rectangular gates.

### Shaft (Submerged Upstream Intake)

- **Reservoir W.S.**
- **Hoist Air Vent**
- **Trashrack**
- **Circular Bulkhead Gate**
- **Bellmouth**
- **Bonnet Cover**
- **Steel Encasement**
- **Wheel or Roller-Mounted Gate**

**Hoist House**

**NOTES AND COMMENTS**

Intake arrangement used principally on earth dams. Shaft usually located near axis of dam, either in dam or abutment. Abutment location is preferable to avoid joint between abutment rock and dam fill. Intake bulkhead installation requires drawing reservoir down or placement from a barge and the employment of divers.
Note X: Bottom lip on Hoover Dam cylinder gates was modified as shown to provide a definite spring point and reduce downpull.
Types of Tainter gates.
<table>
<thead>
<tr>
<th>TYPE</th>
<th>SCHEMATIC ILLUSTRATION</th>
<th>NOTES AND COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERTICAL INTAKE ON DAM OR ABUTMENT</td>
<td><img src="image" alt="Image of type A" /></td>
<td>Intake types used principally on concrete dams and on earth dams with abutment intakes. Type A used primarily for single line outlet works. Type B used for all types of power outlets and for branched and manifold type of outlet works.</td>
</tr>
<tr>
<td>SMALL SLOPE INTAKE ON DAM</td>
<td><img src="image" alt="Image of type B" /></td>
<td>Type of intake frequently used on thin-arch concrete dams. Used for all types of power outlets and for branched and manifold outlet works. Gantry crane is usually provided for handling gate and staplings for multiple outlet installations.</td>
</tr>
<tr>
<td>LARGE SLOPE INTAKE ON ABUTMENT</td>
<td><img src="image" alt="Image of type C" /></td>
<td>Intake used mainly for abutment intakes on earth dams. Hoist stems must be provided with support wheels. Reduction in effective weight for gravity closing may require the provision of closing thrust by the hoist, or the use of roller-mounted gates.</td>
</tr>
</tbody>
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1.0 INTRODUCTION

1.1 The Project

Salma dam project is located near Chist-e-Sharif in Herat Province of Afghanistan. It is a multi-purpose project on river Hari Rud. The project envisages hydropower generation with an installed capacity of 42 MW (three units of 14 MW each) and irrigation of 75,000 hectares. A 107.5 m long earth and rock fill dam would be constructed to divert flow towards powerhouse on the right bank downstream of dam. The spillway is located on the right bank. The spillway consists of three spans of 8 m wide separated by 2 piers 7 m and 5 m thick. The flow over spillway is controlled by 11.17 m high radial gates. The design maximum discharge is 2100 m$^3$/sec. The MWL and FRL are at EL. 1645.84 m and 1643.5 m respectively. The spillway has been provided with ski-jump bucket energy dissipator. The 2.0 m x 2.4 m size irrigation sluice with sill at EL. 1587 m is provided through the dam body below the 5 m thick pier and opens on the right most spillway chute, 2 m right to the divide wall and would carry discharge of 15 m$^3$/sec. The sluice is provided with two bends of 160 m radius, first turning right and the other to left opening on the right side of divide wall. The power intake with sill level at EL. 1592.9 m passes below 7 m thick pier and carries discharge of 63 m$^3$/sec to the power house. Figures 1, 2, 3 and 4 show the index plan, general layout plan, upstream elevation and section of the spillway through irrigation sluice. Salient features of the project are given in Annexure- I.

1.2 Analysis of Design

1.2.1 Irrigation Sluice

The irrigation sluice of size 2.4 m (h) x 2 m (w) provided on right side of power intake is below the 5 m wide pier and carries a design discharge of 15 m$^3$/sec. It is provided with elliptical entrance transitions on all sides except bottom which is straight horizontal. Figure 5 shows plan and cross section of the irrigation sluice. Figure 6 shows the plan, cross section and elevations of irrigation sluice gate. The flow is proposed to be controlled by vertical lift type service and emergency gates.
provided after the entrance transition. Air vents of size 1000 mm diameter and 700 mm diameter are provided downstream of the service gate and emergency gate respectively. Steel liners are provided around the control gates and for a distance of 12 m beyond the gate. The sluice is provided with a slope of 1:100 longitudinally. The exit portal center line is shifted to the right by 2.5 m by providing two bends of radius 160 m each, right turning at a chainage 35.445 m and left turning at chainage 70.499 m. Though the sluice carries 15 m$^3$/sec with part service gate under normal conditions, the sluice may carry discharge with 100 % service gate open also under rare conditions.

It is proposed to provide two gates along the sluice to control the flow. The service gate is for regulation purpose while, emergency gate on upstream side of service gate is for emergency closure. The service gate is a vertical lift slide type of gate with hydraulic hoist. The emergency gate is also vertical slide type but will only be either fully closed or fully open. It will be operated in case of any malfunctioning of downstream service gate or for the maintenance of service gate. The grooves of service and emergency gates are of size 240 mm x 200 mm. The gate will be operated using a hydraulic hoist. The sluice portion downstream of the groove is provided with rounding and an offset of 20 mm with a ramp of 1:24. This is provided to reduce the effects of vortex formation in the gate groove and avoid direct attack on the corner by the jet issuing from below the gate. This rounding and offset with ramp is provided on roof also.

1.2.2 Control Gates

The service gate has upstream skin plate with downstream seal as shown in Figure 6. The gate has a lip angle of 45°. As per the drawing No. G/IS-703 dated 25.09.06 the gate lip details at “Detail-III”, an additional stainless steel plate No. 23 of thickness 4 mm has been provided which protrudes abruptly in to the flow. The skin plates are supported by vertical and horizontal girders on downstream which further transfer the load to the two vertical sliding blocks on each side. Horizontal girders are provided with three drain holes of 30 mm diameter.

The emergency gate is provided 3000 mm upstream of the service gate. The dimensions and design are same as the service gate. The only difference being the size
of air vent being 700 mm instead of 1000 mm in case of service gate.

The service gate is proposed to be used for regulation of flow through the sluice. The emergency gate is proposed to be lowered under emergency condition or for the maintenance of the service gate etc. The emergency gate lowering is under unbalanced condition wherein the service gate may be at part or full gate opening. The raising of emergency gate is under balanced condition.

1.3 Previous Studies

Hydraulic model studies were conducted to assess the hydrodynamic forces experienced by the service and emergency gate with 45° lip angle for various reservoir water levels and operating conditions. The results were reported vide Technical Report No. 4584 of November 2008. The conclusions of the studies reported vide above report are as follows:

- The maximum hydrodynamic down pull force on emergency and service gate with 45° lip angle is 51 tonnes.
- The maximum hydrodynamic uplift force on emergency and service gate with 45° lip angle is 18 tonnes.
- It is recommended to provide 800 mm diameter air vent downstream of the emergency gate instead of 700 mm as proposed to take care of escapage of air during filling of sluice by crack opening. This will also help during the emergency gate lowering.
- It is recommended to provide 1100 mm diameter air vent downstream of the service gate instead of 1000 mm to satisfy the air demand during full gate opening.
- The bottom shape of the gate lip with 45 degree lip angle is considered hydraulically satisfactory for both service and emergency gates as the pressures were found to be positive at various gate openings up to FRL El 1643.5 m.
The stainless steel plate provided along the lip may be extended up to the second girder which is at 775 mm from the top of the gate.

Shri. B.V. Kulkarni, WAPCOS, New Delhi, Shri. S.K.G. Pandit, Director, CWC, New Delhi and Shri. G.D. Ray, Consultant, WAPCOS, New Delhi visited CWPRS Pune on 8th and 9th July 2008 and witnessed the running model of sluice gate with lip angle of 45°. They opined that the uplift and downpull force experienced by the gate with 50° lip angle may be lesser than the 45° lip gate. This was supported by the existing model study results for other projects and published literature. In view of this CWPRS was asked to conduct the experiments to assess the hydrodynamic forces experienced by the sluice gate with 50° lip angle. The pressures on the barrel immediately downstream of the gate will assist the designer in deciding the length of the steel liner to be provided to protect against the cavitation damages. CWPRS was requested to conduct experiments to find out the pressures immediately downstream of the gate on the barrel. In view of these discussions, studies for sluice gate with 50° lip angle were taken up. This report presents the hydrodynamic forces experienced by the gate of 50° lip angle, the pressure along the lip of the gate and the pressures on the barrel immediately downstream of the service and emergency gate.

2.0 TERMS OF REFERENCE

Hydraulic model studies were conducted for both emergency and service gates with lip angle of 50° to assess:

- Hydrodynamic uplift and down pull forces on sluice gate of 50° lip angle.
- Pressures along the gate lip.
- Pressures immediately downstream of the gates on the sluice barrel.

3.0 THE MODEL
A 1:15 scale geometrically similar model of the sluice including the bell mouth entrance, gate grooves, downstream barrel, air vents etc. were fabricated in smooth transparent perspex. Photo 1 shows the views of the model. The sluice model was fitted to an open masonry chamber of 5 m height which represented the reservoir. Two pumps of capacity 5 cusecs and 15 cusecs supplied water to the chamber. The gates were fabricated in mild steel plates geometrically similar to the prototype gates. Photos 2 and 3 show the upstream and downstream views of the model gate. The thickness of the individual girders were scaled down and rounded off to the nearest commercially available thickness of M.S. plates. The gate was connected to the gate operating mechanism using a rigid M.S. round bar. A load cell of 50 Kg capacity was also introduced between the gate and gate operating mechanism for measurement of load experienced by the gate during lowering and raising in flowing water. The flow through model sluice was measured by a Rehbock weir. The air velocities were measured with the Pitot tube.

Froudian criterion was used to express the mathematical relations between the dimensions and quantities of model and prototype. The general relations of the hydraulic quantities are expressed in terms of model scale and are presented in the Table 1.
### Table – 1

Model Scale Relations for Various Parameters

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Scale relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1:15</td>
</tr>
<tr>
<td>Area</td>
<td>1:225</td>
</tr>
<tr>
<td>Velocity</td>
<td>1: 3.9</td>
</tr>
<tr>
<td>Discharge</td>
<td>1:871</td>
</tr>
<tr>
<td>Pressure in m of water head</td>
<td>1:15</td>
</tr>
</tbody>
</table>

#### 4.0 MODEL STUDIES

#### 4.1 Hydrodynamic Force measurement

The hydrodynamic forces on the control gates during raising and lowering operation were measured by a load cell of 50 Kg capacity. Various views of sluice gate are presented in Figures 4, 5 and 6.
The studies were divided into two categories viz. the emergency gate studies and service gate studies. In view of the design criterion the emergency gate lowering studies were conducted in combination with part gate opening of service gate. The service gate was envisaged to operate under unbalanced condition when the emergency gate is fully open. Therefore, the studies on service gate were conducted with emergency gate fully open condition only. Studies for all these combinations of gates were conducted for reservoir water levels of El. 1622.75 m and FRL El. 1643.5 m.
4.2 Hydrodynamic forces on Emergency Gate

The studies to assess the hydrodynamic forces on emergency gate were conducted with various combinations of service gate opening and Reservoir Water Levels. These combinations along with the maximum hydrodynamic forces experienced by the gate are presented in Table 2.

The variation of hydrodynamic force experienced by the emergency gate is presented in Figures 7 to 14. The maximum uplift of 15 tonnes and maximum downpull of 47 tonnes is experienced by the emergency gate for FRL El. 1643.5 m when the service gate is fully open.

4.3 Hydrodynamic forces on Service Gate

The studies were conducted to assess the hydrodynamic forces on service gate operation for various Reservoir Water Levels. The service gate design is same as the emergency gate in all respects except the position of gate well. The experiments were conducted on service gate by keeping the emergency gate fully open. It was found
that the hydrodynamic forces experienced by the service gate are same as the emergency gate. Therefore the variation of hydrodynamic force experienced by the service gate is not presented separately. The data presented for emergency gate for El. 1622.75 and 1643.5 m with service gate fully open, is also applicable for the service gate. The maximum uplift of 15 tonnes and maximum downpull of 47 tonnes is experienced by the service gate for FRL El. 1643.5 m.

Table 2

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Reservoir Water Level El. (m)</th>
<th>Service gate opening</th>
<th>Emergency gate opening</th>
<th>Maximum hydrodynamic force experienced by emergency gate in Tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Downpull</td>
</tr>
<tr>
<td>1.</td>
<td>1622.75</td>
<td>100 % open</td>
<td>100 to 0%</td>
<td>28.0</td>
</tr>
<tr>
<td>2.</td>
<td>1622.75</td>
<td>75 % open</td>
<td>100 to 0%</td>
<td>27.0</td>
</tr>
<tr>
<td>3.</td>
<td>1622.75</td>
<td>50 % open</td>
<td>100 to 0%</td>
<td>25.2</td>
</tr>
<tr>
<td>4.</td>
<td>1622.75</td>
<td>25 % open</td>
<td>100 to 0%</td>
<td>18.0</td>
</tr>
<tr>
<td>5.</td>
<td>1643.50</td>
<td>100 % open</td>
<td>100 to 0%</td>
<td>47.0</td>
</tr>
<tr>
<td>6.</td>
<td>1643.50</td>
<td>75 % open</td>
<td>100 to 0%</td>
<td>38.0</td>
</tr>
<tr>
<td>7.</td>
<td>1643.50</td>
<td>50 % open</td>
<td>100 to 0%</td>
<td>38.0</td>
</tr>
<tr>
<td>8.</td>
<td>1643.50</td>
<td>25 % open</td>
<td>100 to 0%</td>
<td>28.2</td>
</tr>
</tbody>
</table>

4.4 Bottom Shape of the Gate lip

The pressure distribution on the bottom shape of the gate lip for 50° lip of emergency and service gate was studied by providing manometer tappings. These studies were conducted for the reservoir water levels of El. 1622.75 m and El. 1643.50 m with various gate openings of emergency/service gate. Figures 15 to 18 show the pressure distribution on the gate lip for RWL El. 1622.75 m and 1643.50 m for various gate openings. The pressure tube 1 (PT1) is near the edge of lip, while PT9 is on the upstream vertical face of the gate and remaining are in between these points as shown in Figure 15. The pressure at the PT9 during 10% gate opening is almost
equal to the upstream reservoir water level indicating stagnating pressure occurrence with small head loss at this point. The pressure along the lip (from PT9 to PT1) goes on decreasing as the velocity goes on increasing towards PT1. Similar trend is seen for almost all the gate openings from 10% to 60%. But for gate openings of 70% and above, stagnating point of flow occurs at a point between PT7 to PT3. In the region above point PT7, an upward flow and below PT3, flow is downward-forward which causes reduction in pressure as shown in Figure 16 and 18. When the gate is fully withdrawn from the flow, i.e. at 100% gate opening, the stagnating flow point is around PT1, whereby the pressure is maximum at PT1 as seen in Figure 16 and 18.

These results indicate that the pressures were generally positive along the lip, when the gate was at various part gate openings with reservoir water level at FRL El. 1643.5 m and El. 1622.75 m. It could therefore be inferred that the gate lip with lip angle of 50° is also hydraulically satisfactory and acceptable.

As per the drawing No. G/IS/-703 dated 25.09.2006, gate lip details at “Details-III” an additional stainless steel plate No. 23 of thickness 4 mm has been provided which protrudes into the flow. Since the velocity of flow at these gate lip points is very high, there is every possibility of peeling of the plate and leading to cavitation. In view of this it is advisable to provide the stainless steel plate starting from gate lip to at least till the second girder (from top) wherein the flow velocities will not be able to peel it from the gate and further cavitation damage will be averted.

4.5 Flow conditions and pressure along sluice barrel downstream of gates

Pressures along the sluice barrel immediately downstream of the gate were acquired using manometers as shown in Photo 6, which would be useful in assessing the requirement of provision of steel liners.

The flow conditions in the sluice downstream of emergency gate while emergency gate is partly open is observed. Free or open channel flow is observed through out for the emergency gate opening of up to 88% for reservoir water level El. 1643.5 m. It is completely pressurized (pipe flow) beyond the gate opening of 92%, while transitory flow is observed in which mixture of air and water flows during the gate opening between 88 to 92%. The air is drawn from airvents in to the flow. Similar flow conditions were observed for the operation of service gate also.
Figures 19 to 21 present the pressures along the side wall of the barrel. The piezometer tappings are placed along the vertical side wall at a level of El. 1588.83 (top row), 1588.23 (middle row) and 1587.67 m (lower level). Figures 19 and 20 present the pressure variation along the vertical side wall at El. 1588.83 m and 1588.23 m for RWL El. 1643.5 m during the operation of emergency gate. Since the piezometer tappings are at El. 1588.83 m and El. 1588.23 m, water surface in the sluice is observed to be below this level and pressure is not noticed up to the gate opening of 60% and above. Therefore, Figures 19 and 20 present the pressure variation from 60% to 100% gate opening only. Figure 21 presents the pressure variation along the side wall at El. 1587.67 m (lower row) and the water surface in the sluice is more than this level for gate opening of 40% and above. The pressures observed at the gate opening below 88% are varying around a mean of approximately zero, while these pressures increase a lot for the gate opening of beyond 92%. For 90% gate opening, pressures vary between these two limits, indicating the effect of
air-water flow conditions. These figures very clearly indicate the transitory zone between the gate openings of 88 to 92%. The observations indicated that the maximum negative pressure experienced was of the order of -2.0 m on the side wall of the sluice. The negative and positive pressure continues cyclically along the sides. No negative pressure was noticed on the bottom of the sluice. The velocities in this region are very high and are of the order of 30 m/sec. In view of this, it is recommended to provide stainless steel lining of suitable thickness along the sluice barrel up to at least 12 m downstream of the service gate slot (downstream edge). The stainless steel liner must be flushed with the sluice inner wall and the liner should not have any offset away or protrude inside the flow.

5.0 CONCLUSIONS

5.1 The maximum hydrodynamic down pull force on emergency and service gate with 50° lip angle is 47 tonnes.

5.2 The maximum hydrodynamic uplift force on emergency and service gate with 50° lip angle is 15 tonnes.

5.3 The bottom shape of the gate lip with 45 and 50 degree lip angle are considered hydraulically satisfactory for both service and emergency gates as the pressures were found to be positive at various gate openings up to FRL El 1643.5 m. The lip angle which is structurally more stable may be adopted.

5.4 The pressures on the barrel for full sluice flow (pipe flow) are all positive.

5.5 The flow in the barrel will be free (open channel) flow for emergency/service gate opening of 88% and below.

5.6 The flow will be under transitory phase (partially open channel and closed conduit type along the whole length of the sluice) between the emergency/service gate openings of 88% to 92%.

5.7 The flow through the sluice will be closed conduit type beyond the emergency/service gate opening of 92%.

5.8 The sluice barrel experiences a maximum negative pressure of -2.0 m which reduces (asymptotic to zero) as the distance from the gate slot increases. In view of this and very high flow velocities in this region, steel liner of proper
thickness is recommended on all four sides of barrel up to 12 m downstream of the service gate slot (downstream edge).

5.9 The steel liner ends must be flush with the concrete surface without any offset either into or away from the flow.
### ANNEXURE – I

#### SALMA DAM PROJECT, AFGHANISTAN

#### SALIENT FEATURES

<table>
<thead>
<tr>
<th>Location</th>
<th>162 km east of Herat town, 2 km downstream of Salma village in Herat province, on the river hari rud.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>34° 24’ N</td>
</tr>
<tr>
<td>Longitude</td>
<td>63° 49’ E</td>
</tr>
<tr>
<td>River</td>
<td>Hari Rud.</td>
</tr>
</tbody>
</table>

**Hydrology**

- **Catchment area**: 11700 sq. Km.

**Annual precipitation**

- A) **maximum**: 300 mm.
- B) **minimum**: 100 mm.

**Discharge**

- A) **maximum recorded annual flood**: 723 m$^3$/sec
- B) **minimum recorded annual flood**: 99 m$^3$/sec

**Design flood**

- **Diversion tunnel capacity**: 2100 m$^3$/sec
- 1115 m$^3$/sec

**Reservoir**

- **Maximum water level (MWL)**: El 1645.84 m
- **Full reservoir level (FRL)**: El 1643.50 m
- **Minimum draw down level (MDDL)**: El 1602.00 m
- **Gross capacity**: 633 million m$^3$
- **Live storage capacity**: 514 million m$^3$
- **Water spread**: 20 km (28 km along the road)
- **Length**: East west 20 km
- **Width**: North south 3.7 km (max.)

**Dam**

- **Type**: Earth and rock fill (cobble & gravel)
- **Height**: 107.5 m
- **Length at top**: 534 m
- **River bed level**: El 1547 m
- **Existing proposed excavated bed level**: El 1540 m
- **Top of dam**: El 1647.50 m
### Diversion tunnel

<table>
<thead>
<tr>
<th>Type</th>
<th>Horse shoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>8.5 m</td>
</tr>
<tr>
<td>Length</td>
<td>630 m</td>
</tr>
</tbody>
</table>
| Invert         | Level at inlet portal El 1552.425 m  
                 | Level at outlet portal El 1549.63 m |

### Spillway

<table>
<thead>
<tr>
<th>Location</th>
<th>Right bank between chainages 311.6 to 347.6 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crest</td>
<td>El 1633.50 m</td>
</tr>
<tr>
<td>Bottom</td>
<td>El 1600.00 m</td>
</tr>
<tr>
<td>Length</td>
<td>154.95 m</td>
</tr>
<tr>
<td>Flip bucket</td>
<td>El 1579.69 m (invert)</td>
</tr>
<tr>
<td>Spans</td>
<td>3 nos. Each 8 m wide</td>
</tr>
<tr>
<td>Piers</td>
<td>2 nos. 7 m and 5 m thick</td>
</tr>
<tr>
<td>Gates</td>
<td>Radial gates 3 nos. Each of 8 m x 11.085 m high</td>
</tr>
<tr>
<td>Discharge</td>
<td>2100 m$^3$/sec</td>
</tr>
</tbody>
</table>

### Irrigation sluice

<table>
<thead>
<tr>
<th>No. Of sluices</th>
<th>One</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of sluice</td>
<td>Through spillway pier</td>
</tr>
<tr>
<td>Thickness of pier through which sluice passes</td>
<td>5 m</td>
</tr>
<tr>
<td>Discharge</td>
<td>15 m$^3$/sec for MDDL El. 1602 m.</td>
</tr>
<tr>
<td>Sill level of sluice</td>
<td>El 1587 m</td>
</tr>
<tr>
<td>Top bell mouth</td>
<td>$\frac{x^2}{5.76} + \frac{y^2}{2.58} = 1$</td>
</tr>
<tr>
<td>Side bell mouth</td>
<td>$\frac{x^2}{4} + \frac{y^2}{0.4356} = 1$</td>
</tr>
<tr>
<td>Bottom bell mouth</td>
<td>Straight</td>
</tr>
<tr>
<td>Energy dissipation arrangements</td>
<td>The sluice end meets the chute floor tangentially in the form of a trajectory.</td>
</tr>
</tbody>
</table>
| Air vent        | 800 mm dia. downstream of emergency gate,  
                 | 1100 mm dia. downstream of service gate.   |

### Power sluice

<table>
<thead>
<tr>
<th>No. of sluices</th>
<th>One</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of sluice</td>
<td>Through spillway pier</td>
</tr>
<tr>
<td>Thickness of pier</td>
<td>7 m</td>
</tr>
<tr>
<td>Design discharge</td>
<td>63 m$^3$/sec</td>
</tr>
<tr>
<td>Sill level of sluice</td>
<td>El 1592.51 m</td>
</tr>
<tr>
<td>Size of gate</td>
<td>Rect. 3.52 m x 6.72 m</td>
</tr>
<tr>
<td>Air vent</td>
<td>900 mm downstream of service gate.</td>
</tr>
</tbody>
</table>

### Power house

---

Page 229
<table>
<thead>
<tr>
<th><strong>Type</strong></th>
<th>Surface power house</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions</strong></td>
<td>65.4 m x 18.5 m</td>
</tr>
<tr>
<td><strong>Design head</strong></td>
<td>76 m</td>
</tr>
<tr>
<td><strong>No. of units</strong></td>
<td>3 of 14 MW each</td>
</tr>
<tr>
<td><strong>Installed capacity</strong></td>
<td>42 MW</td>
</tr>
</tbody>
</table>

**Power tunnel/pressure shaft**

<table>
<thead>
<tr>
<th><strong>Diameter</strong></th>
<th>4.25 m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>457 m (from intake to power house)</td>
</tr>
</tbody>
</table>

**Penstock**

<table>
<thead>
<tr>
<th><strong>Number</strong></th>
<th>One branching into three near the power house</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diameter</strong></td>
<td>2.46 m</td>
</tr>
</tbody>
</table>

**Energy and power output**

<table>
<thead>
<tr>
<th><strong>Energy generation in 90% dependable year</strong></th>
<th>86.6 GWH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy generation in 75% dependable year</strong></td>
<td>186.13 GWH</td>
</tr>
</tbody>
</table>
Figure 1. Salma dam project, Afghanistan

Index map
Figure 7. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1622.75 m, Service gate 100% open

Figure 8. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1622.75 m, Service gate 75% open
Figure 9. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1622.75 m, Service gate 50% open

Figure 10. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1622.75 m, Service gate 25% open
Figure 11. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1643.5 m, Service gate 100% open

Figure 12. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1643.5 m, Service gate 75% open
Figure 13. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1643.5 m, Service gate 50% open

Figure 14. Hydrodynamic Force on Emergency Gate with 50° lip
Condition: RWL = 1643.5 m, Service gate 25% open
Figure 15. Pressures along Service gate lip (50°) for RWL El. 1622.75 m; for 10 - 50% gate opening

### Pressure Tube Tappings on Gate Lip

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Distance from lip (mm)</th>
<th>Height from lip edge (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>160</td>
<td>158</td>
</tr>
<tr>
<td>3</td>
<td>210</td>
<td>263</td>
</tr>
<tr>
<td>4</td>
<td>230</td>
<td>337</td>
</tr>
<tr>
<td>5</td>
<td>409</td>
<td>495</td>
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<tr>
<td>6</td>
<td>415</td>
<td>567</td>
</tr>
<tr>
<td>7</td>
<td>515</td>
<td>649</td>
</tr>
<tr>
<td>8</td>
<td>546</td>
<td>750</td>
</tr>
<tr>
<td>9</td>
<td>548</td>
<td>900</td>
</tr>
</tbody>
</table>

Conditions:
- RWL El. 1622.75 m, Emergency gate fully open,
- Service gate opening:
  - □ 10 % open
  - ○ 20 % open
  - △ 30 % open
  - ∀ 40 % open
  - ● 50 % open
Figure 16. Pressure along service gate lip (50°) for RWL El. 1622.75 m; for 60 to 100% of gate openings
Figure 17. Pressures along Service gate lip (50°) for RWL El. 1643.5 m; 10 - 50% gate opening

Conditions:
RWL El. 1643.5 m, Emergency gate fully open,
Service gate opening:
- □ 10 % open
- ○ 20 % open
- △ 30 % open
- ▽ 40 % open
- ◆ 50 % open
Figure 18. Pressures along service gate lip (50°) for RWL El. 1643.5 m; for 60 to 100% of gate openings
Figure 19. Pressures on sluice barrel vertical side wall, downstream of emergency gate.
Figure 20. Pressures on sluice barrel vertical side wall, downstream of emergency gate
Reservoir water level EL 1643.5 m, Service gate fully open, Manometer tappings at EL 1587.675 m (Lower row)

Emergency gate opening:
- ■ 40 % open
- ○ 60 % open
- △ 80 % open
- ▽ 88 % open
- ◊ 90 % open
- × 92 % open
- → 100 % open

Figure 21. Pressures on sluice barrel vertical side wall, downstream of emergency gate
Structural steel fabrication for Hydro-mechanical equipments i.e Gates and Hoists can be carried out in shop or at the construction site. Fabrication of steelwork carried out in shops is precise and of assured quality, whereas field fabrication is comparatively of inferior in quality. In India construction site fabrication is very common in large projects due to inexpensive field labor, high cost of transportation, difficulty in the transportation of large members, higher excise duty on products from shop. Beneficial taxation for site work is a major financial incentive for site fabrication. However, fabrication of Hydro-mechanical equipments is generally carried out in Workshops due to the level of accuracy and precision required. If the same work is carried out at site the methods followed in site fabrication are similar but the level of sophistication of equipment at site and environmental control would be usually less. The skill of personnel at site also tends to be inferior and hence the quality of finished product tends to be relatively inferior. Further, shop fabrication is efficient in term of cost time and quality.

1.0 Sequence of activities in fabricating shops

Sequence of fabrication in shop is usually as under with a little variation:-

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Sequence of Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surface cleaning</td>
</tr>
<tr>
<td>2</td>
<td>Cutting and machining</td>
</tr>
<tr>
<td>3</td>
<td>Punching and drilling</td>
</tr>
<tr>
<td>4</td>
<td>Straightening, bending and rolling</td>
</tr>
<tr>
<td>5</td>
<td>Fitting and reaming</td>
</tr>
<tr>
<td>6</td>
<td>Fastening (bolting, riveting and welding)</td>
</tr>
<tr>
<td>7</td>
<td>Finishing</td>
</tr>
<tr>
<td>8</td>
<td>Quality control</td>
</tr>
<tr>
<td>9</td>
<td>Surface treatment</td>
</tr>
<tr>
<td>10</td>
<td>Transportation</td>
</tr>
</tbody>
</table>
1.1 Surface Cleaning

Structural sections from the rolling mills may require surface cleaning to remove mill scale prior to fabrication and painting. Hand preparation, such as wire brushing, does not normally conform to the requirements of modern paint or surface protection system. However, in some applications manual cleaning is used and depending on the quality of the cleaned surface they are categorized into Grade St-2 and Grade St-3.

Blast cleaning is the accepted way of carrying out surface preparation in a well-run fabrication shop. Abrasive sand or steel particles are projected on to the surface of the steel at high speed by either compressed air or centrifugal impeller to remove rust and roughen the surface before applying the protective coating.

Flame cleaning is another method of surface cleaning. In this method the surface is cleaned using an oxy-acetylene torch which works on the principle of differential thermal expansion between steel and mill scale. In another method the steel piece is immersed in a suitable acid and the scale and rust are removed.

1.2 Cutting and Machining

Following surface preparation, dimensional marking & cutting to length is always the first process to be carried out. Cutting is done by any of the following methods:-

- Shearing and cropping by Hydraulic shears
- Flame Cutting or Burning
- Arc Plasma Cutting
- Cold Sawing
- Punching and Drilling

Most fabrication shops have a range of machines, which can form holes for connections in structural steel work. The traditional drilling machine is the radial drill, a manually operated machine, which drills individual holes in structural steelwork. But this method has become too slow for primary line production. Therefore, larger fabricators have installed NC (Numerically Controlled) tooling, which registers and drills in response to keyed in data. It is also possible to punch holes, and this is particularly useful where square holes are specified such as anchor plates for foundation bolts.

Rolled steel may get distorted after rolling due to cooling process. Further during transportation and handling operations, materials may bend or may even undergo distortion. This may also occur during punching operation. Therefore before attempting further fabrication the material should be straightened. In current practice, either rolls or gag presses are used to straighten structural shapes.
Gag press is generally used for straightening beams, channels, angles, and heavy bars. This machine has a horizontal plunger or ram that applies pressure at points along the bend to bring it into alignment. Long plates, which are cambered out of alignment longitudinally, are frequently straightened by rollers. They are passed through a series of rollers that bend them back and forth with progressively diminishing deformation.

Misalignments in structural shapes are sometimes corrected by spot or pattern heating. When heat is applied to a small area of steel, the larger unheated portion of the surrounding material prevents expansion. Upon cooling, the subsequent shrinkage produces a shortening of the member, thus pulling it back into alignment. This method is commonly employed to remove buckles in girder webs between stiffeners and to straighten members. It is frequently used to produce camber in rolled beams. A press brake is used to form angular bends in wide sheets and plates to produce cold formed steel members.

1.3 Fitting and Reaming

Before final assembly, the component parts of a member are fitted-up temporarily with rivets, bolts or small amount of welds. The fitting-up operation includes attachment of previously omitted splice plates and other fittings and the correction of minor defects found by the inspector. In riveted or bolted work, especially when done manually, some holes in the connecting material may not always be in perfect alignment and small amount of reaming may be required to permit insertion of fasteners. In this operation, the holes are punched, 4 to 6 mm smaller than final size, then after the pieces are assembled, the holes are reamed by electric or pneumatic reamers to the correct diameter, to produce well matched holes.

1.4 Fastening Methods

The strength of the entire structure depends upon the proper use of fastening methods. There are three methods of fastening namely bolting, riveting and welding. A few decades back, it was a common practice to assemble components in the workshop using bolts or rivets. Nowadays welding is the most common method of shop fabrication of steel structures. In addition to being simple to fabricate, welded connection considerably reduce the size of the joint and the additional fixtures and plates. However, there is still a demand for structural members to be bolted arising from a requirement to avoid welding because of the service conditions of the member under consideration. These may be low temperature performance criteria, the need to avoid welding stresses and distortion or the requirement for the component to be taken apart during service e.g. bolts in crane rails or bolted crane rails.

1.5 Finishing

Gate structural members like roller tracks/ thrust pads and thrust bearings whose ends must transmit loads by bearing against one another are usually finished to a smooth even surface.
Finishing is performed by sawing, milling or other suitable means. Several types of sawing machines are available, which produce very satisfactory finished cuts. One type of milling machine employs a movable head fitted with one or more high-speed carbide tipped rotary cutters. The head moves over a bed, which securely holds the work piece in proper alignment during finishing operation. The term finish or mill is used on detail drawings to describe any operation that requires steel to be finished to a smooth even surface by milling, planning, sawing or other machines.

1.6 QUALITY CONTROL IN FABRICATION

Quality assurance during fabrication of gate components assumes utmost importance in ensuring that the completed gate assemblies behaves in the manner envisaged during design stage. Any deviation from these design considerations as reflected in detail drawings may introduce additional stresses to the structure and affect its strength and durability. This may also affect the sealing performance of the gates.

In order to ensure that the fabrication can be carried out in accordance with the drawings, it is necessary that inspection and checking is carried out in accordance with an agreed Quality Assurance Plan (QAP). The plan should elaborate on checks and inspections of the raw materials and also of the components as they are fabricated, joined etc. For fabrication activities being carried the absence of controlled environment (as in an organized workshop), the quality of workmanship of such fabrication is likely to suffer. It has, therefore, become all the more important to motivate the fabricators to appreciate the usefulness of Quality Assurance Plans and introduce the system in all their works and at site as well.

1.7 Painting

The gates and hoist components are painted in accordance with provision of IS:11477

Following gates and hoist components are painted to protect them against corrosion:-

- Embedded parts,
- Gate leaf,
- Hoists and its supporting structures

Paints are applied during manufacture and during maintenance.

1.7.1 Surface Preparation:

Surface preparation shall include through cleaning, smoothing, drying and similar operation that may be required to ensure that the primer and or paint is applied on suitable surfaces. Weld
spatters or any other surface irregularities shall be removed by any suitable means before cleaning. All oil grease and dirt shall be removed from the surface by the use of clean material spirits, Xylol or white gasoline and clean wiping materials. Following the solvent cleaning, the surfaces to be painted shall be cleaned of all rust, mill scale and other lightly adhering objectionable substances by sand blasting. Surface of stainless steel, nickel, bronze and machined surface adjacent to metal work being cleaned or painted shall be protected by making tape or by other suitable means during the cleaning and painting operations. Primers shall be applied as soon as the surface preparation is complete and prior to the development of surface rusting. In case there is considerable time gap, the surface shall be cleaned prior to priming.

1.7.2 Shop painting:

All embedded parts which come in contact with concrete shall be cleaned and given two coats of cement Latex to prevent rusting during the shipment while awaiting installation. Embedded parts which are not in contact with concrete and gate parts shall be given two coats of zinc rich primer with epoxy resin to obtain a dry film thickness of 75 microns, which shall be followed by two coats at an interval of 24 hours of coal tar blend epoxy resin part so as to get a dry film thickness of 80 microns in each coat. Total dry film thickness of paint shall be 300 microns.

The following surfaces are not to be painted unless or otherwise specified:

a) Machine finished or similar surface
b) Surfaces which will be in contact with concrete
c) Stainless steel overlay surfaces.
d) Surfaces in sliding or rolling contact
e) Galvanized surfaces, brass and bronze surfaces.
f) Aluminum alloy surfaces

All finished surfaces of ferrous metal including bolts, screw threads etc., that will expose during shipment or while awaiting installation shall be cleaned and given heavy uniform coating of gasoline soluble rust preventive compound or equivalent.

1.7.3 Hoist and supporting structure:

A) Structural components

Primer coats of zinc phosphate primer shall be applied to give a dry film thickness of 40±5 microns. One coat of alkyd based micaceous iron oxide paint to give a dry film thickness of 65 ± 5 microns followed by two coats of synthetic enamel paint confirming to IS 2932 – 1974 to give a dry film thickness of 25 ± 5 microns per coat. The interval between each coat shall be 24 hours. The total dry thickness of all coats of paint including the primary coat shall not be less than 175 microns.
B) **Machinery:** Except machined surfaces all surfaces of machinery including gearing, housing, shafting, bearing pedestals etc., shall be given one coat of zinc phosphate priming paint to give minimum film thickness of 50 microns. Motors and other bought out items shall be painted if necessary. The finished paint shall consists of three coats of aluminum paint confirming to IS2339 – 1963 or synthetic enamel paint confirming to IS 2932 – 1977 to give a dry film thickness of 25±5 microns to obtain a minimum dry film thickness of 125 microns.

1.7.4 Inspection and testing of painting

The following steps involved in inspection of painting are general inspection before and during painting

- Viscosity test of paints
- Thickness test – using Elcometer
- Inspection of general appearance of finished work.

The aim of inspection and testing is to ascertain whether the recommended practice is being employed during every stage of application and whether the final results fulfill the object of painting, inspection therefore means a close supervision while the work is in progress. Any test carried out should be non-destructive nature or, if of destructive nature, should be either restricted to areas which can be restored without marring the general appearances, or be such that it is possible to restore easily without necessitating a complete repetition of the work.

When inspecting general painting work while in progress, it should be ensured:

- That painting follows immediately after pre cleaning or pre treatments; that any contamination which may occur in the interim period is removed, that special precautions are taken when painting after galvanizing;
- That no painting is carried out when there is danger of dew;
- That tools used are clean and not excessively worn;
- That the paint in the drums is thoroughly mixed prior to application; that drums are inspected to make sure that no sediment is left in them;
- That if paint has thickened because of long storage or because of the evaporation of the solvents, its viscosity is adjusted as recommended by the paint manufacturer;
- That each coat is allowed to dry sufficiently but not excessively before applying the following coat; that manufacturer’s instructions for drying time are adhered to properly; and
That every individual coat is properly applied, reasonably level and smooth and free from runs and ‘holidays’ (minute uncovered areas).

2.0 ERECTION

General:

Erection of gates, embedment and hoist machinery and structure is the process by which the fabricated structural members are assembled together to form the skeletal structure. The erection is normally carried out by the erection contractor. The erection process requires considerable planning in terms of material delivery, material handling, member assembly and member connection. Proper planning of material delivery would minimize storage requirement and additional handling from the site storage, particularly heavy items. Erection of structural steel work could be made safe and accurate if temporary support, false work, staging etc. are erected. Before erection the fabricated materials should be verified at site with respect to mark numbers, key plan and shipping list. The structural components received for erection should be stacked in such a way that erection sequence is not affected due to improper storing. Care also should be taken so that steel structural components should not come in contact with earth or accumulated water. Stacking of the structures should be done in such a way that, erection marks and mark numbers on the components are visible easily and handling do not become difficult. It is emphasized that safe transportation of fabricated items to the site, their proper storage and subsequent handling are the pivotal processes for the success of fabrication of structural steel work.

As seen from the past executed projects, the accuracy and high quality of civil construction and erection of embedded metal parts plays predominant role in safe, satisfactory and trouble free erection and subsequent smooth operation of the hydro-mechanical equipments.

2.1 Sequence of Activities during Erection

- Receiving material from the shop and temporarily stacking them, if necessary.
- Lifting and placing the member and temporarily holding in place.
- Temporarily bracing the system to ensure stability during erection.
- Aligning and permanently connecting the members by bolting or welding.
- Connecting cladding to the steel structural skeleton.
- Application of a final coat of painting.
3.0 Welding

Metal arc welding is the most widely used welding process for the fabrication, installation and erection of embedment, gate leaves and hoists. The main features of this process are as follows:

- Immediate heating.
- Depth of fusion and heating is fixed by electrode type size and current and can be controlled somewhat but not closely, by the operator.
- Nearly all metals can be welded.
- Welding can be carried out in all positions.
- Wide range of thickness can be welded.

The welding process involve:

- Preheating: Reduces stress and distortion
- Preparation for welding: Comprises cleaning the weld surface
- Welding: Requirement of proper welding technique
- Post heating: To reduce residual stresses in metal

Precautions for quality welds

Each bead and layer shall be thoroughly cleaned of all slag and spatter before the next bead or layer is deposited. Welds shall be free from cracks, tears and gross porosity. Defective welds shall be removed by gauging, chipping or grinding and the joint re-welded. Where complete penetration welds are to be welded from both sides, the root of the first side welded shall be gauged to sound metal before the second side is welded. When welding in the vertical position, the progression shall be upwards for all passes.

3.1 Welding defects, causes and types

Normal welds always contain minute slag inclusions or porosity as revealed in non-destructive testing. Such small imperfections which cause some variations in the normal average properties of the weld—metal are called discontinuities. When discontinuity is large enough to affect the function of the joint, it is termed as defect and are caused due to:

- Substandard welding consumables.
- Inefficient workmanship.
- Lack of cleanliness.
- Un-favourable properties of the base metal.
- Low ambient temperature and humid atmosphere.

Following defects are normally found :-

**Incomplete Penetrations**: This defect occurs at the root of the joint when the weld metal fails to reach it or weld metal fails to fuse completely with the root faces of the joint. As a result, a void remains at the root zone which may contain slag, inclusions. In a fillet weld, poor penetrations at the root zone can give rise to cracking of single butt weld. In a weld adequate root penetration is ensured by size of electrode, sufficiently high current and directing the arc towards the root during deposition of the root pass. Rectification of this defect is a very costly proposition because it requires removal of the entire thickness of the weld and re-welding.

**Lack of Fusion**: Lack of fusion is the poor adhesion of the weld bead to the base metal and caused due to scale (rusting), dirt, oxide, slag and other non-metallic substances which prevent the underlying metal from reaching metallic temperature. It can be prevented by keeping the joint surface clean and adequate welding current.

**Undercut**: Undercutting is when the fillet weld reduces the cross-sectional thickness of the base metal, which reduces the strength of the weld and work pieces. This defect is usually caused by:

- Excessive welding current
- Too high speed of arc travel
- Wrong electrode angle or excessive side manipulation
- Also causes due to damp or improperly formulated electrodes.

Note: In the case of statically loaded structures the presence of small and intermittent undercutting will reduce fatigue endurance of the welded joint and hence it should not be permitted.

The defect is rectified by filling up the under cut groove with weld pass. If under cut is deep and contains slag, it should be clipped away before re-welding. If the rectification being carried out on thick joints and on high tensile steels, the welding procedure including preheating should correspond to the recommended procedure for particular steel.

**Overlap**: The defect occurs at the toes of weld and consists of weld – metal which has over flowed on the base metal surface without actually fusing to later. It can be isolated
intermittent or continuous. It occurs more often in fillet welds and results in an apparent increase in the weld size.

**Causes:**

- It is occurred by an incorrect manipulation of the electrode, where by the weld metal flows away from the fusion zone.
- Use of too large an electrode in relation to the welding position, and excessive current coupled with a too low welding speed also promote its occurrence.
- When a single – pass fillet larger than 7.5mm in leg length is made in the horizontal position, the molten metal tends to sag and causes overlapping in at the toe of the horizontal member.

**Rectification:**

Slight and intermittent over lapping may be ignored in statically loaded structures, but it should not be permitted in dynamically loaded structure as over laps act as stress–raiser. Overlap is rectified by grinding, chipping or gouging out the excess infused weld metal. Care should be taken to leave the smooth surface.

**Slag Inclusions:** Slag inclusions are detected by the normal non destructive testing methods. While non – metallic inclusions are observed in the weld micro structure at high magnification.

Non metallic particles of comparatively large size entrapped in the weld metal are termed as slag inclusion. Slag inclusions usually occurs in multi pass weld due to imperfect cleaning of the slag between the disposition of successive passes. It may also be caused by heavy mill scale, loose rust, dirt, grit and other substances present on the surface of base metal. Slag trapped in under cuts or between uneven preceding runs may give rise to elongated lines of included slag when a subsequent weld pass is deposited.

The melting characteristic of the welding consumables and particularly the viscosity of the rusting slag has an important bearing on inclusion. The molten slag should float freely to the surface of the weld pool and easily removable on solidification. It results in loss of strength and hair line cracks

**Prevention:**

- Use proper welding consumables.
- Keep joint surfaces (especially gas cut surfaces) and bare filler wires perfectly clean and clean the base metal thoroughly before welding.

- Avoid under cuts and gaps between deposited perfectly clean and clean the base metal thoroughly before welding.

- Avoid under cuts and gaps between deposited passes.

- Clean the slag thoroughly between weld passes.

**Porosity** :- The presence of a group of gas pores in a weld caused by the entrapment of gas during solidification is termed as Porosity. The pores are in the form of small spherical cavities either clustered locally or scattered through out the weld deposit. Sometimes entrapped gas gives rise to single large cavity, which is termed as a blow hole. In some rarer cases, elongated or tubular gas cavities are presented. These are referred to as piping or worm holes.

The gases are evolved by the chemical reactions in the welding and these gases may have high solubility in the molten weld metal, but as the metal solidifies and cools, their solubility decreases rapidly and they are released from the metal. Sometimes if the weld metal solidification and cooling is too rapid, the gas gets entrapped in the form of Porosity.

**Causes :**

- Chemically imperfect welding consumables for example deficient in deoxidizers

- Faulty composition of the base metal or electrode wire for example, high sulphur content.

- Oil, grease moisture and mill scale on the joint surface.

- Excessive moisture in the electrode coating or submerged – are flux.

- Inadequate gas shielding or impure gas in a gas shielded process.

- Low welding current or too long an arc.

- Quick freezing of the weld deposit.

Puddling of the weld metal and use of preheat or higher current allow sufficient time for the dissolved gases to escape from the weld metal. Presence of small, finally dispersed porosity is normally not expected to affect the static and even dynamic properties of a welded joint. However excessive porosity blow holes or piping must be guarded against
as they seriously impair these properties. Their presence is detected by the conventional NDT methods. The defective portions must be removed and re-welded.

Cracks: Crack is defined as a discontinuity caused by the tearing of the metal while in a plastic condition (hot crack) or by fracturing of the metal when cold (cold crack). Hot cracks are those that occur at elevated temperatures and are usually solidification related. These cracks occur at temperatures above 540°C and when observed under the microscope are seen to have traveled across the boundaries between the grains (intergranular). If the cracks has extended to the surface, the fractured surface is found to be coated with the blue scale or possibly black scale. Cold cracks are those that occur after the weld metal has cooled to room temperature and may be hydrogen related. Most forms of cracking result from the shrinkage strains that occur as the weld metal cools. Cracking can occur in the weld metal, at the fusion line or in the base metal.

3.2 Post Weld Fabrication Difficulties

Welding Distortions

When laying a weld bead, filler metal is deposited at a high temperature above the melting point of material. This is approximately 1,370 deg C for steel. The weld wants to shrink as it cools to room temperature, but is restrained from doing so by the adjacent cold base metal. This restraint creates high-residual tensile stress that causes the weld to act like a stretched rubber band, with the work piece holding the ends. For this reason, when the clamps that hold the work piece are removed the base metal is allowed to move (or spring back) the part is distorted. Thinner material is more susceptible to this because it has less stiffness. Stainless steels are also more susceptible because they have greater thermal expansion and lower thermal conductivity than carbon steels.

How to manage fabrication distortions

A full awareness of distortion is vital to all concerned with welding including the designer, detailer, factory foreman and the welders, as each in their actions could cause difficulties through lack of understanding and care. Weld sizes should be kept to the minimum required for the design in order to reduce distortional effects; in many cases, partial penetration welds can be used in preference to full penetration welds, deep penetration welds in preference to ordinary fillet welds. Some distortional effects can be corrected, but it is much more satisfactory to plan to avoid distortion and thereby avoid the difficulties and costs of straightening and flattening to achieve final acceptability.

Control of distortion

These can be avoided by taking following steps:-
- Avoid overwelding. The bigger the weld, the greater the shrinkage: correctly sizing a weld not only minimizes distortion, but also saves weld metal and time.

- Intermittent welding. Use intermittent welds instead of continuous welds where possible to minimize the amount of weld metal.

- Fewer weld passes. Because shrinkage accumulates from each weld pass, a fewer number of big passes results in less distortion than a greater number of small passes with small electrodes.

- Place welds near the neutral axis, or the center of the part. Reduce warpage by providing less leverage for the shrinkage forces to pull the plates out of alignment.

- Balance welds around the neutral axis. Welding on both sides of the plate offsets one shrinkage force with another, to minimize warpage.

- Use the backstep welding technique. The general progression of welding in this technique may be left to right, but each bead segment is deposited from right to left.

- All members that are welded will shrink in their length, so each member will either be fabricated over-length and cut to length after welding, or an estimate of shrinkage will be added to anticipate the effect during the fabrication of the member.

- For the control of angular distortion and bowing, there are two methods of control that can be considered if the distortion is likely to be of significance:

  Pre-setting. The section is bent in the opposite direction to that in which it is expected to distort and welding is then carried out under restraint. When cool, the clamps are removed and the section should spring straight. Trials and experience can determine the extent of pre-bend for any particular member.

  Clamping. The units are held straight by clamps whilst the welding is carried out, which reduces the distortion to tolerable amounts.

- Thermal stress relieving. Another method for removing shrinkage forces is thermal stress relieving, i.e., the controlled heating of the weldment to an elevated temperature, followed by controlled cooling.
- Peening. Peening the weld bead stretches it and relieves the residual stresses. But peening must be used with care. For example, a root bead should never be peened because of the increased risk of concealing or causing crack.

- Peening on the final pass is not permitted because it can cover a crack and interfere with visual inspection.

4.0 Other Issues in Fabrication

- Non availability of standard steel material

  The non-standard steel plates may be undersize (thickness-wise), may lack sufficient carbon content, rendering the material dangerously brittle; and may fail in tension tests.

- Delay in importing items such as bearings etc.

  It occurs due to delay in order placement, items being non standard, strikes or traffic congestion at ports. It causes fitment delays in assemblies

- Inadequate or lack of facilities for stress relieving in the shop / site etc.

- Lack of machines of desired ratings and capabilities etc.

- Lack of Inspection and quality monitoring mechanism at shop floor.

- Strikes of labourers

- Lack of inspection or quality monitoring instrumentations at shop or site.

- Non availability of skilled man power.

- Outsourcing of job to other contractors resulting in comprise of quality.

- Change in design during the progress of work etc.

5.0 Problems faced during erection of hydraulic gate & its components

- Accessibility of site where erection is proposed. Presence of railway bridge & road bridge causes hindrance of projects

- Carrying of various gate and its components assemblies to the erection site due to water way between road and the site of erection.

- Limited capacity of gantry crane for material handling etc.

- Lack of catwalk bays, stairs, rungs, ladders etc
- Distance between work space and storage yard may cause delay
- Limited access in tunnels possess difficulties in movement of gate components
- Lack of infrastructure facilities at Project site like storage yard, roads, markets, hospitals etc.
- Lack of infrastructure facilities from contractors like consumables welding rods, grinding wheels, gas cylinder, gas cutters, lubricants etc.
- Administrative delays from Project Authority for contractor’s material and machinery induction, labour permit renewals, various inspections.
- Problems due to delay in timely payments.
- Lack coordination with other contractors.
- Lack of working space.
- Unavailability of tower/mobile cranes.
- Removal of additional equipments, reinforcements etc
- Simultaneous working with various civil contractors
- Lack of material handling equipment with the contractor.
- Natural barriers resulting in inaccessibility.
- Weather like rainy season, monsoon season etc.
- Accidents and diseases leading to lack of motivation in the workers
- Interferences or disturbance of already work done i.e. taking support, welding, damaging scaffolding, insulations etc.
- In foreign country, customs clearance takes time
- Hampering of work due to blasting etc wastage of time during transportation of materials etc.
- Reference axis and bench marks availability.
- Time of flood occurrence and max. flood level to decide the location machinery and parts to be placed.
Chapter 13
Operation and Maintenance Gates and Hoists

1.0 General:
Proper maintenance of Hydraulic gates and hoists is very important for satisfactory operation of Gates and to achieve the envisaged benefits from the project. For systematic operation and maintenance of the gates and their operating equipment, the availability of comprehensive Operation and Maintenance manual for the equipment is essential.

2.0 O&M Manuals
The O&M Manuals for Hydraulic gates and hoists normally should include the following:-
- The design features of various components.
- Particulars of bought-out items and source of availability with addresses and phone Nos.
- Operating instructions.
- Type of lubrication oil and grease to be used and its availability.
- Schedule of maintenance and repairs.

The above are prepared for each hydraulic gate installation and the operation staff shall be made well conversant with them and trained for the job.

3.0 Need for Maintenance
Gated structures need regular maintenance with inspection and monitoring. If faithfully followed under competent management, structures can give totally reliable service long after their initial designed life cycle. For proper maintenance, the steel structures must be periodically inspected. Failure of gates in most of the cases happens due to:
- Non-judicious choice of factor of safety at design stage to account for unforeseen forces.
- Loss of cross-section and strength of members due to near absence of preventive maintenance program.

Corrosion is the biggest culprit causing loss of cross-section of gate components and thereby reducing load carrying capacity of members. Corrosion implies destruction of metal by electro-chemical or simple chemical action.

In order to prevent long term structural damage, corrosion must be controlled through a program of inspection, evaluation and preventive maintenance. Corrosion being the primary reason of gates failure shall be focus of preventive methods adopted to prolong the economic life of steel structural components. There are various detectors like ultrasonic equipment, magnetic crack detectors, nuclear flow detectors and X-Ray detectors which can show the depth of corrosion damage, but the extent to which the tensile strength has been reduced by corrosion could only be found by subjecting an existing piece to various laboratory tests.
Rust is permeable to air and water, therefore the interior metallic iron beneath a rust layer will continue to corrode. Rust prevention thus requires coatings that preclude rust formation.

4.0 Operation and Maintenance of Gates and Hoists

The list of parts involved in maintenance and operation of gates and hoists generally are as follows:

4.1. Vertical Lift Gates:

i. Embedded parts:

- Sill beam assembly
- Roller track
- Seal seat / Upstream Guide
- Top seal seat and side guide
- Dogging arrangement

ii. Gate Parts:

- Skin plate Assembly
- End Verticals or End box
- Horizontal girders
- Vertical Stiffeners
- Roller assembly
- Seal Assembly
- Side guide assembly

iii. Lifting Arrangement

4.2. Radial Gates:

i. Embedded Parts:

<table>
<thead>
<tr>
<th>Common anchorages (Bonded Anchorages)</th>
<th>Independent anchorages (Un-bonded Anchorages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sill beam Assembly</td>
<td>Sill beam assembly</td>
</tr>
<tr>
<td>Wall plate Assembly</td>
<td>Wall plate assembly</td>
</tr>
<tr>
<td>Horizontal Anchor Rods</td>
<td>Anchor girders</td>
</tr>
<tr>
<td>Trunnion Girder</td>
<td>Load Anchors / Tie flats</td>
</tr>
<tr>
<td>Trunnion girder chairs</td>
<td>Yoke girders</td>
</tr>
<tr>
<td>Thrust block (If tie between trunnion is not used)</td>
<td>Rest plate</td>
</tr>
<tr>
<td></td>
<td>Thrust block (If tie between trunnion is not used)</td>
</tr>
</tbody>
</table>
## ii. Gate Leaf

<table>
<thead>
<tr>
<th>Common anchorages (Bonded Anchorages)</th>
<th>Independent anchorages (Un-bonded Anchorages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin plate</td>
<td>Skin plate</td>
</tr>
<tr>
<td>Side guide and seal assembly</td>
<td>Side guide and seal assembly</td>
</tr>
<tr>
<td>Vertical stiffeners</td>
<td>Vertical stiffeners</td>
</tr>
<tr>
<td>Horizontal Girders</td>
<td>Horizontal Girders</td>
</tr>
<tr>
<td>Horizontal Girder Bracings</td>
<td>Horizontal Girder Bracings</td>
</tr>
<tr>
<td>Arm Assembly</td>
<td>Arm Assembly</td>
</tr>
<tr>
<td>Trunnion</td>
<td>Trunnion</td>
</tr>
<tr>
<td>Trunnion pin</td>
<td>Trunnion pin</td>
</tr>
<tr>
<td>Trunnion Bush</td>
<td>Trunnion Bush</td>
</tr>
<tr>
<td>Trunnion Bracket</td>
<td>Trunnion Bracket</td>
</tr>
<tr>
<td>Tie between trunnion or</td>
<td>Tie between trunnion or</td>
</tr>
<tr>
<td>Thrust block</td>
<td>Thrust block</td>
</tr>
<tr>
<td>Lifting Bracket</td>
<td>Lifting Bracket</td>
</tr>
</tbody>
</table>

### 4.3. Rope drum Hoists:

#### A. For Vertical Lift Gates:
- Drive Unit Assembly
- Gear Box Assembly
- Hoist Supporting structures etc.

#### B. For Radial Gates:

<table>
<thead>
<tr>
<th>Upstream Suspension</th>
<th>Down Stream Suspension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Unit Assembly</td>
<td>Drive unit assembly</td>
</tr>
<tr>
<td>Gear box assembly</td>
<td>Gear box assembly</td>
</tr>
<tr>
<td>Hoist bridge</td>
<td>Fixed end support</td>
</tr>
<tr>
<td>Lifting arrangement</td>
<td>Hoist chasis</td>
</tr>
<tr>
<td></td>
<td>Line shaft support girder</td>
</tr>
<tr>
<td></td>
<td>Dial and Dial Assembly etc.,</td>
</tr>
</tbody>
</table>

## 5.0 Operation and Maintenance Schedule& Checks

Operating personnel are required to be properly trained and sufficiently experienced so that they can use their initiative and judgment based on their past experience for situations which may arise during operation. Day to-day experience on operation and difficulties if any, encountered should be faithfully recorded in the log book of gates.
so as to be available for studying the behavior of various structures and equipment. Detailed instructions for inspection and normal maintenance and repairs of gate installation should be given in operation and maintenance manual. However, for carrying out special repairs to gates if any, it is advisable to refer to Experts to execute. Inspection and maintenance experience are compiled in the form of History register of any installation so as to be useful for future designs, investigation of any failure, improper and unusual operation of gates. All such observations shall be recorded in the gates History register maintained for this purpose.

Once the gates have been erected, following precautions/ checks are to be taken before Dry - testing of Gates. The dry testing of the gates is normally done before the wet testing and during dry testing the gate is not subjected to any hydro static loading:

- Checking of all critical dimensions and proper seating of gate over embedded parts is to be ensured. Record of readings may be maintained for future reference.
- Worm reducer, plumber blocks, trunnion pin, gate wheels and gear wheels should be lubricated.
- Removal of temporary supports if any.
- Checking of weld between horizontal girders, arms and trunnions, tees and horizontal girders, cross girders and hoist bridge girders, final welding of lifting bracket etc., and are to be welded if left over. A comprehensive check list is to be maintained.
- Checking tightness of bolts between trunnion with arms and trunnion with horizontal girders, lock plate bolts of trunnion pin, wire rope clamp bolts and other bolts if used are to be tightened properly if loose.
- In case of unbounded anchorage one has to ensure the expansion of tie flats and yoke girder under load.
- The gates are to be inspected thoroughly for projections, temporary supports coming in the way of gate movement and excess concrete are to be removed if any.
- All the rubber seals are to be made wet before lowering the gate preferably with water to reduce heat generated between seal and seal seat and ensure fixing of all bolts and mouldings of site joints.
- Light test may be conducted for checking gap between seal and seal seat.
- All weld tests are to be conducted.

5.1 Maintenance schedules for gates and hoists

(A) Radial Gates

Monthly maintenance:

- Seals and seal seating shall be inspected for leakages. Locations of excessive leakages shall be recorded for taking remedial measures.
- Excessive or wide spread leakages if any shall be reported to Engineer – in charge and remedial measures like tightening of bolts is to be carried out. Further adjustment is carried out during annual maintenance or necessary plan for replacement of parts shall be initiated and carried out before floods.

- If leakage is so much that immediate repair is to be considered and seals are to be repaired or to be replaced by using stop log gates.

- Remove all dirt, girt, etc., from trunnion assembly and lubricate trunnion bearings of the gate with suitable water resisting grease.

- More concentration is to be given for checking of welds:
  - Between yoke girder web and tie flats.
  - Between trunnion and tie between turnnion.
  - Lifting bracket and gate.

**Quarterly Maintenance:**

The maintenance shall preferably be carried out once in three months but not less than thrice in a year including pre- monsoon and post monsoon maintenance. During this maintenance the following checks shall be done:

- All the nuts and bolts of trunnion assembly and its anchorages shall be checked for tightness.

- Check all the welds for soundness and rectify defects; if any.

- Check welding between latching bracket and skin plate with help of magnifying glass for cracks / defects and rectify the defects.

- Clean all drain holes including those in end arms, horizontal girders trunnion and pulley blocks.

- Check all nuts and bolts for tightness and tighten them; if loose.

- Check upstream face of skin plate for pitting, scaling and corrosion. Scale formation shall be removed, pitting shall be filled with weld and ground, and Corroded surface shall be cleaned and painted. In case of gate not being raised every quarter, these can be carried out in annual maintenance.

- The wheel bearings and guide rollers shall be lubricated.

- The seal shall be checked for damages, if damaged, shall be replaced.

- The guide assemblies, wheel assemblies and sealing assemblies shall be cleared of girt, sand or any other foreign material.

- General cleaning is to be done for the following:
  - Trunnion girders / Yoke girders.
  - Trunnion brackets, trunnions, arms and horizontal girders.

- Lubrication is to be attended for:
Bearing at Gate wheels, trunnion bushes, hoist pulleys and pins provide in Hoist Bridge at hoist level and gate.
Rope drum shaft Plummer blocks.
Line shaft Plummer blocks.

- Check tightness of all coupling bolts of motor to work reducer and line shaft. If required they may be tightened.
- Care shall be taken to check the condition of holding rope with rope socket and balancing of gate is to be observed and if necessary adjusted.

**Annual maintenance:**

The following additional checks or maintenance shall be carried out in addition to checks mentioned under quarterly maintenance.

- All the embedded parts shall be checked for defects / damages and shall be rectified where ever noticed and exposed parts shall be painted for longer life.
- The sill beam and guides shall be cleared for all girt, sand etc.,
- The wire ropes shall be checked for equal tension. If broken strands are noticed, the wire rope shall be replaced. Fixing of rope sockets also shall be checked.
- The wire rope shall be greased.
- The guide roller pins shall be lubricated and ensure for its rotation.
- Check the condition of rubber seal. If damaged, replace the seals.

All bolts and nuts holding rubber seals shall be tightened. Adjust seal if leakages are found at local points

**(B) Vertical Lift fixed wheeled**

These gates are provided for controlling water discharge for flood control, water supply, irrigation and power generation etc., The gates shall be thoroughly inspected for cracks, defects or damages periodically. A schedule of maintenance is proposed which may be adopted with modifications, if required, to suit site conditions and use of gate.

**Monthly maintenance:**

- Wheels are to be greased properly.
- Check wheel rotation by hand for free rotation.
- Balance points same as Radial Gates

Nature of Quarterly Maintenance and Annual Maintenance for vertical lift gates is same as for Radial gates and the re-painting of the gates shall be carried out at intervals to be decided on the basis of painting schedule of the gates. Similarly, the inspection, testing and maintenance of the hoist shall also be carried out periodically as per the maintenance manual.
For installation with large number of gates ie., more than 10Nos. it is very difficult to take up maintenance in one go in the lean period available. Hence the No. of gates divided into 3 groups and thorough maintenance of welding, painting shall be carried out at least one in three to five years depends on requirement.

(C) Electrically Operated Fixed Hoists for Radial Gates and Vertical Gates

The periodical maintenance of bought out items like motor, brakes, radicons, etc., shall be carried out as per the manufacturer’s advice / maintenance schedule.

Daily Inspection:

- Entrance to all hoist platforms shall be kept locked. All keys shall remain with the shift supervisor.
- A cursory daily inspection shall be made of hoist and gate to ensure that there is no unusual happenings and ensure operation when called for.

Monthly Maintenance:

- Clean the dust of all hoisting machinery and hoist platform.
- Check oil level in gear boxes and replenish wherever required with oil of proper grade.
- Apply grease of suitable grade by grease gun through all the greasing nipples and replace grease nipple if missing.
- Lubricate all bearings, bushings, pins, linkages, etc.,
- Check all the fuses on power lines and ensure closing of panel board covers not to entry of dust and moist.
- All bolts and nuts on gear boxed, hoist drum and shaft couplings should be checked for tightness.
- Check the supply voltage.
- Check the expansion provision in case of independent anchorages.
- Starters should be cleaned free of moisture and dust.
- Each individual contactor should be examined to make sure that it operated freely.
- All wearing parts should be examined and take remedial action to avoid reoccurrence.
- The magnet faces should be cleaned if the contacted Hum.
- Examine all connections to see that no wires are broken and no connections are loose.
- Clean the surface of the moving armature and magnet cone which comes together when the contractor closes, free of dust or grease of any kind.
• The contact tips should be kept free from burns or pits by smoothening with fine sand paper or emery paper.

• Replace the contact tips which have worn half – way.

• Do not lubricate the contacts.

• Quarterly Maintenance:

• Carry out all those listed for monthly maintenance.

• Drain sample gear oil from each of the gear boxes; If excessive Foreign particles or sludge is found, the oil shall be drained, flushed and filled with new oil.

• All the geared couplings shall be greased.

• Raise and lower the gate by hoist motor and check for smooth and trouble free operation of gate without excessive vibration.

• Observe current drawn by motor at the time of lifting and check if it is more than normal. If so, stop the hoist and investigate the cause and rectify.

• Check for condition of painting of various components and remove rust wherever noticed and repaint the portion after proper cleaning as per painting schedule.

• Check Electrical connection and wiring:
  a. From supply point to main switch.
  b. Main switch to starter.
  c. Starter to motor.
  d. Contact points of starter.
  e. From starter to all lighting points, availability of bulbs and its glowing.

Annual Maintenance:

• The annual maintenance shall be combined with one of the quarterly maintenance; the following shall be carried out in addition to those mentioned under Quarterly Maintenance.

• All trash, sediments and any foreign material shall be cleared off the lifting rope and lifting attachment.

• All ropes shall be checked for wear and tear and if broken wires more than permissible or marked corrosion is noticed, the rope shall be replaced. Refer IS code for maintenance of wire ropes.

• All wire ropes shall be checked and all visible oxidation shall be removed.

• All wire ropes shall be greased with cordium compound or equivalent brand.
- Adjust the rope tension of wire if unequal.
- Check the overload relays and limit switches for proper functioning.
- Check tightens of all nuts & bolts, soundness of welds. All bolts shall be tightened and defective welding must be rectified.
- Check the pulleys, sheaves and turn buckles for soundness.
- Check the limit switches and adjust for design limits duly operating.
- The effectiveness of the brakes shall be checked by stopping the gate in intermediate operation duly raising and lowering operations. The brakes shall be adjusted; if needed.
- When the gate is operated, there should not be any noise or chatter in the gears.
- Check for all gears and pinions for proper mesh, uneven wear and adjust for proper contact and grease the gears.
- Repaint the hoist components, hoisting platform and its supporting structures after a time interval depending upon the painting schedule.

5.2 General maintenance on Radial Gates / Vertical Gates

It shall be done every third and sixth years in accordance with IS7718, IS: 10096 (part 3) latest. In addition to check mentioned under annual, following checks will be carried out:-

(A) For every three years:
- Check seals for damage and alignment;
- Check seal bolts for damage;
- Check for damage to wire rope;
- Check for any damage to pulleys and pins;
- Check bearings for damages;
- Check gears and pinions for damage;
- Check Plummer blocks for damage;
- Check for any painting damage.

(B) For every Six years:

In addition to check mentioned under annual, following checks will be carried out every six year.

(a) Check for damaged / cracked welds at the following:
   a. Skin plate joints
   b. Splice joints
   c. Hoist bridges
   d. Arms, Horizontal girders and bracings
   e. Tie flats
f. Trunnion girders / Yoke girders
g. Trunnion brackets
h. Tie between trunnion

(b) Check Wheel assemblies for the following:
   a. Any breakage
   b. Freezing
   c. Corrosion
   d. Misalignment

(c) Check seal seats, seal tracks, side guides for the following:
   a. Any damages
   b. Corrosion
   c. Pitting
   d. Misalignment

(d) Check Hoist Bridge and Platforms
   a. For any welding cracks
   b. Bent or loose bolts and nuts
   c. Cracks in the bending or motors
   d. Rope drum etc.,

5.3 Lubrication Schedule for gates and Hoists

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parts to be lubricated</th>
<th>Mode of Lubrication</th>
<th>Lubricant</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Trunnion pin bush bearing</td>
<td>Pressure grease gun</td>
<td>Servo gear – 20 or bearing grease</td>
<td>Once in three months as per site conditions</td>
</tr>
<tr>
<td>2</td>
<td>Gate Wheel bearings</td>
<td>Pressure grease gun</td>
<td>Servo Gear – 20 or Bearing Grease</td>
<td>Once in three months as per site conditions</td>
</tr>
<tr>
<td>3</td>
<td>Guide rollers</td>
<td>Pressure grease gun</td>
<td>Bearing Grease</td>
<td>Once in three months as per site conditions</td>
</tr>
<tr>
<td>4</td>
<td>Hoisting wire rope</td>
<td>Hand applied</td>
<td>Servo Gear – 120 or Cordium Compound</td>
<td>Once in a year before monsoon sets in</td>
</tr>
<tr>
<td>5</td>
<td>Worm reducer</td>
<td>Oil bath</td>
<td>Servo HP - 30</td>
<td>Indicator level to be maintained always</td>
</tr>
<tr>
<td>6</td>
<td>Spur Gear Bearings</td>
<td>Pressure grease gun</td>
<td>Bearing Grease</td>
<td>Once in three months as per</td>
</tr>
<tr>
<td></td>
<td>7 Line shaft bearings</td>
<td>Pressure grease gun</td>
<td>Bearing Grease</td>
<td>Once in six months as per site conditions</td>
</tr>
<tr>
<td>----</td>
<td>------------------------</td>
<td>---------------------</td>
<td>---------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>8 Gear Wheels</td>
<td>Hand applied</td>
<td>Chassis Grease</td>
<td>Once in six months as per site conditions</td>
</tr>
<tr>
<td></td>
<td>9 Drum shaft</td>
<td>Pressure grease gun</td>
<td>Chassis Grease</td>
<td>Once in three months as per site conditions</td>
</tr>
<tr>
<td></td>
<td>10 Lifting Arrangement and buckles</td>
<td>Hand applied</td>
<td>M. P. Grease</td>
<td>Once in six months as per site conditions</td>
</tr>
<tr>
<td></td>
<td>11 Hand operation mechanism and other relating parts</td>
<td>Hand applied</td>
<td>Servolin - 140</td>
<td>Once in three months as per site conditions</td>
</tr>
</tbody>
</table>

5.4 Do’s and Do not’s for Operation and Maintenance of Gates

<table>
<thead>
<tr>
<th>DO’s</th>
<th>Don’ts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Authorised Personnel should be allowed near control Pane for operation of gates.</td>
<td>1. Un authorized persons should not be allowed to operate gates.</td>
</tr>
<tr>
<td>2. Technically qualified or trained operators should be allowed to operate gates.</td>
<td>2. Unqualified persons technically should not be allowed to operate gates.</td>
</tr>
<tr>
<td>3. Operate the gates only when there is required power supply as per the design is available.</td>
<td>3. Not to operate gates during low voltage period.</td>
</tr>
<tr>
<td>4. Adjust the brakes when the gate is lowered fully and rest on sill.</td>
<td>4. Not to adjust the brakes when gate is not dogged.</td>
</tr>
<tr>
<td>5. Attend maintenance during pre-monsoon season</td>
<td>5. Not to adjust the brakes when gate is not dogged.</td>
</tr>
<tr>
<td>6. Use proper tools for attending repairs / adjustments</td>
<td>6. Maintenance works should not be attended during rains.</td>
</tr>
<tr>
<td>7. Conduct Dry test before putting into operation</td>
<td>7. Do not operate gates without Dry testing.</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>---</td>
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</tr>
<tr>
<td>9.</td>
<td>Insulate damaged electrical wiring, which are exposed to atmosphere</td>
</tr>
<tr>
<td></td>
<td>9. Do not allow any persons to operate gate if Bare wires are seen</td>
</tr>
<tr>
<td>10.</td>
<td>Protect Hoist gear box and motors from rains</td>
</tr>
<tr>
<td></td>
<td>10. Not to keep gear box cover open after daily maintenance</td>
</tr>
<tr>
<td>11.</td>
<td>Ensure wire rope tightness on either side equally before operating gate</td>
</tr>
<tr>
<td></td>
<td>11. Not to operate gate when the wire rope is slacked</td>
</tr>
<tr>
<td>12.</td>
<td>Safety precautions should be taken during maintenance works</td>
</tr>
<tr>
<td></td>
<td>12. Not to wear loose dresses during operation of gates</td>
</tr>
<tr>
<td>13.</td>
<td>Cut off power supply after operation of gates</td>
</tr>
<tr>
<td></td>
<td>13. Do not allow power supply to motors when it is not at all required</td>
</tr>
<tr>
<td>14.</td>
<td>Check connections and functioning of limit switches before operation</td>
</tr>
<tr>
<td></td>
<td>14. Advised not to operate gate if limit switches are not functioning</td>
</tr>
<tr>
<td>15.</td>
<td>Ensure before operation that no foreign materials fall in the gear teeth</td>
</tr>
<tr>
<td></td>
<td>15. Not to switch on Hoist motors if foreign material found in between teeth of gear wheels</td>
</tr>
<tr>
<td>16.</td>
<td>Check tightness of Plummer block, drive unit, line shaft, coupling bolts</td>
</tr>
<tr>
<td></td>
<td>16. Do not operate gate if any bolts of Plummer block and coupling bolts are found loose</td>
</tr>
<tr>
<td>17.</td>
<td>Ensure no foreign particles stuck up in between roller and roller track/ wall plate and rubber seals etc.,</td>
</tr>
<tr>
<td></td>
<td>17. Not advised to operate gates if foreign material found in between rollers and roller track and wall plates and rubber seals etc.,</td>
</tr>
</tbody>
</table>
Chapter 14
Operation and Maintenance of Radial Gates

It should be ensured that the three-phase supply is available from M.S.E.B. If it is not available start the standby generator and switch over to generator supply. In any case the electrical motor should be allowed to run on two phase supply.

Switches, relays etc. should be checked before operation.
The gates should be operated by an experienced and qualified operator, who should come on duty in sober condition.

The gates should be operated only after receiving orders from the competent authority in charge of the gates. Before the gates are operated, all the tools, such as spanners, oil cans etc. should be removed from the gates.

Before the gates are operated the villagers living on the bank of river on the downstream side should be suitably warned about the floods, which will occur as a result of water being released from the gates.

Before operating the gates it should be ensured that the brake is working properly.

The gate operation schedule fixed by the Central Designs Organization Nashik for each dam is given in Appendix – E and the same should be followed.

Avoid operating the gates at a particular distance where vibrations noticed are more and obtain instructions from C.D.O. Nashik.

Electrical operation:-

Normal Schedule of operation of gates.

To derive uniform intensity of discharge, so as to achieve satisfactory E.D. and to avoid three-dimension flow, uniform operation of gates becomes obligatory. A schedule of operation of spillway gates based on theoretical considerations and composite model studies, has to be furnished to the maintenance engineers of the dam. The normal sequence of operation of gates shall be as follows.

1) Any time during the operation, the differential gate openings should not differ by 0.5 Meters or more.

2) End gates are to be opened first and starting from the centre the other gates are to be opened in a symmetrical manner, through gradual increase in opening as above.
3) For releasing extra floods, gates in other bays should be opened in the same fashion as above.
4) If bays in the spillway portion are two or more, the sequence in which the same bays should be operated for letting out floods shall be based on model studies.
5) While closing the gates, the operation should be reversed.
6) The bay operated last while letting out floods should be operated first during closing operation.

**Raising the gate**

After getting order from the engineer in-charge or from the competent authority to raise the gate, proceed as follows:
1) Put the main switch “ON”
2) Actuate the control switch “FORWARD”. Then the gate will start rising up gradually at the speed of about 450 mm per minute.
3) For partial opening, actuate the “STOP” push button, when the gate reaches the desired height.
4) For full opening of the gate, the present limit switch will trip automatically, thereby disconnecting the supply and stopping at its full height.

**Lowering of the gate**

After getting from the competent authority order to lower the gate, proceed as follows:
1) Put the main switch “ON”
2) Actuate the control switch “REVERSE” or “CLOSE”. The gate will start lowering down at a speed of 450 mm/min. The limit switch will trip the supply of the motor, when the gate reaches its lowest position.
3) While lowering, if the gate is reached at a certain required level, operate the “STOP” push button to stop the gate at the intermediate position.
4) Switch OFF the main switch.
5) Lock the cover of the drive unit.

**Stand – by supply**

Normally diesel-generating sets are provided at the site for use in the event of failure of the M.S.E.B. supply. In the case of a generating set based on electrical batteries, it should be ensured that the batteries are kept well charged, so as to assure quick starting of
the generator engine. All the ammeters, volt meters should be checked and in working condition. Phase line indicator should be provided to ensure that all the three phases are getting supply. These set should be tested well in advance before starting gate operation.

**Record of operation**

Operation record is kept in two parts.
Part – I order book & Part – II Log book, Specimen forms of both the books are given in Appendix –C.
Necessary entries should be made in the order book and log book for each operation of the gate.

**Manual Operation**

The radial gates can be operated manually for emergency in the event of electric failure. Even two labours can operate the gate easily at a speed of 10 mm/min.

Since the operating of gates by manual labour will take long time and is a laborious process, an adequate number of labours should be deployed for this purpose in case of opening the gates in emergency.

For manual operation, proceed as follows
1. Remove the pipe socket. This prevents operation by electric power.
2. Release the brake by operating hand lever of the electro-magnetic – brake.
3. Engage the handle with the input shaft of the speed reducer / reduction unit.
4. Rotate the input shaft with handle in appropriate direction to lift or lower the gate.
5. After raising or lowering the gate to required level, bring the hand lever of electro magnetic brake to it’s original position. Remove the handle and replace the pipe socket on input shaft of the reduction unit.
6. Speed: Efforts of two operators at a time are sufficient to lift the gate. Taking into consideration 10 R.P.M. of handle, it will take one hour to lift 12 x5-Meter size gates by 0.6-Meter approx.

**Gate in Locket position**

In the following circumstances the gate should be opened to it’s full height and kept in locked position.
1) When there is No storage against the gate.
2) When the gate is required to be kept open to its full height for hours together to release the tension in wire ropes as well as load on the brake shoe.
Trouble Locating Chart

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Trouble</th>
<th>Probable Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Gate does not raise</td>
<td>1) No supply</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Obstruction in rubber seals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3) Obstruction in guide rollers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4) Fault in electric motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5) Fault in wiring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6) Blown out fuse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7) Brake shoes jammed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8) Wire rope broken</td>
</tr>
<tr>
<td>II.</td>
<td>Gate vibrates</td>
<td>1) Lack of lubricants in trunion and guide rollers</td>
</tr>
<tr>
<td>III.</td>
<td>Motor does not function</td>
<td>1) No supply</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Starter not in order</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3) Blown out fuses in switches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4) Hand operation not removed low voltage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5) All fuses are not working</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6) All fuses are not working</td>
</tr>
<tr>
<td>IV.</td>
<td>Starter not working</td>
<td>1) No supply to starter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Fixed and moving contacts not in order</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3) Limit switch engaged</td>
</tr>
</tbody>
</table>

INSPECTION AND MAINTENANCE OF RADIAL GATES

No pieces of equipment, however well designed and sturdy, will run efficiently unless it is well kept and maintained. Therefore the details of inspection to be done and the schedule of maintenance are given here.

Periodical Inspection

In order to detect normal wear and tear, defects if any, periodical inspection of gate installation should be carried out. The periodical inspection of these gates and hoist should be done as and when necessary. But at least twice a year and corresponding to the periods when the water level in the reservoir is as it's highest/lowest levels. In short pre-monsoon and post-monsoon inspections should be done and the following checks should be done and the following checks should be exercised.
### Inspection of Radial Gates (Anchor Girder, Trunion Brackets and Anchorages)

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Check the nuts and bolts of</td>
<td></td>
</tr>
<tr>
<td>a) Anchor girder chair</td>
<td></td>
</tr>
<tr>
<td>b) Trunion brackets to anchor girder</td>
<td></td>
</tr>
<tr>
<td>c) Nut of horizontal and vertical anchorages</td>
<td></td>
</tr>
<tr>
<td>d) Trunion pin lock plates</td>
<td></td>
</tr>
<tr>
<td>e) Tir channels of bars</td>
<td></td>
</tr>
<tr>
<td>2) Check whether the anchor girder is covered so that water does not accumulate in the slots</td>
<td></td>
</tr>
<tr>
<td>3) Check whether flexible sheath cover is provided to prevent entry of debris in the trunion assembly</td>
<td></td>
</tr>
</tbody>
</table>
| Check for proper functioning
| ---------------Do------------- |
| Cover with 3 mm thick MS plate, if not already covered |
| Cover it, if not already covered |

### End Arms

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Check welding joints of end arms to horizontal girder (with magnifying glass preferably) on joints/stiffeners</td>
<td></td>
</tr>
<tr>
<td>2) Check whether drain holes drilled in the end arm are clear</td>
<td></td>
</tr>
<tr>
<td>3) Check nuts and bolts of end arms to horizontal girder joints</td>
<td></td>
</tr>
<tr>
<td>Check for crackers; Rectify accordingly</td>
<td></td>
</tr>
<tr>
<td>Check them if choked</td>
<td></td>
</tr>
<tr>
<td>Check for tightness</td>
<td></td>
</tr>
</tbody>
</table>

### Horizontal Girders

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Check welding of</td>
<td></td>
</tr>
<tr>
<td>a) Stiffeners of horizontal girder</td>
<td></td>
</tr>
<tr>
<td>b) Horizontal girder to ‘T’ stiffeners of skin plate</td>
<td></td>
</tr>
<tr>
<td>c) Locking arrangement brackets of skin plates</td>
<td></td>
</tr>
<tr>
<td>2) Check drain arrangement of horizontal girder</td>
<td></td>
</tr>
<tr>
<td>Check for crack and other defects and rectify accordingly</td>
<td></td>
</tr>
<tr>
<td>Check for weld crack</td>
<td></td>
</tr>
<tr>
<td>Clear them if choked</td>
<td></td>
</tr>
</tbody>
</table>
## Skin Plate Assembly and Rubber Seals

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Check the following welding joint ‘T’ and skin plate</td>
<td>Check for crack and other defects and rectify if necessary</td>
</tr>
<tr>
<td>a) Vertical joints of skin plate from upstream side and downstream side</td>
<td></td>
</tr>
<tr>
<td>b) Lifting bracket to skin plate</td>
<td></td>
</tr>
<tr>
<td>2. Check the skin plate for pitting, scaling and corrosion on upstream side</td>
<td>Check welding with magnifying glass and rectify if required</td>
</tr>
<tr>
<td>Scaling formation should be removed pitting should be filled with weld / and grinded for finish. For corrosion clean it and apply paint</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>If condition is poor replace it, check the cause of undue wear before replacement.</td>
</tr>
<tr>
<td>a. Check the condition of the side and bottom rubber seal</td>
<td>Check for wear and tear, tightness and replace if required.</td>
</tr>
<tr>
<td>b. All the nuts and bolts fixing rubber seals to skin plate</td>
<td>Removed it</td>
</tr>
<tr>
<td>c. Check if there is any undesirable material in between seal and brass plate seal and skin plate</td>
<td>Study the cause of deformation and rectify it.</td>
</tr>
<tr>
<td>d. Check the deformation of seal</td>
<td></td>
</tr>
<tr>
<td>e. Check whether there is abnormal abrasion on seal seat</td>
<td></td>
</tr>
</tbody>
</table>

## Inspection of Hoist Wire Ropes, Required Plates etc

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Check condition of wire rope</td>
<td>If the condition is poor, then replace the wire rope and if 10% broken wires are within the length of one meter and more than 20% broken wires within the length of 10 Meters, wire rope should be replaced.</td>
</tr>
<tr>
<td>b) Check equalizer plate assembly and sockets</td>
<td>Check condition of pin and every year those should be removed, cleaned and refitted after lubrication.</td>
</tr>
<tr>
<td>c) Check lifting bracket pin</td>
<td>Check for rusting, jamming in the turn buckles.</td>
</tr>
<tr>
<td>d) Check tension in wire ropes</td>
<td>Adjust both the wire ropes for equal tension.</td>
</tr>
<tr>
<td>e) Check if ends of wire ropes are properly fastened to drum.</td>
<td>If found loose, tighten the studs provided for</td>
</tr>
</tbody>
</table>
### Gear Train Assembly

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Check condition of gears and pinions.</td>
<td>Check uneven wear and contact, adjust properly.</td>
</tr>
<tr>
<td>b) Check position of gears and pinions.</td>
<td>Bring them to correct position, if found shifted to either side.</td>
</tr>
<tr>
<td>c) Check shafts and coupling used for connecting drive unit and gear train.</td>
<td>Visual inspection and coupling nuts to be checked.</td>
</tr>
</tbody>
</table>

### Seal Beam and Wall Plates

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Check the following joints</td>
<td>Check for crack and other defects and rectify.</td>
</tr>
<tr>
<td>a) Wall plate to seal beam</td>
<td>Rectify the joints using proper welding electrodes</td>
</tr>
<tr>
<td>b) Two segments of wall plates</td>
<td>-------Do-------</td>
</tr>
<tr>
<td>c) Brass / stainless steel cladding to MS plate.</td>
<td>Pitting to be filled in by welding or metallic plate. Rusted portion should be painted after cleaning.</td>
</tr>
<tr>
<td>2) Check wall plate and sill beam for pitting and rusting</td>
<td></td>
</tr>
</tbody>
</table>

### Guide Roller

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Check the roller for its’s movement</td>
<td>Make up roller free if jammed</td>
</tr>
<tr>
<td>2) Check the nuts, bolts and guide roller</td>
<td>Check for wear and tear and tightness</td>
</tr>
</tbody>
</table>

### Locking Arrangement

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Check whether the locking device function well</td>
<td>Check the function by operating lever.</td>
</tr>
<tr>
<td></td>
<td>Rectify the same if movement is not smooth.</td>
</tr>
<tr>
<td>2) Check the nuts, bolts and studs of locking devices</td>
<td>Tighten the bolts if required</td>
</tr>
<tr>
<td>3) Check the drain holes</td>
<td>Clean them if required</td>
</tr>
</tbody>
</table>
**Drive Unit**

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Check condition and foundation of</td>
<td>Replace worn out linear, adjust brake shoes carefully, so that both shoes hold the drum, when supply is cut off or both the shoes should</td>
</tr>
<tr>
<td>electro – magnetic brake</td>
<td>move out simultaneously if switched on. Brake drum and liner should always be free from grease, oil and etc.</td>
</tr>
<tr>
<td>b) Check all electrical connections of</td>
<td>Check for the loose connections, proper insulation (rats and crabs damage the insulation). Overload relay of the starter is to be adjusted</td>
</tr>
<tr>
<td>hoist motor, brake, starter limit switch</td>
<td>for correct position and should not be disturbed.</td>
</tr>
<tr>
<td>etc.</td>
<td></td>
</tr>
<tr>
<td>c) Check manual operation</td>
<td>------</td>
</tr>
<tr>
<td>d) Check condition of position</td>
<td>Check for it’s proper function and rectify</td>
</tr>
<tr>
<td>Indicator and all it’s accessories.</td>
<td></td>
</tr>
<tr>
<td>e) Check speed reducer/reduction unit</td>
<td>Check for smooth operation and check oil level</td>
</tr>
</tbody>
</table>

**Inspection of Nuts and Bolts**

<table>
<thead>
<tr>
<th>Points to be inspected</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Hoist frame</td>
<td>Check for wear and tear and tightness</td>
</tr>
<tr>
<td>b) Drive unit</td>
<td>Tighten if required or replace for</td>
</tr>
<tr>
<td>c) Gear boxes</td>
<td>Undo wearing.</td>
</tr>
<tr>
<td>d) Muff coupling</td>
<td>----Do----</td>
</tr>
<tr>
<td>e) Flange coupling</td>
<td>----Do----</td>
</tr>
<tr>
<td>f) Bearing housing</td>
<td>----Do----</td>
</tr>
</tbody>
</table>

**General Inspection**

**Check that:**

a) The gate operation should be trouble free and there should not be unusual sound.

b) On load (that is, when there is water) there should be no undue vibrations in gate and structure.

**Current Drawn by Motor**

Observe the current drawn by motor at the time of lifting of gate. If any excessive current drawn is noticed, operation of hoist should be stopped immediately and reason for the same may be investigated and rectified.
### Tolerable Current

<table>
<thead>
<tr>
<th>Size of Gate Meters</th>
<th>H.P. of Motor</th>
<th>Tolerable Current Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 x 8</td>
<td>10</td>
<td>10 to 15 Amps.</td>
</tr>
<tr>
<td>12 x 6.5</td>
<td>10</td>
<td>10 to 15 Amps.</td>
</tr>
<tr>
<td>12 x 5</td>
<td>5</td>
<td>5 to 7.5 Amps.</td>
</tr>
</tbody>
</table>

### Maintenance of Radial Gates

As regards maintenance of radial gates, particular attention may be paid to the following items:

1. Lubrication as per schedule
2. Wire ropes and
3. Painting

The details are as follows:

#### Schedule of Lubrication

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Part to be lubricated</th>
<th>Lubricant recommended</th>
<th>Approx. Qty/gate</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main reduction gear Drive unit assembly</td>
<td>Gear oil GX90 or equivalent</td>
<td>25 ml</td>
<td>Top up as when required change after three years</td>
</tr>
<tr>
<td>2</td>
<td>Small reduction unit of gate position indicator</td>
<td>MP grade grease No.2 or equivalent</td>
<td>10 Gms.</td>
<td>Apply every six months</td>
</tr>
<tr>
<td>3</td>
<td>Bushings in rope drum and all bearings</td>
<td>MP grade grease No.2 or equivalent</td>
<td>3 Kg</td>
<td>Apply every year prior to monsoon</td>
</tr>
<tr>
<td>4</td>
<td>Spur gear trains</td>
<td>MP grade grease No.150 or equivalent</td>
<td>5 Kg</td>
<td>Apply after every three months</td>
</tr>
<tr>
<td>5</td>
<td>Electric motor, bearings</td>
<td>MP grade grease No.2</td>
<td>As per Requirement</td>
<td>Apply after every two years</td>
</tr>
<tr>
<td>6</td>
<td>Electromagnetic brake hinges and pins</td>
<td>MP grade grease No.2</td>
<td>---Do---</td>
<td>Apply every three months</td>
</tr>
<tr>
<td>7</td>
<td>Equalizer plate assembly pins</td>
<td>MP grade grease No.2</td>
<td>---Do---</td>
<td>Apply every year prior to monsoon</td>
</tr>
<tr>
<td>8</td>
<td>Wire ropes</td>
<td>Cardium compound</td>
<td>35 kg</td>
<td>Apply every pre and post monsoon</td>
</tr>
<tr>
<td>9</td>
<td>Turn buckle and pins, lifting bracket pins</td>
<td>MP grade grease</td>
<td>2 Kg</td>
<td>Change every year prior to monsoon. Remove the pin Every year and lubricate</td>
</tr>
<tr>
<td>10</td>
<td>Guide Roller</td>
<td>MP grade grease</td>
<td>1 Kg</td>
<td>Change every six months</td>
</tr>
</tbody>
</table>
Maintenance of Wire Ropes

Maintenance of Wire Ropes means applying the cardium compound every year prior to monsoon.

Lubrication

In manufacture, wire ropes are fully lubricated (including fiber core and layers) to reduce internal abrasion, to exclude external moisture and delay corrosion. In service the initial lubricant will tend to dry out and therefore it is desirable to lubricate all ropes at regular intervals.

Lubricants

The lubricant employed should be free from all harmful substances, such as acids and alkalies. It should be of a light grade that may penetrate between the wires and strands of the rope being wiped off or absorbed by surface dirt.

Cardium compound is recommended as a lubricant.

Application

It is desirable that the rope be clean and dry. A jet of oil or wire brushing are some of the cleaning methods used preparatory to application of a lubricant.

An easy and effective method of applying a lubricant is to brush the lubricant on the rope. The brush is dipped into the lubricant and applied.

The lubricant may also be applied by hand with leather gloves. The method is especially good where a heavy, non-flowing lubricant is applied. It is desirable to heat the lubricant to get a smoother and better application.

Inspection of Wire Rope

The wire ropes should be inspected at regular intervals. Close examination will not only indicate, when it is time to put on a new rope, but it will also reveal many other things about the way the wire rope does it’s work and whether it is suited to the job. It should be

<table>
<thead>
<tr>
<th></th>
<th>Trunion pin</th>
<th>MP grade grease</th>
<th>1 kg</th>
<th>Change quarterly. Pin should be lubricated till grease squeezes out from the side. Gate should be lifted once or twice and pin again lubricated to ensure proper greasing.</th>
</tr>
</thead>
</table>

Note:- Specifications of required lubricants is given in above Table Lubricants of H.P./B.P./I.O.C. can be used.
ensured that the end of the wire rope on the lifting bracket is positively held in socket filled by zinc.

**Discarding a Wire Rope**

Generally a rope should be withdrawn from service, when it is considered that:

a) The loss of strength in the rope due to wear, corrosion or both is approaching one sixth of original strength

b) The loss of strength due to fatigue, surface embrittlement or cracked and broken wires of any kind is approaching one tenth of original strength.

c) The outer wires have lost about one third of their depth as a result of any kind of deterioration.

d) The outer wires are becoming loose and displaced for any reasons.

e) The rope has become kinked, distorted or damaged and a damaged piece cannot be removed.

f) Examination of rope leaves any doubt as to its safety for any reason whatsoever.

**Paints**

**Need of Painting**

Iron and steel structures are exposed to sun, rain, air and deteriorate due to corrosion. Once corrosion is set in, it works continuously eating the metal. Only 2 mm corrosion allowances has been provided in the design of gate. Therefore to protect the gate from deterioration, paints are used on the surface from upstream and downstream side.

For painting the gate parts I.S.14177 guidelines for Painting System for Hydraulic Gates and Hoist must be followed. Instruction in this I.S. regarding surface preparation, selection of paint and application of paints should be adopted as per I.S. 14177 year 1991.

**Recommended Paints**

In IS – 14177 paints can be recommended are epoxy type paints. However following paints can be recommended considering the past experience being their cost is less than epoxy paints.
Schedule of recommended paints is given below.

<table>
<thead>
<tr>
<th>Name of gate part to be painted</th>
<th>Paint recommended</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gate leaf upstream side</td>
<td>Anticorrosive Coal Tar Black Paint IS-290</td>
<td>Two coats once in a year or as required</td>
</tr>
<tr>
<td>2 Gate leaf downstream side and all other parts except hoist covers and tie bars</td>
<td>Do</td>
<td>Single coat once in two year depending upon the condition</td>
</tr>
<tr>
<td>3 Hoist covers of MS</td>
<td>Do</td>
<td>Once in a year</td>
</tr>
<tr>
<td>4 Railing pipes</td>
<td>Do</td>
<td>Once in a year</td>
</tr>
</tbody>
</table>

Note:-
1. Brass plates and rubber seals should not be painted.
2. Decorative type enamel paints are not recommended being corrosion resistance is main object of painting.

**Application**

Before painting, surface must be perfectly cleaned and free from moisture, dust, dirt, oil, grease etc. If surface shows cracks, it is advisable to scrap or burn old film.

The paint should be stirred well before applying. Painting can be done by brush or spray gun.

**Precautions**

The Tar based anticorrosive paints have pungent smell and painter get allergic action due to this bad smell. It is suggested that while using this paint, painter should be provided with hand gloves and goggles for better efficiency.

**Inspections & Maintenance of Radial Gates**

1) Any discriminations or derivations if experienced (viz. leakage, obstructions, obstacles, unusual sound or noise, jamming, fast or slow operation of radial gates) should be noted during recording of operation of radial gates.

2) Calibration of all Meters and indicators should be done before and after monsoon.

3) Communication and electrical facility kept ready at all times with standby arrangement in the event of any unpredicted incidence.

In the event of any emergency alarming and lightning signals should be ready in addition to other communication facility with nearest controlling office.
4) A set of tools, accessories and handles (for manual operation) should be kept ready on radial gate site.

5) Only technically experienced and legally designated staff should always do all Radial gate operation, repairs and maintenance.

6) Strict security should be exercised for preventing any trespassers and unauthorized person on main dam. (Bridge and on dam)

7) Water lubrication system for rubber seal is checked for proper functioning.

### Tools

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Double ended spanner set 6 mm to 38 mm</td>
<td>2 sets</td>
</tr>
<tr>
<td>2.</td>
<td>Ring spanner sets 5 mm to 30 mm</td>
<td>2 sets</td>
</tr>
<tr>
<td>3.</td>
<td>Screw driver 150 mm, 200mm and 300 mm</td>
<td>2 each</td>
</tr>
<tr>
<td>4.</td>
<td>Anchor rod spanner as per size of anchor rod nut (40 mm to 100mm)</td>
<td>1 No.</td>
</tr>
<tr>
<td>5.</td>
<td>Spanner for rubber seal (Box and ring)</td>
<td>4 each</td>
</tr>
<tr>
<td>6.</td>
<td>Spanner for Trunion bracket bolts</td>
<td>1 No.</td>
</tr>
<tr>
<td>7.</td>
<td>Grease gun 20 liter capacity</td>
<td>1 No.</td>
</tr>
<tr>
<td>8.</td>
<td>Hand grease gun</td>
<td>1 No.</td>
</tr>
<tr>
<td>9.</td>
<td>Oil Can 20 ml. capacity</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>10.</td>
<td>Insulating plier 150 mm &amp; 200 m</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>11.</td>
<td>Cutting plier 150 mm &amp; 200 m</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>12.</td>
<td>Cutting plier 150 mm &amp; 200 mm</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>13.</td>
<td>Line tester 500 volts</td>
<td>1 No.</td>
</tr>
<tr>
<td>14.</td>
<td>Multimeters</td>
<td>1 No.</td>
</tr>
<tr>
<td>15.</td>
<td>Spirit Level 150 mm, 300 mm</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>16.</td>
<td>Outer and inner caliper 250mm</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>17.</td>
<td>Assorted files set 300mm long</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>18.</td>
<td>Hammer sets 1 kg. 2 kg. &amp; 5 kg</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>19.</td>
<td>Steel rule 300, 600 &amp; 900 mm</td>
<td>1 No. each</td>
</tr>
<tr>
<td>20.</td>
<td>Straight edge 1200 mm</td>
<td>1 No.</td>
</tr>
<tr>
<td>21.</td>
<td>Steel tapes 2 mtr. 15 mtr. &amp; 30 mtr</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>22.</td>
<td>Chain pulley block 2 ton &amp; 5 ton</td>
<td>1 No.</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Quantity</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>23</td>
<td>Single and double sleeve pulley block 150 mm.dia</td>
<td>2 Nos. each</td>
</tr>
<tr>
<td>24</td>
<td>Single phase welding set optional</td>
<td>1 No.</td>
</tr>
<tr>
<td>25</td>
<td>Hacksaw frame 300 mm</td>
<td>1 No.</td>
</tr>
<tr>
<td>26</td>
<td>Pipe wrench 250, 300, 450 &amp; 600mm</td>
<td>1 No.</td>
</tr>
<tr>
<td>27</td>
<td>Battery charger 24 volts</td>
<td>1 No.</td>
</tr>
<tr>
<td>28</td>
<td>Electric grinder, straight/angle 100/180</td>
<td>1 No.</td>
</tr>
<tr>
<td>29</td>
<td>Wire brush 100 mm</td>
<td>12 Nos.</td>
</tr>
<tr>
<td>30</td>
<td>Probable drill (Electric) 12 mm. caps.</td>
<td>1 No.</td>
</tr>
<tr>
<td>31</td>
<td>Parallel jaw bench vice 100 mm</td>
<td>1 No.</td>
</tr>
<tr>
<td>32</td>
<td>Punch 6 mm to 25 mm for rubber seals</td>
<td>1 No.</td>
</tr>
<tr>
<td>33</td>
<td>Center punch 100 mm</td>
<td>2 sets</td>
</tr>
<tr>
<td>34</td>
<td>Plumb bob 65 mm Dia.</td>
<td>6 Nos.</td>
</tr>
<tr>
<td>35</td>
<td>Pulling and lifting machine 5 ton capacity Tir – for make</td>
<td>1 No.</td>
</tr>
<tr>
<td>36</td>
<td>Electrical tong tester 600V per 200 Amps.</td>
<td>1 No.</td>
</tr>
<tr>
<td>37</td>
<td>Gas cutting regulator Oxygen</td>
<td>1 No.</td>
</tr>
<tr>
<td>38</td>
<td>Gas cutting regulator Acetylene</td>
<td>2 Nos.</td>
</tr>
<tr>
<td>39</td>
<td>3 cell torch</td>
<td>1 No.</td>
</tr>
<tr>
<td>40</td>
<td>Commander torch</td>
<td>1 No.</td>
</tr>
<tr>
<td>41</td>
<td>Buckets of various sizes 10lits. 16 lits and 20 lits</td>
<td>1 No.</td>
</tr>
<tr>
<td>42</td>
<td>Measuring cans 1 lit. 2 lit., 5 lit.</td>
<td>1 No. each</td>
</tr>
<tr>
<td>43</td>
<td>Electrically operated portable warning signal (siren)</td>
<td>1 No.</td>
</tr>
<tr>
<td>44</td>
<td>Blowlamp</td>
<td>1 No.</td>
</tr>
<tr>
<td>45</td>
<td>First aid box</td>
<td>1 No.</td>
</tr>
<tr>
<td>46</td>
<td>Tool boxes</td>
<td>3 Nos.</td>
</tr>
<tr>
<td>47</td>
<td>Steel Cupboards Small</td>
<td>1 No.</td>
</tr>
<tr>
<td></td>
<td>Steel Cupboards Big</td>
<td>2 Nos.</td>
</tr>
<tr>
<td>48</td>
<td>Tachometer</td>
<td>1 No.</td>
</tr>
</tbody>
</table>

**Note:** this list is for general purpose. The quantity can be varied and items can be added and deleted depending upon the No. of gates in consultation with the Executive Engineer of the Chief Gate Erection Unit concerned.
II) Spare Parts and Materials

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rubber seals sides</td>
<td>2 sets</td>
</tr>
<tr>
<td>2</td>
<td>Rubber seals bottom</td>
<td>2 sets</td>
</tr>
<tr>
<td>3</td>
<td>Nut bolts (Galvanize) for rubber seals for</td>
<td>2 sets</td>
</tr>
<tr>
<td>4</td>
<td>Wire ropes 12 mm, 24 mm, 32 mm and 36 mm depending on the size of gate for</td>
<td>2 gates</td>
</tr>
<tr>
<td>5</td>
<td>Wire rope sockets</td>
<td>4 Nos</td>
</tr>
<tr>
<td>6</td>
<td>Guide roller</td>
<td>1 No.</td>
</tr>
<tr>
<td>7</td>
<td>Various fuses (Kit Kat) And fuse wire (5A to 100 A) one coils each</td>
<td>6 Nos.</td>
</tr>
<tr>
<td>8</td>
<td>Electrical moving and fix contacts for starter limit switch etc.</td>
<td>2 dozen each</td>
</tr>
<tr>
<td>9</td>
<td>Brake shoe with liners</td>
<td>2 sets</td>
</tr>
<tr>
<td>10</td>
<td>Brake coil</td>
<td>2 sets</td>
</tr>
<tr>
<td>11</td>
<td>Flexible couplin for hoist motor</td>
<td>3 Nos</td>
</tr>
<tr>
<td>12</td>
<td>Rubber bushes (for couplings)</td>
<td>12 Nos.</td>
</tr>
<tr>
<td>13</td>
<td>Starter assembly</td>
<td>2 Nos</td>
</tr>
<tr>
<td>14</td>
<td>P.V.C. electrical wires 3/20, 7/20, 1/16 SWG</td>
<td>1 coil each</td>
</tr>
<tr>
<td>15</td>
<td>Paint shalimastic – L.C</td>
<td>40 lit.</td>
</tr>
<tr>
<td>16</td>
<td>Painting brushes: 4”</td>
<td>6 Nos</td>
</tr>
<tr>
<td>17</td>
<td>Manila rope 20 mm, 25 mm</td>
<td>50 kg. Each</td>
</tr>
<tr>
<td>18</td>
<td>Coir strings</td>
<td>5 kg.</td>
</tr>
<tr>
<td>19</td>
<td>Polish paper – rough and smooth</td>
<td>6 No. Each</td>
</tr>
<tr>
<td>20</td>
<td>Wooden planks 40 mm thick 300 x 2500 mm</td>
<td>6 Nos</td>
</tr>
<tr>
<td>21</td>
<td>Line thread bundle</td>
<td>1 No.</td>
</tr>
<tr>
<td>22</td>
<td>Chalk stick box</td>
<td>1 No.</td>
</tr>
<tr>
<td>23</td>
<td>Lettering paint – white and red</td>
<td>100 ml each</td>
</tr>
<tr>
<td>24</td>
<td>Lettering brushes</td>
<td>6 No.</td>
</tr>
<tr>
<td>25</td>
<td>20 mm wire rope slings 2m, 3 m long</td>
<td>2 each</td>
</tr>
<tr>
<td>26</td>
<td>Wire rope clamps (12 mm, 16 mm, 18 mm, 25 mm)</td>
<td>4 each</td>
</tr>
<tr>
<td>27</td>
<td>Nuts and bolts 6 mm x 30 mm</td>
<td>1 kg</td>
</tr>
<tr>
<td></td>
<td>12 mm x 50 mm</td>
<td>3 kg</td>
</tr>
<tr>
<td></td>
<td>18 mm x 50 mm</td>
<td>3 kg</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>Quantity</td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>25</td>
<td>25 mm x 75 mm</td>
<td>3 kg</td>
</tr>
<tr>
<td>28</td>
<td>M.S. washer for above</td>
<td>3 No.</td>
</tr>
<tr>
<td>29</td>
<td>Empty tins 20 lit.</td>
<td>3 No.</td>
</tr>
<tr>
<td></td>
<td>10 lit</td>
<td>3 No.</td>
</tr>
<tr>
<td></td>
<td>5 lit</td>
<td>3 No.</td>
</tr>
<tr>
<td>30</td>
<td>Plastic jar 5-lit</td>
<td>1 No.</td>
</tr>
<tr>
<td></td>
<td>10-lit</td>
<td>1 No.</td>
</tr>
<tr>
<td>31</td>
<td>Gas hoses red and black 5 mm</td>
<td>25 m each</td>
</tr>
<tr>
<td>32</td>
<td>Cylinder key</td>
<td>1 No.</td>
</tr>
<tr>
<td>33</td>
<td>Regulator spanner</td>
<td>1 No.</td>
</tr>
<tr>
<td>34</td>
<td>Cutogen spanner</td>
<td>1 No.</td>
</tr>
<tr>
<td>35</td>
<td>Hand screen for welder</td>
<td>1 No.</td>
</tr>
<tr>
<td>36</td>
<td>Colored glasses 80 mm x 100 m German make</td>
<td>3 No.</td>
</tr>
<tr>
<td>37</td>
<td>White glasses 80 mm x 100 mm</td>
<td>1 doz</td>
</tr>
<tr>
<td>38</td>
<td>Leather hand gloves</td>
<td>2 pairs</td>
</tr>
<tr>
<td>39</td>
<td>Electrical holder 400 Amp. Capacity</td>
<td>2 No.</td>
</tr>
<tr>
<td>40</td>
<td>Welding cable 400 Amp</td>
<td>50 mtr</td>
</tr>
<tr>
<td>41</td>
<td>Gas cutting nozzles 3/64” and 1/16”</td>
<td>2 each</td>
</tr>
<tr>
<td>42</td>
<td>Rubber hand gloves for wireman 600 V</td>
<td>1 pair</td>
</tr>
<tr>
<td>43</td>
<td>Electric bulb 250 x 60 W</td>
<td>3 each</td>
</tr>
<tr>
<td></td>
<td>X 40 W</td>
<td>3 each</td>
</tr>
<tr>
<td>44</td>
<td>Rain Coats</td>
<td>6 No.</td>
</tr>
<tr>
<td>45</td>
<td>Gum boots</td>
<td>6 pairs</td>
</tr>
<tr>
<td>46</td>
<td>Lubricants</td>
<td>5 lit</td>
</tr>
<tr>
<td></td>
<td>Gear oil – 90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red oxide paint</td>
<td>20 lit</td>
</tr>
<tr>
<td></td>
<td>Galvanized paint</td>
<td>10 lit</td>
</tr>
<tr>
<td></td>
<td>Grease (as per requirement)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engine oil</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>Hand lamp with outdoor workshop cable 25 mtr</td>
<td>2 Nos.</td>
</tr>
<tr>
<td>48</td>
<td>Inspection lamps</td>
<td>2 Nos.</td>
</tr>
<tr>
<td>49</td>
<td>Ladders</td>
<td>2 Nos.</td>
</tr>
<tr>
<td>50</td>
<td>Safety helmets</td>
<td>6 Nos.</td>
</tr>
</tbody>
</table>
III) SPARE FOR DIESEL GENERATOR SET

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fan belt</td>
</tr>
<tr>
<td>2.</td>
<td>Oil filter</td>
</tr>
<tr>
<td>3.</td>
<td>Diesel filters</td>
</tr>
<tr>
<td>4.</td>
<td>Injector</td>
</tr>
<tr>
<td>5.</td>
<td>Carbon brushes</td>
</tr>
<tr>
<td>6.</td>
<td>Generator brushes</td>
</tr>
<tr>
<td>7.</td>
<td>Voltage regulator</td>
</tr>
<tr>
<td>8.</td>
<td>Dynamo brushes</td>
</tr>
<tr>
<td>9.</td>
<td>Engine oil</td>
</tr>
<tr>
<td>10</td>
<td>Battery charger</td>
</tr>
<tr>
<td>11</td>
<td>Battery Electrolyte Hydrometers</td>
</tr>
</tbody>
</table>

Operation and Maintenance Of Radial Gates & Fixed Wheel Gates

**General:** Proper maintenance of Hydraulic gates and hoists is very important for satisfactory operation of Gates and to achieve the **envisaged benefits from the project.** For systematic operation and maintenance of the gates and their operating equipments, it is very necessary that a comprehensive operation and maintenance manual which shall include:

- Particulars of bought-out items and source of availability with addresses and phone Nos.
- Operating instructions.
- Type of lubrication oil and grease to be used and its availability.
- Schedule of maintenance and repairs.

The above are prepared for each hydraulic gate installation and the operation staff shall be made well conversant with them and trained for the job.

The list parts involved in maintenance and operation of gates and hoists generally are as follows:

1. **Vertical Lift Gates:**
   i. **Embedded Parts:**
      - Sill beam assembly
      - Roller track
      - Seal seat / Upsteam guide
      - Top seal seat and side guide
      - Dogging arrangement
   ii. **Gate parts:**
      - Skin plate Assembly
      - End verticals or End box
      - Horizontal girders
      - Vertical Stiffeners
      - Roller assembly
      - Side guide assembly
      - Lifting arrangement
2. **Radial Gates:**
   
   i. **Embedded Parts:**

<table>
<thead>
<tr>
<th>Common anchorages (Bonded Anchorages)</th>
<th>Independent anchorages (Un-bonded anchorages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Sill beam Assembly</td>
<td>➢ Sill beam assembly</td>
</tr>
<tr>
<td>➢ Wall plate assembly</td>
<td>➢ Wall plate assembly</td>
</tr>
<tr>
<td>➢ Horizontal Anchor Rods</td>
<td>➢ Anchor girders</td>
</tr>
<tr>
<td>➢ Trunnion Girder</td>
<td>➢ Load Anchors / Tie flats</td>
</tr>
<tr>
<td>➢ Trunnion girder chairs</td>
<td>➢ Yoke girders</td>
</tr>
<tr>
<td>➢ Vertical rods</td>
<td>➢ Rest plate</td>
</tr>
<tr>
<td>➢ Thrust block (if tie between trunnion is not used)</td>
<td>➢ Vertical rods etc.,</td>
</tr>
<tr>
<td></td>
<td>➢ Thrust block (If tie between trunnion is not used)</td>
</tr>
</tbody>
</table>

   ii. **Gate Leaf:**

<table>
<thead>
<tr>
<th>Common anchorages (Bonded Anchorages)</th>
<th>Independent anchorages (Un-bonded anchorages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Skin plate</td>
<td>➢ Skin plate</td>
</tr>
<tr>
<td>➢ Side guide and seal assembly</td>
<td>➢ Side guide and seal assembly</td>
</tr>
<tr>
<td>➢ Vertical stiffeners</td>
<td>➢ Vertical stiffeners</td>
</tr>
<tr>
<td>➢ Horizontal Girder Bracings</td>
<td>➢ Horizontal Girder Bracings</td>
</tr>
<tr>
<td>➢ Arm Assembly</td>
<td>➢ Arm Assembly</td>
</tr>
<tr>
<td>➢ Trunnion</td>
<td>➢ Trunnion</td>
</tr>
<tr>
<td>➢ Trunnion pin</td>
<td>➢ Trunnion pin</td>
</tr>
<tr>
<td>➢ Trunnion Bush</td>
<td>➢ Trunnion Bush</td>
</tr>
<tr>
<td>➢ Trunnion Bracket</td>
<td>➢ Trunnion Bracket</td>
</tr>
<tr>
<td>➢ Tie between trunnion or Thrust block</td>
<td>➢ Tie between trunnion or Thrust block</td>
</tr>
<tr>
<td>➢ Lifting Bracket</td>
<td>➢ Lifting Bracket</td>
</tr>
</tbody>
</table>

3. **Rope drum Hoists**

   A. For Vertical Lift Gates:
   
   ➢ Drive Unit Assembly
   ➢ Gear Box Assembly
   ➢ Hoist Supporting structures etc.
Chapter 15

Sealing Arrangement for Vertical and Radial Gates

Introduction:

Seals are required to prevent loss of water, seal leakage in the gates subjected to high head that can cause long term damage to downstream concrete works. These are designed to retain water, prevent water penetration, or limit contaminated run off. The inherent elasticity and resilience of RC Gate seals allow it to retain its sealing effectiveness in situations where there are fluctuating movements caused by water pressure, traffic, subsidence or seismic movement. Seals are required to prevent loss of water. Jets emitted at inadequately sealed sills, sides are a major source of gate vibration and gate noise. In addition; seal leakage in gates subjected to high head can cause long term damage to downstream concrete works. Since fluctuating pressure due to flow through gaps is major cause of gate vibration, aspects of seal arrangement.

Seals are normally specified to have a shore A hardness of 65 with a tolerance of 5. High head gates often have seals of greater hardness. At hardness significantly lower than 65, coefficient of friction between a seal and stainless steel surface increases. The friction coefficient is also affected by the surface finish of seal contact surface.

Seals are used in following type of gates to prevent leakage:

- Radial Gates
- Stop Log Gates
- Under Sluice Gates
- Automatic Tilting Gates
- Draft Tube Gates
- Desilting Service Gates
- HR Gates
- Vertical Lift Gates
- Spill Way Gates
- Swing Gates
- Bulk Head Gates

Types of Sealing Arrangements:

a. **Upstream sealing:** Skin plate and seals of these types of gates is provided on the upstream of gate frame. Sealing is achieved by positive thrust on stem rod of gate. (ref. fig. 1)

b. **Downstream sealing:** Skin plate and seals of these types of gates is provided on the downstream of gate frame. Sealing is achieved by water thrust on gate leaf. (ref. fig. 2)
Types of Seals: (fig. 3)

a. **Musical Note Rubber Seal:** This can also be referred as P Type seal / J type Seal. Musical Note Rubber Seal is available with either Solid Bulb or Hollow Bulb. Hollow Bulb seals are recommended for gates operated up to 15 Mtrs, while Solid bulb are used for heads from 15 Mtrs. (refer fig.4)

b. **Z type Rubber Seal:** These Z type rubber seals are moulded to the required shape and the sealing effect is obtained partly due to initial interference with the embedded sealing plate and partly due to the deflection under load. This type of seal is used on gates on the crests of dams and weirs.(refer fig.5)

c. **Double Stem Seals:** These types of design are preferred for heads exceeding 30 Mtrs. Double Stem Seals can be used as Top Seals, Side Seals as well as Bottom Seals. (refer fig. 6)

d. **Flat Rubber Seal:** Rubber Concept produces different types of Flat rubber Seal, these can be Flat type, wedge type, Round bottom type. These types pf Seals are generally employed as Bottom Seals. (refer fig.7)

e. **PTFE Cladded Rubber Seals:** Rubber Concept offer PTFE cladding / Teflon Cladding over various type of Rubber Seals, such as Musical Note Rubber Seals/P type Rubber Seal , Z type Rubber Seal, Double Stem Rubber Seals. The purpose of PTFE cladding is to prevent seal from being drawn into the space between the clamp bar and seal plate, while retaining its flexibility (Unlike Metal Cladding). This will increase the life of Rubber Seals. Chemically treated PTFE strips of 1.0 to 2.0 mm are used for cladding to ensure zero failure of bonding between Rubber and PTFE. (refer fig.6 & 6a)

Seal materials:

Compounds, based on following elastomers, are used for the manufacturing of Rubber Dam Gate Seals:

- Natural Rubber (As per IS: 11855 / IS: 15466)
- EPDM Rubber
- PolyChloroprene Rubber / Neoprene Rubber

Effect of seals on Hoisting Capacity:

The capacity of the hoist is based on the algebraic sum of the following:
a) All weights consisting of:
   1) Gate leaf along with its components including ballast, if any
   2) Moving parts of hoist such as stems, gate stem, piston, etc.

b) Water load on gate components including buoyancy, wherever necessary.

c) All frictional forces comprising OE
   1) wheel/sliding friction;
   2) Guide friction;
   3) Trunion friction, if hoist is used for radial gates;
   4) Seal friction including bearing pad friction in case of slide gates;
   5) friction of moving parts of hoist.

Apart from water tightness, the coefficient of friction of seals should be as less as possible to reduce capacity of hoist required for gate operation.

**Precompression of Rubber seals:**

The seals are fitted onto a gate leaf by means of seal base plates, seal clamp plates and screws. The seals are so fixed that in a gate closed position they are deflected back and bear tightly against seal plates embedded in a gate slot and prevent leakage. This deflection is achieved by a provision of precompression in seal.

**Performance of Seals:**

Performance of seals depends upon various factors such as quality of rubber, dimensions of the seal, method of mounting adopted, type of cladding used, amount of precompression and alignment of seal plates embedded in gate slots.

Various qualities of rubber used for gates seals are as follows

- a. Hardness of rubber.
- b. Tensile strength,
- c. Resistance to wear (i.e. abrasion),
- d. Water absorption,
- e. Permanent set,
- f. Ageing resistance under various condition of temperature,
- g. Coefficient of friction.

**Physical Properties required for seals:**
i) Shore A durometer hardness 65 +/- 5
ii) Elongation at break, percent, Min 450 IS 3400
iii) Tensile strength, N/mm², Min. 14.5
iv) Mass of water absorbed in 7 days, percent, Max.10
v) Tensile strength after accelerated aging test of 48 hrs in oxygen at 70 +/- 1 °C and 2.1 +/- 0.1 N/mm² pressure shall not be less than 80% of the strength before aging.

**Permissible leakage:**

The maximum permissible leakage as per IS 4623-2000 should not be more than 5 lit/min/meter length of seal in case of crest gates and medium head conduit gates and 10 lit/min/meter length of seal in case of high head gates.
Reference Figures

Figure 1

Figure 2
Chapter 16

Safety Assurances of Hydro-Mechanical Equipments

1. Introduction

1.1 Controlled releases & utilization of water from the Reservoir is an important necessity in order to derive the maximum benefit from any project in the water resources sector in an economical manner. For controlling the flows through the dams, canals, penstocks or outlets for purposes of irrigation, domestic use, flood control, navigation and power, the hydro-mechanical equipments which consists mainly the hydraulic gates and their operating system; form the most vital component. The hydro-mechanical equipment forms a very small component of the total cost of the project, but they are one of the most crucial components in determining the success of the project.

1.2 There have been numerous incidents in the world, in which the gates have malfunctioned sometimes with disastrous results. The major causes of many such incidents and failures are attributed to faulty hydraulic design, maintenance or improper operation, especially in case of high head gates. Phenomenon of cavitations and vibration in and around the high head gate threatens the very safety of the hydraulic gates. Therefore, measure should be evolved at planning and design stage itself to control, if not eliminate, the hazardous consequences by making such hydro-dynamic alignment and layout along the flow path and in the gate body, which assure a positive pressure or at least reduce the negative pressure as much as possible.

1.3 The hydraulic gates are moving facilities provided in dams, barrages, hydropower projects, and reservoir and river control. These are neither like concrete dam nor like other reinforced concrete hydraulic structure, which always remain stagnant. Therefore, the gates are more complicated and critical components than the dam proper and other hydraulic structures. Evidently, gates are of vital importance for water resources projects and should always be in smooth functioning. Their failure to fulfill the intended purpose can have devastating results, sometime may even endanger the safety of the entire project. While most recorded instances of unsatisfactory operation or failures of gates are due to hydrodynamic causes, however mechanical or electrical inadequacies can be just as serious because the structure does not perform as designed. In practice, shortcomings due to hydraulic or hydrodynamic factors are difficult to rectify, whereas mechanical or electrical faults can usually be repaired or improved.

1.4 The higher the head, the more serious the hydraulics problems; the larger the gate area, the more serious the structural problems and manufacturing difficulties; the larger the total dynamic pressure, the more serious the hoist problems. These three parameters, i.e. the water head, the gate opening area and the total dynamic pressure are the major indices, which require to be seen in totality for smooth functioning. The expertise in design, fabrication and erection are important factors, which contributes significantly for assurances of the smooth and satisfactory operation of the gated structure.
The safety to the Hydro Mechanical Equipments can be assured by making appropriate provision/taking appropriate action right from the planning to the maintenance stage. Such provisions/actions are discussed below:

2.0 Planning and Design Stage

The maintenance affects the reliability and safety of any structures significantly. Therefore, the gated structures should always be designed and constructed with facilities for placing emergency, bulkheads/stop logs gates at upstream of the main gate for attending to its maintenance requirements and as well as for closing/isolating the waterway in case of any emergency/malfunctioning of service gate (Fig-1 & 2).

Floating bulkheads (Fig-3) may provide a solution in the circumstances, where the provisions are not made initially in the original planning for emergency closure of the bay by means of an emergency/bulkheads gate but their requirement becomes important and the equipment or space is not available on the dam for handling them. However, the design of such floating bulkheads is complicated in regards to the control for their sinking.

Orifice or tunnel spillways have submerged inlets and such structures should be generally provided with one gate just downstream of the entrance while at the entrance there should be provision of a stop logs/bulkhead gate. The latter is to serve as a guard gate in case of emergency or when the former requires servicing/maintenance (Fig-4).

The installations having water head less than 30m, a Bulk head gate to be installed in the u/s of the regulating gate (slide or fixed wheel type) can be provided for maintenance purposes. Whereas for water head more than 30m, an emergency gate of fixed wheel type for maintenance purposes and as well as a service gate in its downstream is preferable. However, the installation exposed to extreme higher head, two gates in tandem with similar construction is generally adopted (Fig-5).

Special design of gated structures is required for combined operations of gates e.g. flood release combined with sediment flushing. Control gates for such applications are preferably top sealing radial gates and in some case vertical-lift wheel type gates. In either case, the gates are designed for upstream sealing and the maintenance gate is usually vertical-lift type.

The crest gates for dams, barrages and open channels are designed generally to have upstream skin plate & adequate (at least 0.3m) freeboard between the top of gates and the maximum water level. These provisions could reduce significantly, the maintenance requirement and the damages to the downstream structural members of gate.

The parts of high head gates should be stress relieved to resist the dynamic and fatigue loading resulting from vibrations. Stainless steel cladding of bottom lip of gate will be advantageous to resist cavitations & abrasion under high velocity flow.
The vertical lift gate (Fig-6) should have a sloping bottom lip (generally $45^0$ for high head) for ensuring a reduced down pull forces and eliminating unstable flow reattachment in order to have vibration free operation of the gated installations especially during small openings when the gate is subject to be worst affected.

The high head gated installations (water head exceeding 30 m) invariably suffer from cavitations and vibration problems resulting from either due to inappropriate design of gate slots or due to high velocity jet flow caused by serious water leakage. Therefore the gate slot in such case should be appropriately designed. This will reduce cavitations/ vibration problems significantly. Apart from that the bottom lip of the gate should be appropriately designed and an air vent should be provided just downstream of the gate slot for facilitating proper ventilation (i.e. air supply) to the waterway. However, it should be ensured that the inlets of the air vents should be located in such a manner that the high water levels, waves, debris, etc., do not interrupt the aeration.

Other factors, affecting the cavitations phenomena are roughness of surfaces, distance between two adjacent gate slots and entrance shape of piers/ conduit. Therefore, these should be provided suitably based on the result obtained from the proper model test particularly in case of the high head gates.

In case of high head outlets, the bonnet type gated installation is necessary for satisfactory performance. In a bonnet type arrangement, the gate is withdrawn into embedded steel bonnet, when fully opened. It is desirable to design the top 300mm of the embedded bonnets to withstand internal hydrostatic loads and the imposed hoist loads without the aid of surrounding concrete. The bonnet covers should be invariably bolted to bonnets or gate frames, so that the water load on the bonnet covers is distributed to the concrete surrounding through the bonnets and gate frames. Direct transfer of load from bonnet covers to the top concrete lift should be avoided for safety.

The high head intake gates for power tunnels and bottom outlets should invariably provided with shaft type arrangement (Fig-7). However, in such cases it must be ensured that gate shafts should never be allowed to be submerged under water otherwise they may be damaged due to the vertical flow.

The rubber seals are provided invariably for ensuring the water-tightness of gates (Fig-8 & 9). Thus the seal should be designed in such a way that it should not cause any flow irregularities. This is must for having safe and satisfactory operation of the gates. At the same time, the seal assembly should be simple and should allow for easy installation and removal. The seal material and its mounting must be capable of transferring the initial stress (due to interference) to the seal. The seal fixture must allow the seal to deform/bend under the water pressure and allow easy adjustment to take care of reasonable inaccuracies in sealing surfaces during fabrication and erection.

For the vertical lift gates under extremely high head condition, the metal sealing surfaces have been found to be more suitable. However, such sealing require high degree of accuracy during manufacturing and erection.
For radial gates having top seal, it is important to design the top seals in a proper manner to avoid undesirable water jets during partial gate operation. It is the usual practice to provide an anti-jet seal fixed on the embedded frame at the top of the embedded frame, in addition to the standard rubber seal fixed to the gate. The standard seal ensures water tightness when the gate is fully closed, whereas the anti-jet seal fixed to the embedded frame make reasonable watertight contact with the gate at partial gate openings. It is often preferable to provide a stainless steel skin plate suitably machined on the upstream side to provide a smooth surface for anti-jet seal contact.

3.0 FABRICATION AND ERECTION STAGE

Consideration of reliability and minimum maintenance is an important aspect for a gate. Use modern and reliable components for gates like maintenance free self lubricating bearings, fluorocarbon clad seals, stainless steels of different grades etc. These items not only provide long term maintenance free service, but also permit very high load carrying capacities.

The selection of suitable bearing surfaces, especially for underwater applications and trunnion bearings of radial gate plays a significant role. Self-lubricating type bearings for gated installations offers satisfactory performance over long period of time. One of the most important requirements in design of a radial gate is to ensure the satisfactory performance of its trunnion bearings even with a reasonable misalignment. Misalignment is likely to occur during erection, or during operation as a result of malfunctioning of gate, due to seismic/ flood loading, due to deflection of piers when an adjacent bay is dewatered.

Similarly, the wheel type vertical lift gates provided with self-lubricating bronze bearing & stainless steel pin are always preferable. Designs of various components of the fixed wheel gates for high head also require careful attention, especially during the analysis of stresses in the wheels, tracks, and track beams, which carry heavy concentrated loads. Reliable bearing installations having a significantly lower coefficient of friction than the self-lubricating bronze bearings for the underwater uses can be engineered, but this type of arrangement relies completely on prevention of ingress of water/silt. Therefore, crucial factor for such applications is the sealing arrangement, because breakdown of the seals are likely to take place and cannot be expected to last longer.

The elastomeric side and top seals, plain or PTFE-faced are satisfactorily used for achieving water tightness of gated installation exposed to water head ranging from low to moderately higher head. Rubber seals with PTFE cladding and metal sealing for gates operating higher heads are preferable. The top and side seals should preferably be effective throughout the travel of the gate to avoid undesirable water jets and consequent problems especially in case of high head regulating gates.

The seal material must have high tensile strength, high resistance against tear/abrasion, low water absorption, adequate resistance to aging apart from low coefficient of friction. For low head application, plain rubber seal can be adopted,
whereas the composite rubber seals with PTFE cladding having low friction coefficient is preferred for moderate to high head applications. The PTFE coating is less resistant to abrasion than the plain rubber, it is therefore obvious that any contamination of the water by suspended abrasive material will have an influence on the erosion of the seals and thereby its life.

By using two rows of top seal fixed on the gate leaf (in case of top seal radial gate one fixed to gate leaf and other fixed on breast wall) help to control the water leakage as well as safe guard against the damages resulting from the emerging water jets from the sealing plane. Therefore, such measures could be very effective in smooth functioning of gated installations.

The regions where cavitations can occur should generally be provided with steel lining, in some case even lined with stainless steel or high strength/hardened alloy steel.

Steel lining of conduit is required for the portion in between maintenance and regulating gate in addition to some distance u/s of maintenance gate and d/s of regulating gates for installations subjected to water head in the range of 30-40m or more. However, complete lining of conduit is desirable for the portion of conduit passing through the dam or gate operating under a head of 100m or more. The conduit area at the gate location is generally kept somewhat lesser than the u/s conduit area to ensure positive water pressures for the fully opened position of the gate.

Hydraulic Hoist are more versatile, smooth and dependable in so far as performance & reliability is concerned, therefore, these can be used in place of Rope drum and screw type of hoists for the operation of gates as far as possible. Overall design of the gates should be sturdy and should provide for adequate rigidity. It is not advisable to be very economical in respect of provisions for gates and hoisting equipment. It may happen sometime that due to some of the unforeseen & unpredictable forces or circumstances, economical provisions may result in unsatisfactory performance or even failure of gate/its operating mechanisms.

4.0 OPERATION STAGE

Hydraulic Hoists (Oil hydraulics) is frequently used now days to operate gates. The hydraulic fluid has to be environmentally compatible. There should be a suitable provision for arresting the gate and stopping delivery of hydraulic fluid in the event of the burst of a flexible hose or a pipe have to be incorporated.

For smaller span of waterway single cylinder hydraulic hoist while for larger span waterway hydraulic hoist having twin cylinder should generally be adopted.

However, when lifting the gate from two points for twin cylinder arrangement, it is essential to synchronize the movement of piston of the cylinders to avoid distortion/malfunctioning of gated structure. The development of accurate electronic piston rod position sensors built into the cylinder head has simplified synchronization and therefore has increased reliability of hydraulic hoists.

From reliability considerations, an oil-hydraulic installation also offers the possibility of automatically interchanging the power packs so that one can act as a
standby to another by incorporating a few additional directional control valves. Moreover, in order to avoid/reduce the vibration problems, it is required that the high head gates be rigidly supported during their operation. Rigidity of supports is also required in case the gate is not capable of self-closing i.e. gravity closure by its own weight. Requirement of rigidity of suspension for high head gates can be fulfilled either by using a screw hoist (limited to small size gate) or by hydraulic hoists more often.

The hydraulic hoist can also meet satisfactorily the important operational requirement of controlled rate of closure to avoid or limit water hammer and also to slowdown further for the final 5 to 10% of travel to avoid damage to the bottom of gate/sill in case of high head installation. Moreover, the rate of opening can also be critical, because it can initiate a reflected wave. Similarly, if hydraulic hoist is used to operate the radial gates, the hydraulic cylinder must be properly hinged to ensure smooth gate operation without undue stresses in the stems and lifting mechanism.

The crucial & important load components, concerning design of hoisting arrangement for high head vertical lift gates, are the hydrodynamic (down pull/uplift) forces and the sliding/rolling friction. These two forces can vary appreciably for different installations and the problem is further compounded because of their variations throughout the length of the travel of the gate. In addition, the coefficient of friction may even vary from time to time, because of its dependency on state of sliding/rolling surfaces and lubrication provided. Model studies can be helpful for satisfactory assessment of hydrodynamic forces, but the accurate assessment of frictional forces is quite difficult in real life situations. Therefore, guaranteeing a satisfactory performance of gated installations in such circumstances is really a challenge. However, a conservative estimate of frictional force (sliding/rolling, seals, guide etc.) is, therefore, imperative in design of hoist for satisfactory performance. In case of self-closing gate, it must be ensured that the submerged weight of the gates always exceeds the opposing forces during the closure operation by at least 20 percent.

As the coefficient of friction depends on the deposition of a lubricant film on the mating surface, the selection of the appropriate values of the same is difficult. Also, the bearing surfaces in the gate slots are subject to high velocity flow and eddy circulation. Such forces can remove the lubricants and thus may increase the frictional coefficient; therefore, provisions for forcing grease between the gate and the gate seats by suitable means to prevent such eventualty are must to ensure smooth operation.

In addition to such provisions, conservative estimate of required hoist capacity is made by assuming a higher value of sliding friction coefficient between the sliding bearing plate and embedded load bearing track plates, which are generally of stainless steel and bronze respectively.

The Rule curve for proper operation of a gate must be developed and should be followed accordingly. Further, it should be reviewed from time to time whenever required and revised accordingly.
5.0 MAINTENANCE STAGE

It is not sufficient only to provide properly designed gates and their operating equipment while the dam is constructed but it is also essential to effectively maintain the installations. Instances are reported in India as well as all over the world, in which failures of gates have occurred due to poor Maintenance of the equipment as stated above. Proper Maintenance of the installed equipment can be assured by providing a qualified and dedicated team of engineers and operators for attending to the maintenance needs from time to time, adequate financial allocation for all the maintenance related issues. The norms for proper maintenance and operation as stated under different BIS Codes and operating manuals are to be followed. Post installation inspection and maintenance is crucial for the proper functioning of the hydro-mechanical equipment. It also affects the performance of the civil structure and eventually success or failure of the whole project. It is very much important that the inspection procedure & operating manual are based on sound practices and as per the design criteria adopted. The inspection responsibilities are required to be delegated to senior and experienced group or groups of project personnel who are well versed with the activities involved in this operation. In the past, a number of cases of distress of hydro-mechanical equipment have been reported e.g. Failure of Singur Dam Radial Gates (A.P.) (Fig-10), Failure of Radial gate of Mohini Pickup Weir (MP), Malfunctioning of Intake Gates of Mahi Project (Rajasthan) (Fig-11), Failure of Hoist of Srisailam Radial Gates (A.P.), etc.

For ensuring satisfactory performance of gated installations, it is desirable to have operation and maintenance (O&M) logbooks for all hydro-mechanical equipments and have adequate spare parts such as Hoist Motor, wire ropes, bearings, oil seals, limit switches, rubber seals, etc. All gates to the extent possible should be operated every year especially before the onset of monsoon. All equipment should be cleaned and lubricated at least prior to onset of monsoon. Debris and ice build-up around gates and wire ropes should be removed. Repair damaged painted surfaces at least once in five years. Hoisting wire ropes and roller-chains should be regularly lubricated to minimize corrosion and ensure smooth hoist operation. The gear teeth should be checked for proper alignment, wear, excessive backlash, cleanliness, corrosion. Housing and mountings of Speed Reducers and their lubricant level should be checked. Mounting fasteners of machinery parts should be checked for tightness and corrosion. Shafts & couplings should be checked for cracks, twisting, strain and misalignment. Bearing housings, pedestals, etc should be checked for cracks and misalignment. Check trunnion bearings for excessive wear, lubrication, lateral slip and loose or missing fasteners. All braking devices should be checked for proper setting of braking torque and complete release. Check for proper ventilation of hoist Motors, unusual noise or odor if any from internal wiring’s insulation. Check all components of Hydraulic Systems: i.e. valves, piping/tubing, switches, pumps, cylinders, hydraulic power units, etc. for signs of leakage and for proper operation. Inspect supporting steel members/concrete. Check that all drain holes are clear that there is no standing water. Inspect wire rope, drums, sheaves, etc.

For safety assurance of gated installations, it is required that Gate Leaf is inspected for deterioration of coatings and loss of metal if any. Trunnion and arms/bracing of
a radial gate are crucial which must be inspected (Fig-12) for any deformed elements and/or members (i.e. beams, flanges, webs etc.). Welded joints should be checked for any discontinuity, loss of weld metal, cracks, corrosion etc. Ensure that drain holes exist and are open on various structural members (Fig-13). Contact surfaces of Wheels, Rollers and Tracks should be checked for corrosion as pitting can cause increased rolling friction. Also check that all wheels and rollers rotate freely. Check condition of gate seals for any damage. Check that embedded sealing surfaces are free of corrosion, pitting, scratches, etc. Check that seal mounting components and clamp bars are in place and that fasteners are tight.

6.0 OTHER FACTORS

In the design of spillway gate for a dam/barrage, to a lesser extent river outlets & other low level sluice gates, reliable mechanical and electrical installations should take into account the possibility of common cause failures, such as seismic disturbance, extreme floods apart from fire, explosion, collision, and of course possible organizational, management, communication and forecasting weaknesses. The trunnions of the radial gates should be protected against corrosion and debris.

The mechanical and electrical considerations of earthquakes comprise precautions such as the rigid support for light fittings and long hydraulic hoist cylinders, where pipe couplings, gate position indicators, etc., can be affected. During a severe earthquake, electrical contactors/ main switches can be inadvertently operated and the operating cranes are liable to be derailed. The above factors may result in malfunctioning of gated installations or render them inoperative.

An essential requirement to avoid common cause failures is to provide at least two opening for outlets and spillways and to separate their operating mechanism physically. For the safety of structures, dependence in regards to operation of gates by highly elaborate devices or computerized electronic equipment can be provided such that the system has proper feedback controls. The use of partly computerized system for flood routing may lead to malfunctioning of the spillway gates equipment by opening them suddenly, or it would equally well happen that when required gate may not operate, and therefore the dam is likely to be over-topped.

There is a considerable preponderance of failures caused by overtopping, especially in the case of embankment dams. Overtopping has generally occurred because the gate operator failed to react to the arrival of a flood in time, or because of power failure at the critical moment and thereby the gates could not be opened for passing the flood. Power failures are common in the area in stormy weather, and it is in just such circumstances that power failure to the gate operating motors would be most likely to happen at the time when it would be most important for the gates to open. Therefore, safety can be ascertained by such designs, which would facilitate the opening of the gate without fail at the right time, and by the right amount, and totally without dependence on power or operator.
SPILLWAY RADIAL GATE & STOPLOGS

Fig-1
SECTION THROUGH BULKHEAD

BULKHEAD INSTALLATION

Fig-3

SECTION THROUGH SLIP AND STEELWAY

Fig-4
Fig-5: VERTICAL LIFT SLIDE GATES IN TANDEM
HIGH HEAD GATE CONSTRUCTION DETAILS

Fig-6
Fig-8
UNSUITABLE BOTTOM SEAL ARRANGEMENT  
CORRECT ARRANGEMENT OF BOTTOM SEAL

Fig-8
WEB

IMPROVISED SCHEME
OF WELDING TIE-
FLATS TO TRUNNION
GIRDER

TIE FLAT

ADDITIONAL PLATE

TRUNNION GIRDER
FLANGE

Fig-10

MEASURES TO TACKLE
ECCENTRIC LOCATION
OF TRUNNION

TRUNNION BRACKET
BASE
CATAPULTING OF SERVICE GATE

Fig-11
CORROSION PREVENTION BY AVOIDING CREVICES

CORROSION PREVENTION BY AVOIDING DRAIN HOLES

Fig- 12

Fig- 13
NATIONAL WATER ACADEMY

The National Water Academy (NWA) located in Pune is a premier institution of Central Water Commission functioning as a ‘Centre of Excellence’ for the training of in-service professionals working in water resources sector. The Academy conducts, all the year round, several short and medium term training programs to cover all the aspects associated with furtherance and management of water resources. Additionally, the Academy also organizes a long term 15 weeks’ Induction Training Program for newly appointed Group ‘A’ officers of Central Water Engineering Services.

For further details please visit NWA website http://nwa.mah.nic.in