A STUDY OF HYDROMECHANICAL ASPECTS OF NAVIGATIONAL LOCK IN INTERNAL WATERWAYS WITH SPECIAL REFERENCE TO NATIONAL WATERWAY-1

A thesis

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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All information in the document has been obtained and presented in accordance with academic rules and ethical conduct.

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ABSTRACT

India has a large scale network of water bodies in the forms of rivers, lakes, canals and backwaters which provides inland transport facilities across major cities of India. Total navigable length of inland waterways in India is 14544 km. The National Waterway-1 (NW-1) is located in India and runs from Allahabad to Haldia. It is the longest waterway in India of length of 1620 km.

All types of vessels are going through this waterway. Farakka Barrage at West Bengal, is the major obstruction in the pathway of NW-1. In 1978, a navigation lock gate was constructed at a branch canal which is starting form Gaziapara adjoining to Farakka feeder canal of the river Ganga. This lock is too old and inefficient and takes two hours or more for a vessel to pass upstream or downstream of Farakka Barrage. Since the modernisation of the existing lock will entail closing down the lock gate for about 8-10 months, it was decided to build a new navigational lock.

In general, navigational lock is a device for raising and lowering ships between stretches of water of different levels in river and canals. It is a complex structure which require the ability to handle the technical difficulties related to both the design and the construction of a lock especially the hydraulic filling and emptying system of the lock. The analysis of Navigation lock consists of force estimation during ship movement in the river and Hawser force criteria which is due to filling/emptying process, design of lock capacity i.e. design of total tonnage of vessel passing through the year, calculation of filling and emptying time. The sequence of locking a vessel upstream is that lowering the water level in the lock to the downstream water level by downstream Radial gates and open the lower gate i.e. downstream Mitre gate and move the vessel into the lock chamber and close the lower gate and fill the lock chamber to the level of the upper pool by upstream Radial gates and open the upstream gate i.e. upstream Mitre gate and move the vessel out of the lock. Lockage of a vessel downstream involves a similar sequence in reverse order. For this operation, two Mitre gates and four Radial gates are proposed and two Caisson gates & eight Bulkhead gates are proposed for maintenance of Mitre gates and Radial gates respectively.

INDEX

Section **Page no.**

List of Figures

List of Tables

List of Abbreviations

NW	⇒	*National Waterway*
ESIA	⇒	*Environmental And Social Impact Assessment*
RIS	⇒	*River Information Service*
TMS	⇒	*Terminal Management System*
DT	⇒	*Displacement tonnage*
CEMT	⇒	*European Conference of Ministers of Transport*
DWT	⇒	*Dead Water Tonnage*
G.V.F	⇒	*Gradually Varied Flow*
C.G.	⇒	*Centre of Gravity*
u/s	⇒	*Upstream*
d/s	⇒	*Downstream*
IWAI	⇒	*Inland Waterway Authority of India*
VPH	⇒	*Vessels Per Hour*
TPH	⇒	*Tonnages Per Hour*
ALT	⇒	*Average Locking Tonnage*
ANDL	⇒	*Average No. of Daily Tonnage*
IACS	⇒	*International Association of Classification Societies*
LRFD	⇒	*Load and Resistance Factor Design*
ASD	⇒	*Allowable Stress Design*
AISC	⇒	*The American Institute of Steel Construction*
PLC	⇒	*Programmable Logic Controller*
GI	⇒	*Galvanized Iron*
EGL	⇒	*Energy Gradient Line*
SHM	⇒	*Structural Health Monitoring*
FEM	⇒	*Finite Element Model*

List of Notations

$\mathbf{E}$ ⇒ *Kinetic Energy*

$\mathbf{W_D}$ ⇒ *Displacement Tonnage (Dt) of the vessel*

$\mathbf{v}$ ⇒ *Velocity of vessel*

$\mathbf{g}$ ⇒ *Acceleration due to gravity*

$\mathbf{C_m}$ ⇒ *Mass coefficient*

$\mathbf{C_e}$ ⇒ *Ecentricity coefficient*

$\mathbf{C_s}$ ⇒ *Softness coefficient*

$\mathbf{D}$ ⇒ *Draught of the vessel*

$\mathbf{B}$ ⇒ *Beam of the vessel*

$\mathbf{L_w}$ ⇒ *Length of the vessel*

$\boldsymbol{\gamma}$ ⇒ *Unit weight of water*

$\mathbf{l}$ ⇒ *Distance from the centre of gravity*

$\mathbf{r}$ ⇒ *Radius of gyration*

$\boldsymbol{\theta}$ ⇒ *Approach angle of vessel*

$\mathbf{F}$ ⇒ *Force due to wind*

$\mathbf{C_w}$ ⇒ *Shape factor*

$\mathbf{A_w}$ ⇒ *Windage area*

$\mathbf{P}$ ⇒ *Wind pressure*

$\mathbf{L_P}$ ⇒ *Length between perpendicular*

$\mathbf{D_M}$ ⇒ *Mould depth*

$\mathbf{D_L}$ ⇒ *Average light draft*

$\mathbf{V_z}$ ⇒ *Design wind speed at any height*

$\mathbf{V_b}$ ⇒ *Basic wind speed at any height*

$\mathbf{k_1}$ ⇒ *Probability factor*

$\mathbf{k_2}$ ⇒ *Terrain, height and structure size factor*

k_3 ⇒ *Topography factor*

V ⇒ *Velocity of water*

F_h ⇒ *Hawser force*

α ⇒ *The angle of the water surface against the horizontal*

K ⇒ *The weight of water displaced by the vessel*

Q ⇒ *Rate of flow*

y ⇒ *Depth of flow*

R ⇒ *Hydraulic radius or hydraulic mean depth*

ρ ⇒ *Density of water*

μ ⇒ *Viscosity of water*

F_r ⇒ *Froud number*

D_0 ⇒ *Hydraulic depth of channel*

A ⇒ *Wetted area*

T ⇒ *Top width of channel*

P ⇒ *Wetted perimeter*

n ⇒ *Manning's constant*

S ⇒ *Slope of bed*

p ⇒ *Pressure of flow*

z ⇒ *Potential head*

dA ⇒ *Area of strip*

dF ⇒ *Total pressure on a strip*

dh ⇒ *Thickness of strip*

dM ⇒ *Moment on a strip*

$\bar{h}$ ⇒ *Distance of C.G. from free surface of liquid*

b_s ⇒ *Width of strip*

M ⇒ *Total moment of all forces*

I_0 ⇒ *Moment of inertia about free surface of liquid*

I_G ⇒ *Moment of inertia about an axis passing through C.G.*

F ⇒ *Hydrostatic force*

h^* ⇒ *Centre of pressure*

H_1 ⇒ *Height of water at upstream side*

H_2 ⇒ *Height of water at downstream side*

F_1 ⇒ *Water pressure on gate at upstream side*

F_2 ⇒ *Water pressure on gate at downstream side*

l_g ⇒ *Width of gate*

C ⇒ *Lock Capacity*

N ⇒ *Average Values of No of Vessels*

G ⇒ *Average Tonnage Per Vessel*

T_c ⇒ *Cycle time*

t ⇒ *Lock Operating Time per day*

D_t ⇒ *Value of Operating Days per year*

f_p ⇒ *Positive longitudinal force*

h_l ⇒ *Low water level/empty lock level*

h_f ⇒ *Filled lock level /upstream water level*

z_0 ⇒ *Lock bottom level*

w ⇒ *Lock width*

L ⇒ *Lock length*

i_w ⇒ *Intake width*

C_d ⇒ *Discharge coefficient*

h_m ⇒ *Maximum opening height*

l_s ⇒ *Ship length*

C_b ⇒ *Ship block coefficient*

A_s ⇒ *Area of ship section*

x ⇒ *Distance of ship to lock gate*

$\mathbf{A_{ws}}$ ⇒ *Area of Wet section*

$\mathbf{\delta h_0}$ ⇒ *Difference between low water level and filled lock level*

$\mathbf{V_i}$ ⇒ *Initial flow velocity*

$\mathbf{V_{ml}}$ ⇒ *Maximal Lock Valve Lifting Velocity regarding longitudinal lock waves for lock filling*

$\mathbf{A_{wsm}}$ ⇒ *Area of Wet section alongside the ship*

$\mathbf{v_{ef}}$ ⇒ *Emptying lock filling volume*

$\mathbf{A_{fis}}$ ⇒ *Area of Filling influenced section*

$\mathbf{C_1}$ ⇒ *Geometric coefficient*

$\mathbf{C_2}$ ⇒ *Geometric coefficient*

$\mathbf{C_{sf}}$ ⇒ *Shape factor*

$\mathbf{V_{mr}}$ ⇒ *Maximum lock valve lifting velocity regarding longitudinal momentum reduction for lock filling*

$\mathbf{V_{hl}}$ ⇒ *Decisive Lock Valve Lifting Velocity*

$\mathbf{T_{h0}}$ ⇒ *Nominal Duration of Lifting of Lock Valve*

$\mathbf{T_{ha}}$ ⇒ *Actual Duration of Lifting of Lock Valve*

$\mathbf{h_o}$ ⇒ *Gate opening height*

$\mathbf{A_k}$ ⇒ *Area of lock gate inflow section*

$\mathbf{T_{lf}}$ ⇒ *Lock filling time*

$\mathbf{A_{wse}}$ ⇒ *Area of Wet section alongside the ship at the end of emptying*

$\mathbf{A_{os}}$ ⇒ *Area of door opening section*

$\mathbf{V_{mw}}$ ⇒ *Maximal lock valve lifting velocity for longitudinal lock waves for lock emptying*

$\mathbf{V_{mfd}}$ ⇒ *Maximal lock valve lifting velocity under fluent discharge condition for lock emptying*

$\mathbf{V_{dl}}$ ⇒ *Average door lifting velocity*

$\mathbf{T_{dl}}$ ⇒ *Maximal door lifting time*

$\mathbf{T_{le}}$ ⇒ *Lock emptying time*

H	⇒	*The head difference between u/s and d/s water levels*
K_b	⇒	*Total bend loss coefficient*
K_e	⇒	*Exit/entrance loss coefficient*
K_o	⇒	*Sum of gate loss, friction loss and entrance loss coeffiecient*
h	⇒	*Minimum submergence required above central line of the pipe*
d_p	⇒	*Height of the pipe/culvert*
P_a	⇒	*Hydrostatic force*
P_U	⇒	*Hydrostatic force u/s of gate*
P_D	⇒	*Hydrostatic force d/s of gate*
K_g	⇒	*Gate loss coefficient*
β	⇒	*Ratio of contracted width to the width of the pipe*

CHAPTER – 1

INTRODUCTION

CHAPTER - I INTRODUCTION

A navigational lock is a device for raising and lowering ships between stretches of water of different levels in river and canals. The differentiating characteristics of a lock is a fixed chamber in which the water level can be fluctuated. Locks are key structures for the development of navigation in natural rivers where dams, weirs and barrages control water levels to allow safe navigation. Locks are complex structures which require the ability to manage the technical difficulties related to both the design and the construction of a lock especially the hydraulic filling and emptying system of the lock. The main components of Navigation lock consists of lock pit, approach channels, filling and emptying system. A navigation lock system comprises of gates and valves at the upstream and downstream of lock chamber. Ships passes through a river when obstructed by hydraulic structures like barrage or dam, bypass them through the lock chamber. Locking of the chamber is done by using a system of gates for entering/leaving of ship and filling/emptying of water and system of valves to raise and lower the water level in the lock chamber. It is like an elevator system for raising and lowering the vessels to the equal level as the pool they want to get to.

It is important that the operation process of a navigation lock progresses steadily within a minimum of time to limit the delay for navigation. Hence it is desired that the filling and emptying procedure of the lock chamber is accomplished at the highest rate with safe operation. Thus the rise or fall of water level occurs at a moderate rate in the lock chamber.

The optimisation of the locking process under constraints of a safe operation of the lock is the principle engineering aspect in the hydromechanical design of a shipping lock in a waterway. It is a challenge to avoid impact of ship on lock gates and minimum delay in ship navigation to maintain the economics of the operation.

India has a large scale network of water bodies in the forms of rivers, lakes, canals and backwaters. These network of waterways provide transport facilities across the cities like few canals and backwaters of Gujrat, Kerala, Goa, West Bengal and Assam. Still these inland waterways are not utilized in India as compare to other nations in the world. Inland Waterways Authority of India is working on various projects for better waterways transportation in India. The transportation through inland waterway can provide an efficient and economic transport infrastructure that is flexible and cost effective.

India has inland waterways with a navigable length of 14,544 km but only 37% i.e. 5700 km is utilized presently. Presently following six waterways have been declared as national waterways:

1. Ganga River Basin from Allahabad to Haldia via Farakka of length of 1620 km.
2. The Brahmaputra River from Dhubri to Shadia of length of 891 km.
3. The West Coast Canal from Kottapuram to Kollam including Champakara and Udyogmandal Canals of length of 205 km.
4. Kakinara Puducherry Canals integrated with Godavari and Krishna Rivers of length of 1078 km.
5. East Coast Canal with Brahmani River and Mahanadi River Delta of length of 588 km.
6. Narmada Canal from Bharuch to Hoshangabad of length of 121 km.

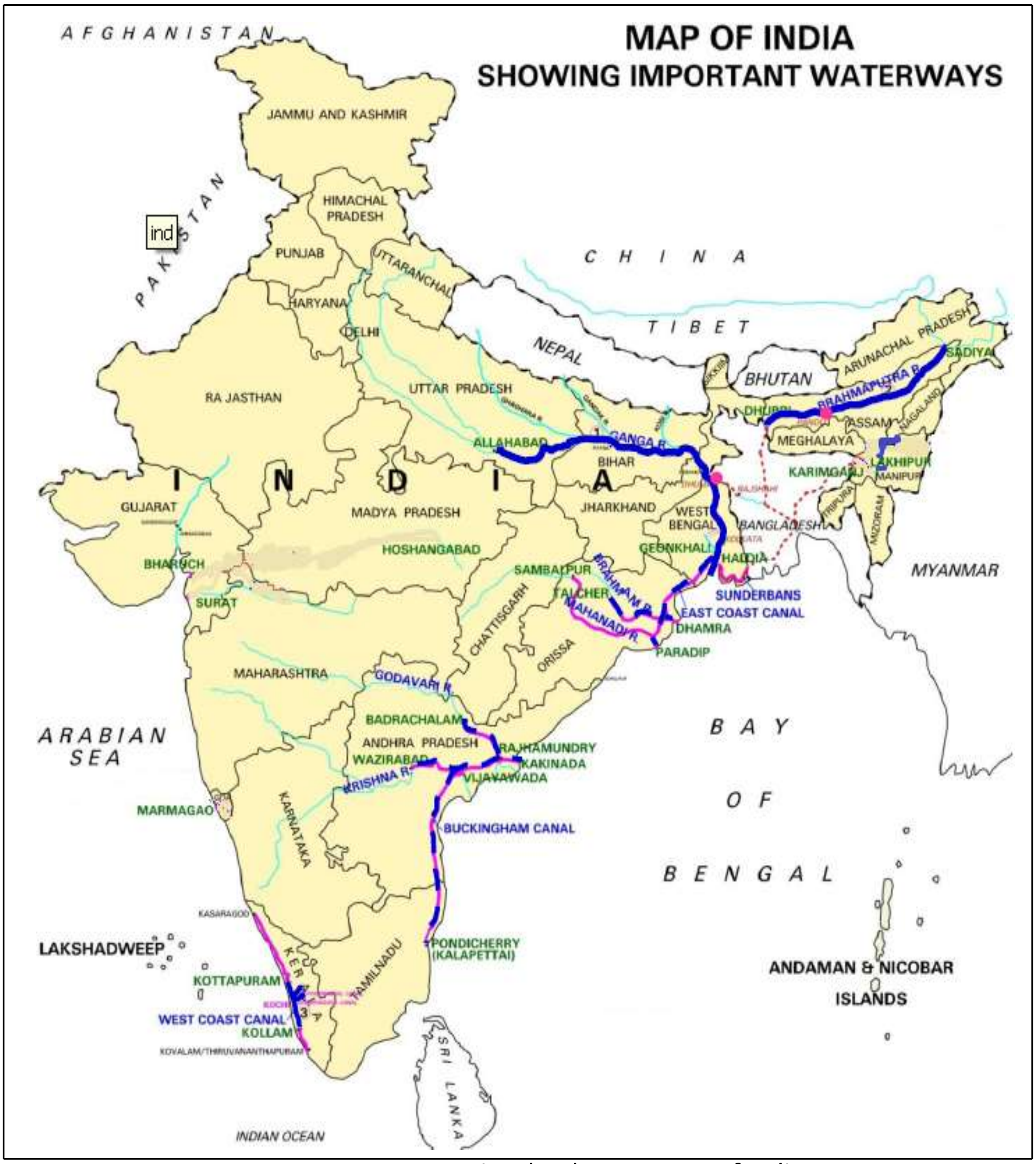

Fig. 1.1: *Important six Inland waterways of India*

(source- **https://en.wikipedia.org/wiki/List_of_National_Waterways_in_India#/media**)

The present study is related to the waterway from Allahabad to Haldia port. There is one major bottleneck in this waterway is the Farakka Barrage. Due to barrage, ships are not passing through there. So, it has been decided that ships will be allowed to pass through 38.3 km length of feeder canal and Navigation lock gate will have to be designed for that purposes.

Fig. 1.2: *New navigational lock concept at Farakka*
(source- **https://twitter.com/IWAI_Ship**)

The enhancement of transport efficiency and reliability of National Waterway-1 (NW-1) are major scope of the First Capacity Augmentation of the National Waterway Project for India and the augmentation of institutional capacity for the development and management of India's inland waterway transport system in an environmentally sustainable manner be the important objective of waterway project.

The project consists of two components. The first component is improving the navigability of NW-1 (Haldia to Varanasi) includes six sub-components:

(i) Financing the project, detailed topographic survey, technical feasibility and detailed engineering studies, environmental and social impact studies, studies for project preparation and supporting technical assistance,

(ii) Construction of permanent protection works for erosion-prone banks in selected location upto 38.3 km,

(iii) Improvement of river fairway through river conservancy works,

(iv) Rehabilitation of the existing Farakka ship lock and construction of a new parallel lock to allow concurrent two-way working,

(v) Construction of: a) six multimodal and inter-modal freight terminals to allow evolution as market clusters, b) two vessel repair and maintenance facilities

(vi) Sixth sub-components consists of: a) enhancement of the existing river information service(RIS) through addition of digital system, improved communication system, b) navigational aids i.e. night navigation facilities , c) development of terminal management system (TMS), and d) regulation of other support services like search and rescue, distress response and casuality incident management and technically upgrading ships.

The second components is focused on construction of New Navigation lock at Farakka for safe movement of vessel and protecting the variation of water level.

CHAPTER – 2

AIMS AND OBJECTIVE

CHAPTER - 2 AIMS AND OBJECTIVE

The National Waterway-1 (NW-1) is located in India and flows from Allahabad to Haldia. It is the longest waterway in India of length of 1620 km. It is of prime importance as compared to all other national waterways considering its locational benefits. The National Waterway-1 runs through major towns of West Bengal, Jharkhand, Bihar and Uttar Pradesh.

In 1975, a barrage was constructed across the river Ganga at Farakka. Depending upon the flow rate in Ganga and the feeder canal, water level of upstream pond and feeder canal is varied. To negotiate this fluctuation of water level, Navigation lock is required.

There is no way to pass ship through Farakka Barrage in the pathway of the waterway. Finally it is decided that ship will have to pass through the feeder canal of Farakka and in order to negotiate the difference in water level a Navigational Lock has to be constructed.

The study will cover the following:

1. Study of following components of Navigational Lock:
   - 1.1 Approach channels
   - 1.2 Lock pit
   - 1.3 Filling arrangement and filling time study
   - 1.4 Emptying arrangement and emptying time study
2. Factors related to design of lock
3. Design calculations
4. Hawser forces
5. Lift of locks
6. Lock capacity
7. Design of gate:
   - 7.1 mitre gate
   - 7.2 Radial gate
   - 7.3 Caisson gate
   - 7.4 Bulk head gate
8. Lock appurtenances:
   - 8.1 Fenders
   - 8.2 Fixed bollards and Floating bollards
   - 8.3 Rubbing strips
   - 8.4 Rung ladders
   - 8.5 Mooring rings
   - 8.6 Capstans

2.1 Study of obstructions in the pathway of the waterway

There are various obstructions in the pathway of national waterway-1 i.e. from Allahabad to Haldia. Major obstruction for passing of ship in the pathway of the waterway is Farakka Barrage at Farakka in West Bengal.

Other obstructions are as following-

- Fluctuation of water level from 16.5 m at Prayagraj to 2 m at Farakka;
- Variation of water velocity from 4 m/s during flood season to 0.2 m/s during dry season;
- Formation of shoal and island causing to splitting of channel;
- Carrying of high silt load around 1600 million tonnes by Ganga annually;
- Braiding and meandering characteristics of river;
- Changing of navigation line due to the lateral migration of river.

2.2 Study of forces generated for ship movement

Ship is decelerated by some obstacle or structure while moving forward in river. The decelerating obstacle is not only the mass of the ship but also a certain amount of water moving along the ship. Generally, current either forces the ship down on the point side of the channel or pushes the ship towards the bend side of the channel according to taking time of turning by pilot. Wind force also be affects on ship. Due to effect of these forces, various loads like berthing load, mooring loads are created. A ship is usually moored with mooring lines along the lock chamber walls during the filling and emptying of a navigational lock. Consequently, forces in the mooring lines are generated by the forces acting on the ship. So, the hydrodynamic and hydrostatic forces are elaborated by it on a ship during the filling and emptying of a lock.

The hydraulic design of a lock filling and emptying system quantify the minimization of the filling and emptying time, followed by so-called hawser forces. The hawser force criteria is set to determine the necessary threshold value of unbalanced hydrodynamic forces on vessel generated during filling and emptying in order to limit the displacement of the vessel and the associated forces in the vessel positioning system. The hawser forces are defined as Forces exerted on the Mooring lines or Hydrodynamic forces on the ship's hull or Hydrostatic forces on the ship's hull or Forces deducted from water level slopes (Ref: A.13.).

2.3 Purpose of provision of navigational lock

To limit the delay for navigation process, it is important that the operation process of a navigation lock progresses steadily within a minimum of time. Hence it is desired that the filling and emptying procedure of the lock chamber is accomplished at the highest rate with safe operation. Thus, the rise or fall of water level occurred at a moderate level in the lock chamber. The important aspect of design of navigational lock in a waterway is to enhance the locking process under the constraints of a safe operation of lock and avoiding the impact of ship on lock gates and minimum delay in the ship navigation to maintain the economics of the operation.

Furthermore, this thesis can be added value to engineering sectors, construction firm and educational institutes. These studies will help to get knowledge of the past behaviour of the channels and provide useful guidelines for designing the navigational lock. The analytical studies for the whole structure to access capacity of lock chamber, filling/emptying time of lock chamber, check for air entrainment and cavitation in the hydraulic system, waves, currents and turbulence generation in the lock chamber. The rate of flow through culverts, head losses particularly in bends and interdependent interaction of various elements such as speed of the opening of the valves with the locking duration.

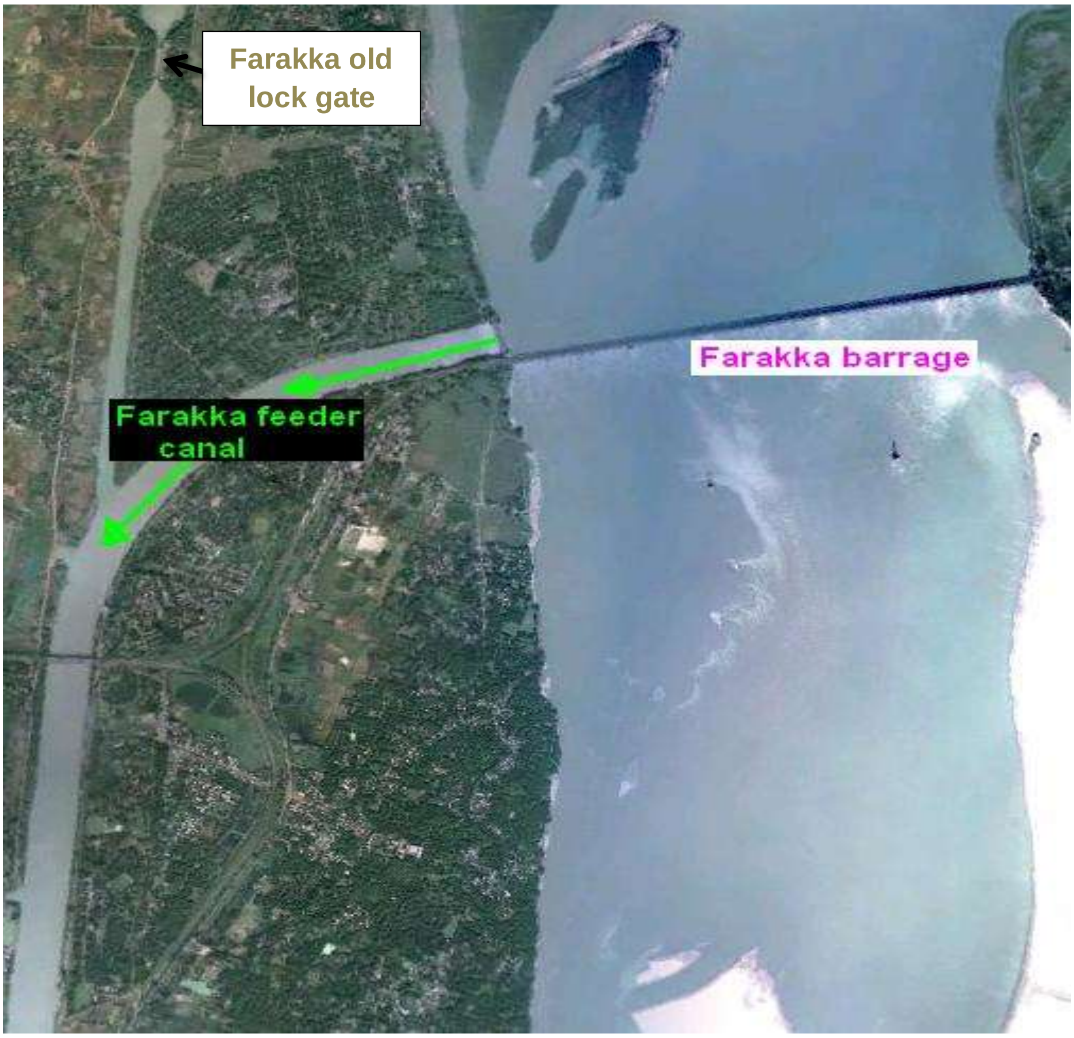

Fig. 2.1: *Farakka feeder canal*

(source- **http://www.livingtravel.com/asia/india/2015_GangesCruise_04.html**)

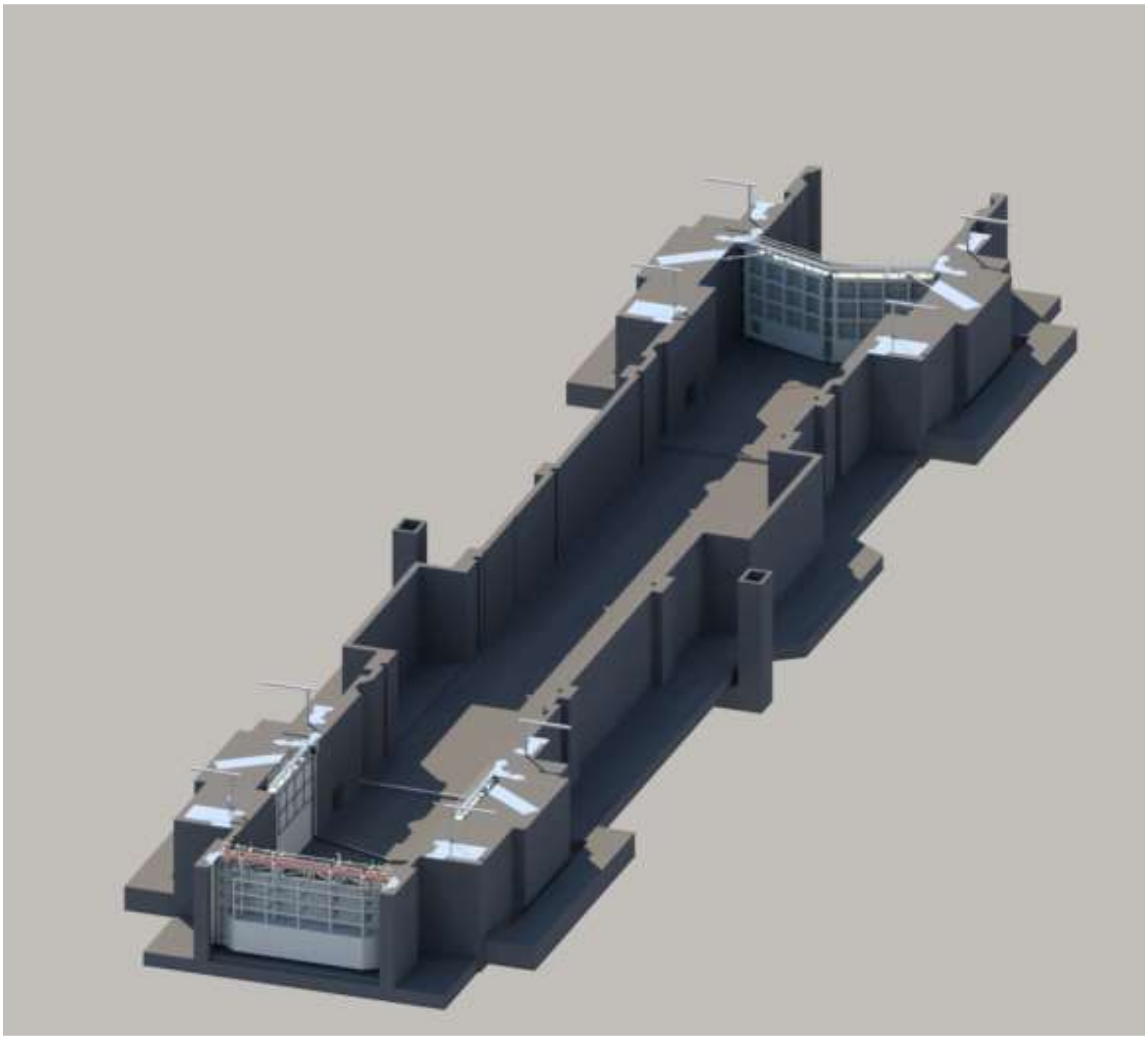

Fig. 2.2: *Three dimensional view of new Navigation lock gate at Farakka*
(source- **http://www.sbe.be/en/reference/navigational-lock-farakka**)

CHAPTER – 3

LITERATURE REVIEW

CHAPTER - 3 LITERATURE REVIEW

- **P. Woelke et al.** *(2011)* presented the results of a ship impact study conducted using various analytical approaches. When a vessel moves forward in a river, it faces various obstruction like wave, wind. So, hydrodynamic forces are generated due to action of current and wind energy. These forces can be simplified by various analytical approaches.

- **J.J. Blok, L.H. Brozius and J.N. Dekkar** *(1983)* presented analysis of impact loads of ships colliding with fixed structures which is the crucial factor in the design calculations. Ships are obstructed due to effect of dynamic energy like wave-current, wind. These loads are simplified by analysis of dimension of ship, underkeel clearance, spring characteristics of the obstacle and collision behaviour.

- **Robert L Fingular** *(2017)* analysed vessel handling in rivers and estuaries. Bank suction and bank cushion effects on a vessel during the movement in a river of straight channel. Bank suction refers to a vessel being pulled towards the bank and on the other hand, bank cushion refers to a vessel being pushed away from the bank. While making a turn with current, it is possible to make different maneuvers like Hug the point, stay in bend and proceed to bend side, middle side of the channel.

- **S. Roux, P. Roumieu, T. De Mulder** *(2010)* presented Hawser force criterion which need to be analysed to find maximum allowable force on a ship during the emptying and filling of lock. The definitions of Hawser forces can be differentiated as Forces exerted on the mooring lines, Hydrodynamic forces and Hydrostatic forces exerted on ship's hull, Forces deducted from the water level slopes. Forces exerted on mooring lines can be defined as reaction forces which are opposing to the ship displacement and needed to sustain the ship in a given position in the lock chamber. Hydrodynamic forces exerted on ship's hull may be defined as pressure forces due to the difference of water level, drag forces generated from the flow around the hull, turbulent forces caused from the energy dissipation in the lock chamber. Hydrostatic forces exerted on ship's hull is defined as hydrostatic pressure distribution along the ship's hull due to differences of water level along the ship's hull. Forces deducted from water level slopes is defined as an approximate estimate of the hydrostatic forces exerted on ship's hull transversal and longitudinal components.

- **K. Verelst, J. Vercruysse, T. De Mulder** *(2013)* obtained pragmatic force criterion for the design of a navigation lock filling and emptying system. Forces are generated in the mooring line generated by forces impacting on vessel while a vessel is usually moored in mooring lines along the lock chamber during the filling and emptying of a navigational lock. The design of filling and emptying system of lock maintain the balance between optimum filling and emptying time of lock and the maximum forces on the ship. So, this pragmatic force criteria quantify maximum value of unbalanced force for design purposes to prevent of vessel and lock infrastructure.

- **T. De Mulder, K. Verelst, J. Vercruysse, W. De Cock, M. Haegeman** *(2010)* analysed Hawser force criteria for navigation lock design for case study of maritime locks. Hawser force criteria can be adopted to determine the maximum unbalanced force acting on ship during the filling and emptying of lock. The force should be under threshold value. Hawser forces criteria provides sufficient grade of safety and comfort during filling and emptying of lock.

- **John P. Davis** *(1989)* presented a report on hydraulic design of navigation locks in an inland waterway of USA. Hydraulic design of locks have been demanded for growth of traffic and safe navigation. In order to maintain the water level variation, the navigational lock has been constructed. The hydraulic analysis consists of lock capacity, filling and emptying system, valve operation. Design of lock capacity determines number of ships passes through the lock chamber per year or estimation of annual tonnage movement. The annual tonnage consists of the number and size of lock chamber, the percentage of days per year that locks are actually operated. Filling and emptying system evaluate the minimization of filling and emptying time constrained by hawser stresses and quantify the threshold value of unbalanced force acted on ship. Valve operation involve in lock filling and emptying system. Filling of lock chamber with water as same level as upper pool has been done by opening of filling valve and emptying of lock chamber for making same level as lower pool has been done by opening of emptying valve.

- **Amit Dhanuka, Shivendra Kumar Agarwal and Honey Mehra** *(2018)* presented a report on Hydraulic design and Structural design of Navigational lock. Navigation lock operation provides to overcome water level variation due to tidal variation or construction of dam/barrage and create safe and secure navigation in a canal or river. This operation can also minimize the delay of navigation. The major components of lock consists of lock pit, approach channels, filling/emptying operation. Design of lock depends on variation of water levels, design of lock capacity, ship dimension, design of filling/emptying system.

- **T. De Mulder** *(2011)* discussed computational fluid dynamics in lock design. For analysis of lock design Velocity and Pressure distribution, Turbulent condition, Boundary condition, Burnoulli's equation are required.

- **Ph. Rigo** *(2009)* presented the PIANC report n° 106 on innovations in lock design. Locks are complex structures for the development of navigation process in rivers where dam, barrages, weir control water levels to allow navigation. They are in the form of strategic infrastructure for Port and Harbour development.

- **R.L. Stockstill, J.E. Hite, Jr.** *(2011)* discussed innovation of lock filling and emptying systems. It is meant as maintaining between minimum time of filling/emptying operation and minimum unbalanced force acted on ship's hull. Innovation design are experimented to reduce construction and maintenance cost. Culvert phenomena are designed to provide steady and uniform flow distribution along the lock which is required to limit the water surface slope.

- **J.A. Hufferd, T.J. Isbester** *(1966)* presented hydraulic model studies used to improve the original design of the underground stilling basin for the Navajo Main Canal headworks structure. There should be placed radial gates in the upstream and downstream lock chamber. This gate allows the water to enter and leaving the lock and violet the backwater effect. This gate have to be designed the sufficient height for safe operation.

- **M.Z. Voorendt, W.F. Molenaar, K.G. Bezuyen** *(2016)* discussed on construction and design of caisson gate. A caisson is defined as a restraining watertight box in order to keep out water during construction. Caisson gates can be used in upstream and downstream of lock chamber. It is used to maintain the mitre gate. Generally, when mitre gates are under maintenance or repaired, then caisson gates are used as replacement work of mitre gates.

- **Ryszard A. Daniel** *(2000)* discussed about mitre gates phenomena in a lock project. Generally lock gates are constructed to maintain the water level variation and enable safe navigation. Mitre gate is most common types of gate designed in a navigation lock project. It is used in both upstream and downstream lock chamber. It allows the ship to enter and leave the lock.

- **Anouk Gerritse** *(2016)* discussed about load principles for drive mechanism of mitre gates. There are many functions in a navigation lock like, navigation, water management, flood protection. There are many problems which effects in the lock gate. Due to safe navigation and maintaining the lock system, all problems have to be solved. Air entrainment forces, cavitation may effects in the system. They should be checked before design. Hydrostatic and hydrodynamic forces acting on gate are analysed for design purposes.

- **George C. Rechardson** *(1964)* discussed that gates and valves for navigation locks are classified according to function as culvert valves, lock gates or emergency closure gates. Mitre lock gates are constructed at both upstream and downstream lock chamber. Mitre gate allowed the ship to enter and leave the lock chamber. Caisson gates are used to maintain the mitre gate while mitre gates are under maintenance. Radial gates are placed at both upstream and downstream lock chamber for allowing water to fill and empty the lock chamber as required. When radial gates are under maintenance, bulkhead gates are used for maintaining purposes. In case of valve, there are two sets of valves are used i.e. one in upper pool and other in lower pool. Valves in the upper pool are used to allow water to fill the chamber and valves in the lower pool are used to allow water to drain out the chamber.

- **Matteo Camporese** *(2013)* discussed about morality of mitre gate used in a lock system. Gates in upstream are facing more current. So, horizontal framed mitre gate is most authentic arrangement to face current. The design of mitre gate structure shall be based on framing. Horizontal member which is the straight girder will support the skin plate of horizontally framed gate. All the current load would be transmitted through girder. Mitre gates are constructed to allow ship to enter and leave the lock chamber.

CHAPTER – 4

NATIONAL INLAND WATERWAYS IN INDIA

CHAPTER - 4 NATIONAL INLAND WATERWAYS IN INDIA

India has a large scale network of water bodies in the form of rivers, lakes, canals and backwaters. These network of waterways are provides transport facilities across the cities like canals in Gujrat, backwaters of Kerala and few waterways in Goa, West Bengal and Assam. Still these inland waterways are not utilized in India as compare to other nations in the world. Inland Waterways Authority of India (IWAI) is working few projects for better waterways transportation in India.

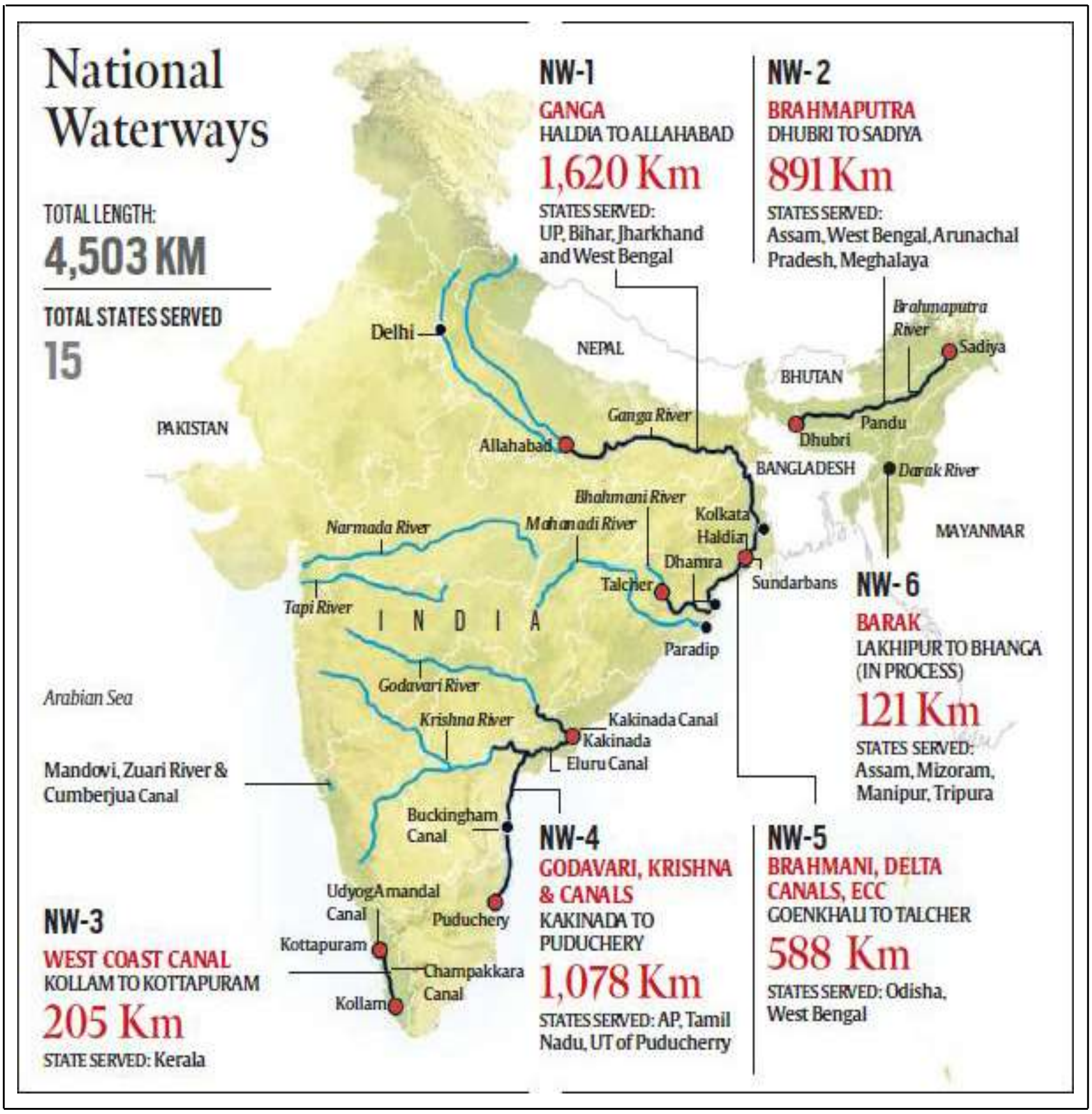

Fig. 4.1: *Six Inland waterways of India*

(source- **http://www.bcompetitive.in/national-waterway-act-2016**)

National Waterway 1

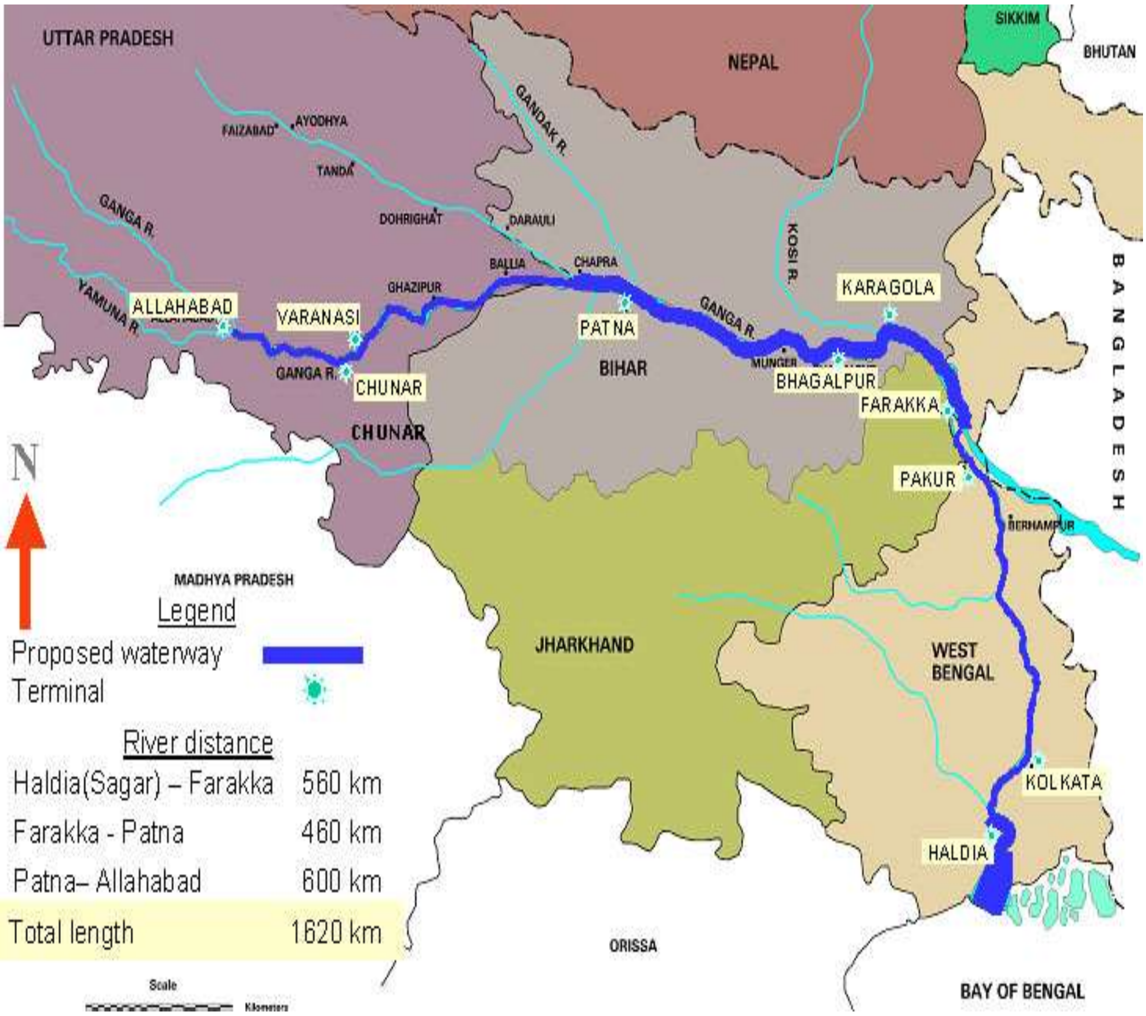

Fig. 4.2: *National waterway 1*

(source- **http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=National Waterway-1**)

National Waterway 1 or NW-1 will starts from Allahabad to Haldia with an distance of 1620 km. The NW-1 flows through states of West Bengal, Jharkhand, Bihar, Uttar Pradesh. There are barrages at Farakka and Jangipur in the pathway of this waterway. The navigable way in the upstream direction after Farakka barrage is through main Ganga river. The NW-1 run through the Ganges, Bhagirathi and Hooghly river system with having fixed terminals at Haldia, Farakka and Patna and floating terminals at most of the riverside cities like Kolkata, Bhagalpur, Varanasi and Allahabad. It will be the longest National Waterway in India. This waterway has more importance as compared to other waterways.

National Waterway 2

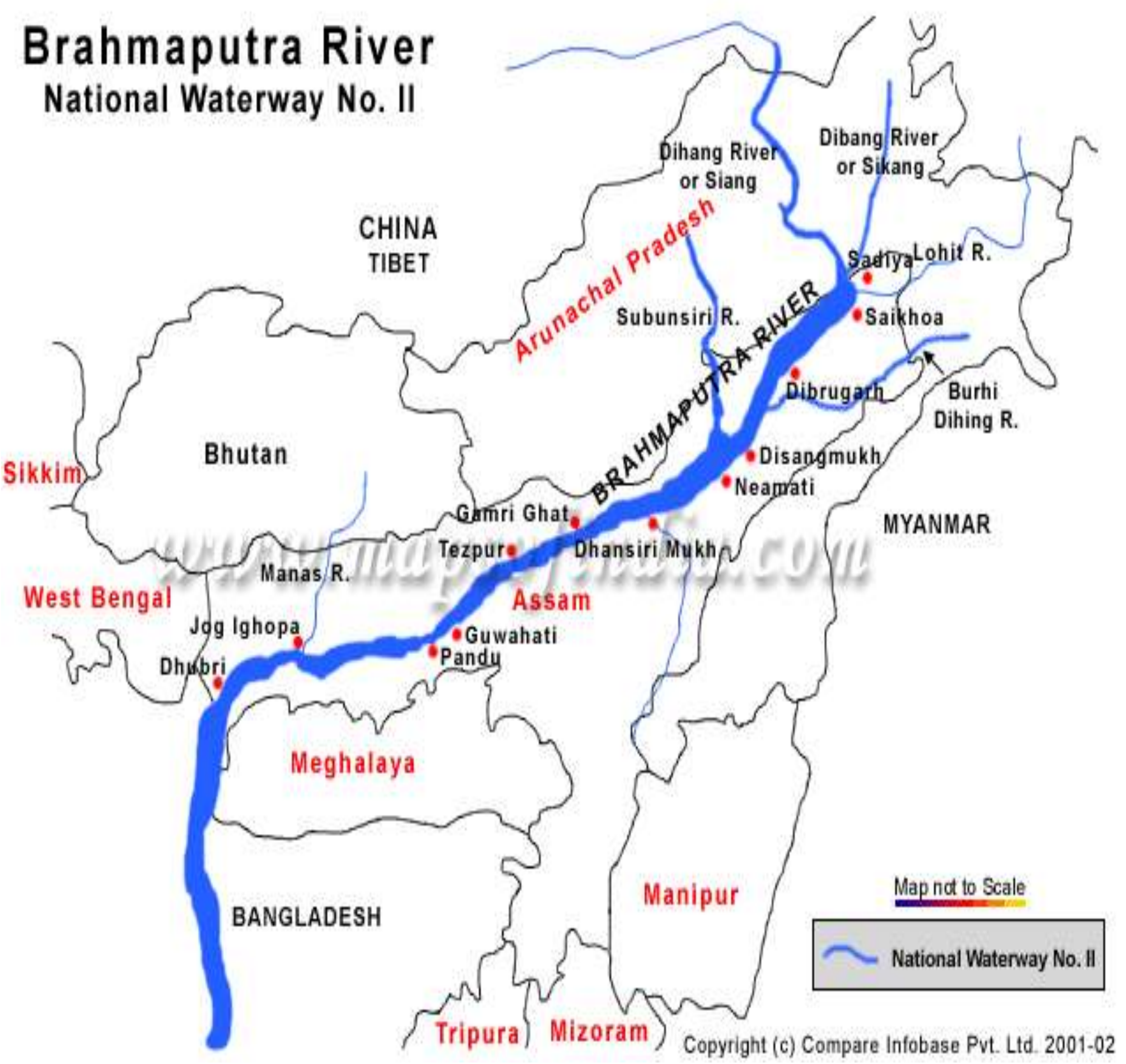

Fig. 4.3: *National waterway 2*

(source- **http://www.mapsofindia.com/maps/inlandwaterways/nationalwaterway2.html**)

National waterway 2 will stretch on Brahmaputra from Sadiya to Dhubri in Assam state. The NW-2 is one of the major freight transportation waterway of north-east India and the third longest waterway with an total length of 891km. There is a important route for IWT vessel through the Brahmaputra along with its continuous water routes leading upto Kolkata and Haldia. The NW-2 run through the Brahmaputra river system with having fixed terminals at Pandu and floating terminals at Dhubri, Pandu, Jogighopa, Tezpur, Silghat, Jamuguri, Neamati and Dibrugarh. It is the fourth longest national waterway in India.

National Waterway 3

National Waterway No. 3

Fig. 4.4: *National waterway 3*

(source- **http://www.iasabhiyan.com/national-inland-waterways-india**)

National waterway 3 or the west coast canal is located in Kerala state and run from Kollam to Kottapuram. The 205 km long west coast canal is India's first waterway with all time navigation facility. The components of this waterway are back waters, natural lakes, river sections and man-made canal sections. The NW-3 consists of west coast canal, Champakara canal and Udyogmandal canal and runs through Kottapuram, Cherthala, Thrikkunnapuzha Kollam and Alappuzha. The NW-3 run through the West Coast Canal system with having terminals at Kottapuram, Aluva, Maradu, Viakom, Thaneermukam (Chertala), Trikkunnapuzha and Kayamkulam. The terminal at Kollam is now under construction process. According to length of all waterways, it has twenty fifth position.

National Waterway 4

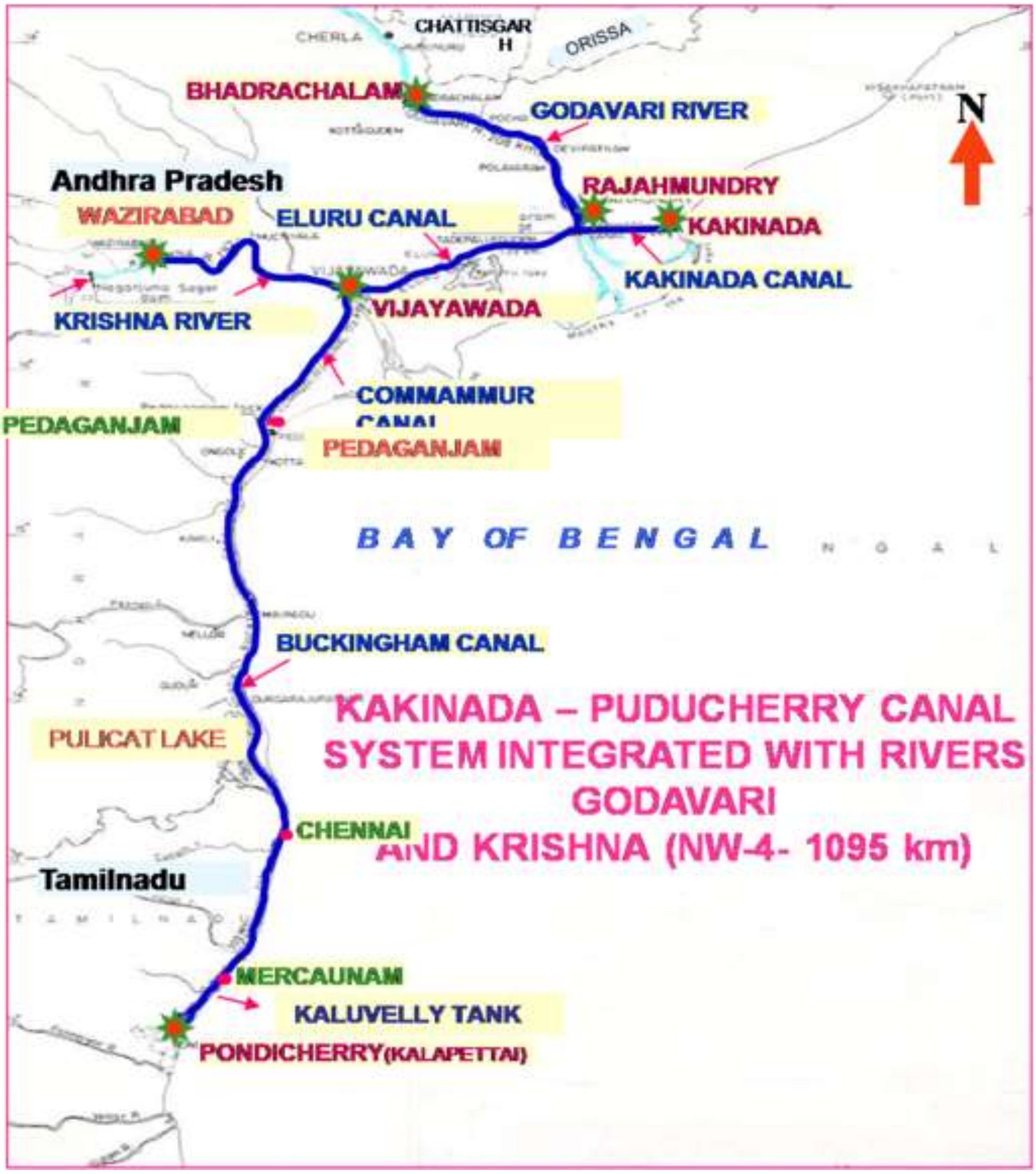

Fig. 4.5: *National waterway 4*

(source- **http://en.wikipedia.org/wiki/National_Waterway_4**)

National waterway 4 is connected from Kakinada to Pondicherry through Canals Tank and river Godavari along with Krishna river. The NW-4 the second longest waterway of India with total length of 1095 km in Andhra Pradesh and Tamilnadu.

National Waterway 5

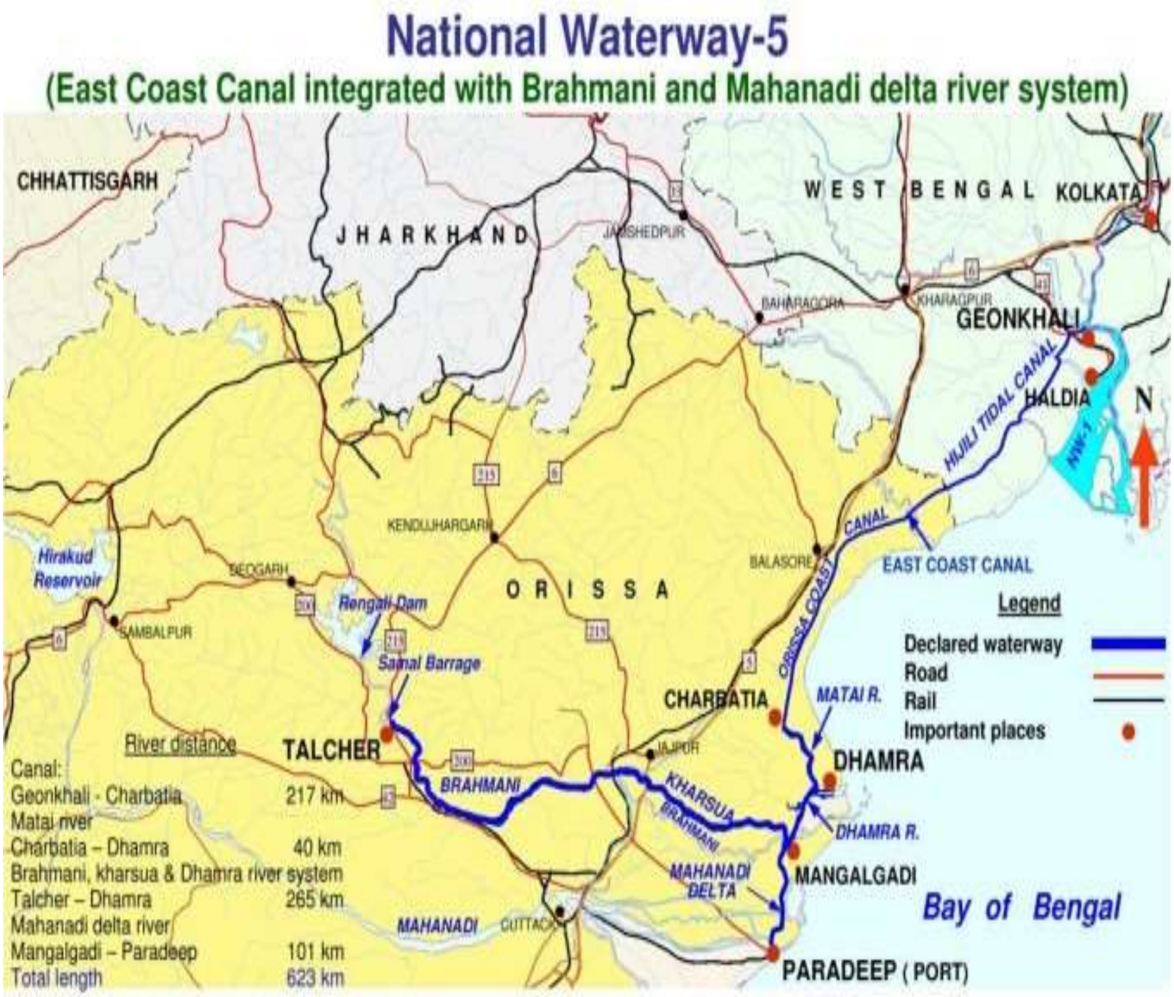

Fig. 4.6: *National waterway 5*

(source- **http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=National_Waterway-5**)

National waterway 5 connects Orissa to West Bengal using the stretch on Brahmani river, East Coast canal matai river and Mahanadi River delta. Generally, the canal stretch between Geonkhali and Charbatia, part of Matai river between Charbatia and Dhamra, part of Brahmani, Kharsua and Dhamra river system between Talcher and Dhamra and Mahanadi delta river system are included in National Waterway 5. The 623 km long canal system will handle the traffic of cargo such as coal, fertilizer, cement and iron. The NW-5 run through the Brahmani river, East Coast canal matai river and Mahanandi River delta system with having terminals at Talcher, Jenapur, Dhamra, Paradip, Balasore, Nasirabad, Geonkhali. According to length, it has seventh position.

National Waterway 6

Fig. 4.7: *National waterway 6*

(source- **http://www.india-wris.nrsc.gov.in/wrpinfo/index.php?title=National_Waterway-6**)

National waterway 6 is the proposed waterway in Assam state and will connect Lakhipur to Bhanga in river Barak. The 121 km long waterway will help in trading between town of Silchar to Mizoram state.

Six important National Inland Waterways are discussed. But the present study is about to the National Waterway-1 connects from Allahabad to Haldia port. It is one major resistor in this waterway is the Farakka Barrage. Due to barrage, ships are not passing through. So, it has been decided that ships will be allowed to pass through 38.3 km length of feeder canal and Navigation lock gate will have to be designed for that purposes.

CHAPTER – 5

SHIP MOVEMENT AND ANALYSIS OF HAWSER FORCES

CHAPTER - 5 SHIP MOVEMENT AND ANALYSIS OF HAWSER FORCES

Ship is decelerated by some obstacle or structure while moving forward in river. The decelerating obstacle is not only the mass of the ship but also a certain amount of water moving along the ship. Generally, current either forces the ship down on the point side of the channel or pushes the ship towards the bend side of the channel according to taking time of turning by pilot. Bank cushion directs the vessel being pushed away from the river bank and bank suction directs the vessel being pulled towards the bank. Wind force also be affects on ship. Due to effect of these forces, various loads like berthing load, mooring loads are created. A ship is usually moored with mooring lines along the lock chamber walls during the filling and emptying of a navigational lock. Consequently, forces in the mooring lines are generated by the forces acting on the ship. So, the hydrodynamic and hydrostatic forces are elaborated by it on a ship during the filling and emptying of a lock.

Factors regarding to Design of Vessel Movement in Waterways are as following:

- ✓ Variation of Water Level (including seasonal variation)
- ✓ Variation of depth of Water and depth of Canal (including seasonal variation)
- ✓ Depth of Water during Lean Season
- ✓ High Flood Level
- ✓ Discharge Conditions (including seasonal variation)
- ✓ Tidal Condition and variation of Water Level, Velocity , Discharge
- ✓ Cross Section
- ✓ Bed and Bank Material
- ✓ Sedimentation characteristics (including Seasonal Variation)
- ✓ Topographic Data
- ✓ Hydrographic Data
- ✓ Drainage data including basin configuration.

5.1 Study of effects on a vessel moving in river

When a vessel take turn in a sharp bend in a narrow channel, then it is affected by bank suction, bank cushion, currents and wind forces. When the bank of a channel is steep then bank cushion and bank suction become strongest and when the edge of a channel shoals gradually and extends into a large area then they become weakest. Generally, bank suction and bank cushion are expanded with the vessel's speed. Channel currents become strongest in the bend side of a channel with counter-currents and shoaling on the lee side of the point. Velocity of the current is greater in deeper water as compared to shallow water.

The ship makes good speed with little help from the engines in a following current.. When a ship is being made a sharp turn with a following current, it is possible to make the following maneuvers (Ref: A.1.):

- Hug the Point
- Stay in the Bend
- Proceed on the Bend Side, Middle of the Channel

- **Hug the point** - A little amount of rudder is carried by the vessel pilot towards the near bank to steer a straight course. When the channel is begins to bend and the vessel moved from the bank, less rudder will be required. This signal permits it to begin the turn. However, around the bend, slack water and eddies makes it difficult to prevent a sheer towards the near bank, especially in shallow water. The current acting under the quarter may affects the stern, and results in an expand in sheer.

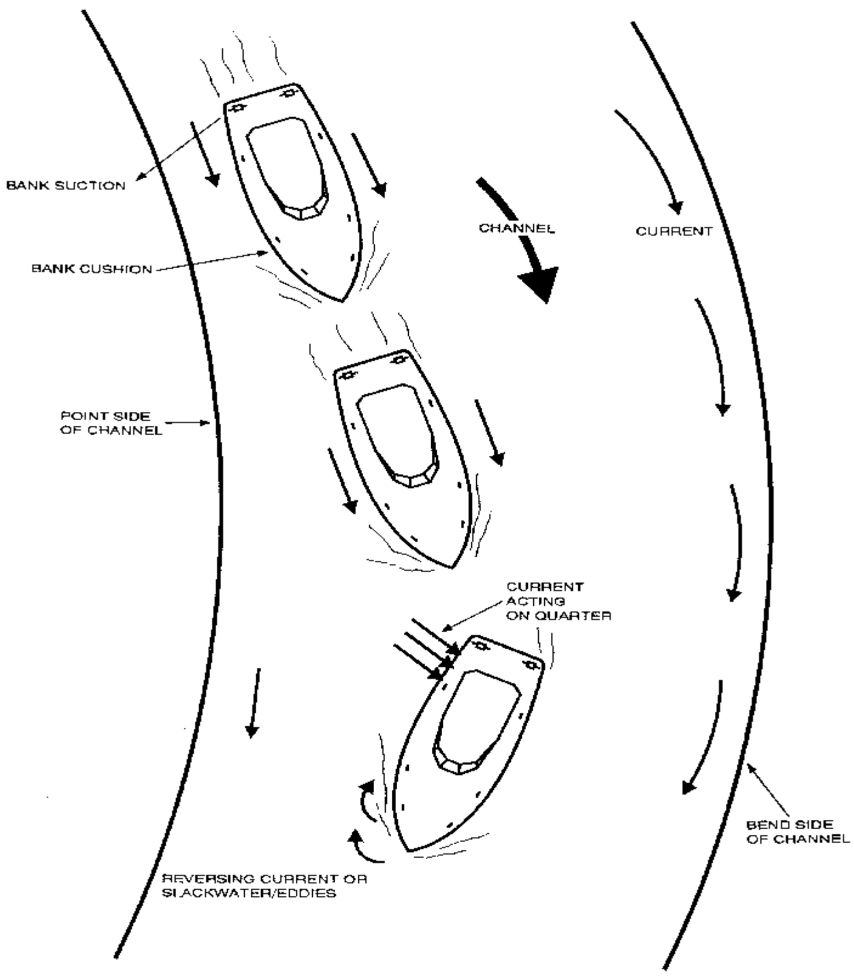

Fig. 5.1: *Nudging the Point: Current Astern*

(source- **https://www.marineinsight.com/naval-architecture/rudder-ship-turning/html**)

- **Stay in the Bend** - This maneuver is a turn in the bend side of channel away from the point side of channel and it takes precise timing. If it is done by taking long time, the vessel is grounded on the bank in the bend. If it is done too soon, there is extreme danger that makes a strong and sudden sheer. The vessel is given the sheer by combination of bank suction on one quarter and current on other quarter. Also, the sheer is increased by the bank cushion under the bow.

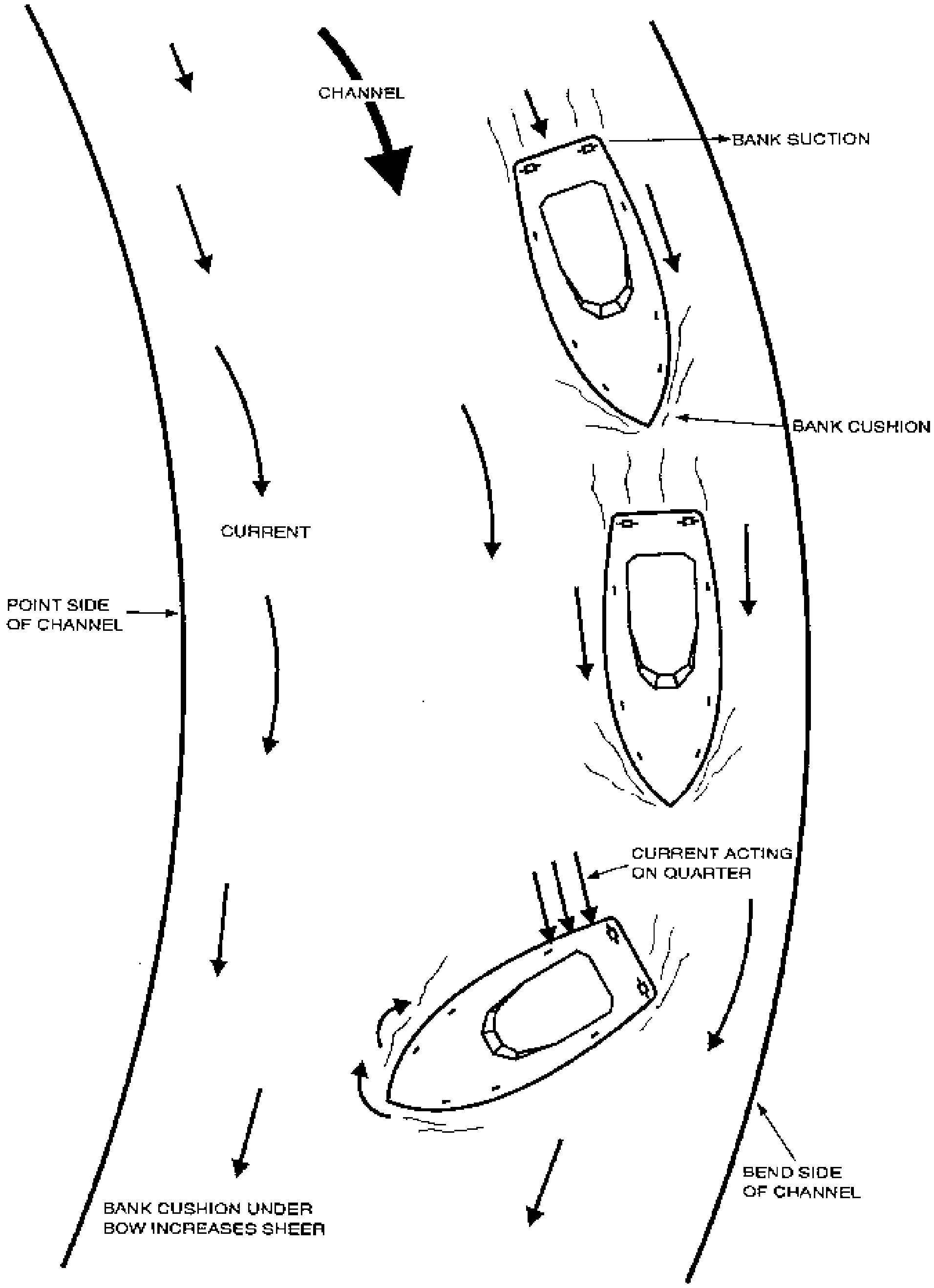

Fig. 5.2: *Keeping in the Bend: Current Astern*

(source- **https://www.marineinsight.com/naval-architecture/rudder-ship-turning/html**)

- **<u>Bend side, middle of the channel</u>** - It is the safest method under the condition of following current approaching the turn steering a course toward the bend side of the middle of the channel. By doing this, the eddies are avoided by the vessels under the point and currents are increased in the bend. The force of the current could be used by operator against the quarter to help in the turn. Then a vessel would be forced towards the bend side and consequently, the turn is commenced early in the bend by a following current. When the vessel is forced by head current towards the point side, then be waited and commenced for turning later.

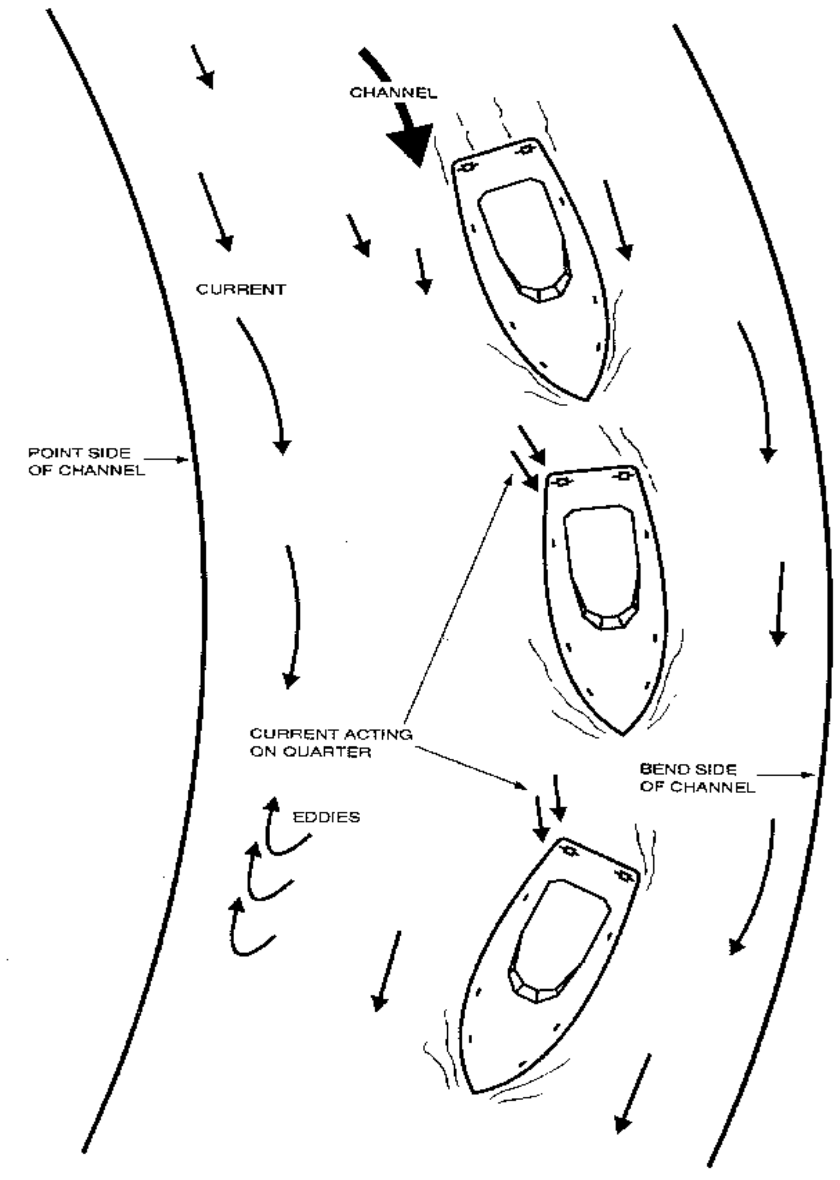

Fig. 5.3: *Approaching Slightly on the Bend Side of the Channel: Current Astern*

(source- **https://www.marineinsight.com/naval-architecture/rudder-ship-turning/html**)

5.2 Load characteristics

Berthing Load

A horizontal force is acted on a berth due to striking of approaching vessel on the berth. The magnitude of this horizontal force is dependent on the kinetic energy that can be absorbed by the rendering system. This kinetic energy is dependent on the weight tonnage of vessel, velocity of vessel, mass coefficient, eccentricity coefficient, softness coefficient and also the velocity of vessel. The berthing load can be determined through the reference of IS: 4851 (Part-III)- 1974. The kinetic energy, E is imparted to a rendering system, by moving of vessel with velocity V m/s is given by:

$$E = \frac{W_D \times v^2}{2g} \times C_m \times C_e \times C_s \qquad \text{(from IS: 4851 (Part III) - 1974)}$$

where,

$W_D \Rightarrow$ Displacement tonnage (DT) of the vessel, in tonnes,
$v \Rightarrow$ Velocity of vessel in m/s, normal to the berth,
$g \Rightarrow$ Acceleration due to gravity in m/s^2 ,
$C_m \Rightarrow$ Mass coefficient,
$C_e \Rightarrow$ Ecentricity coefficient,
$C_s \Rightarrow$ Softness coefficient

- **Mass coefficient -** When a vessel is approached on a berth and as its motion is suddenly checked, the impact force which the vessel imparts be comprises of the weight of the vessel and an effect due to moving of water along with the moving vessel.

a) The mass coefficient C_m should be calculated as follows:

$$C_m = 1 + \frac{2D}{B} \qquad \text{(from IS: 4851 (Part III) - 1974)}$$

Where,

$D \Rightarrow$ Draught of the vessel in m,
$B \Rightarrow$ Beam of the vessel in m,

b) in case of a vessel which has a length much greater than its beam,

$$C_m = 1 + \frac{\frac{\pi}{4} D^2 L_W}{W_D} \qquad \text{(from IS: 4851 (Part III) - 1974)}$$

where,

$D \Rightarrow$ Draught of the vessel in m,
$L_W \Rightarrow$ Length of the vessel in m,
$\gamma \Rightarrow$ Unit weight of water
$W_D \Rightarrow$ Displacement tonnage (DT) of the vessel, in tonnes,

- **Eccentricity coefficient –** When a vessel is approached on a berth at an angle θ and touches it at a point either near the bow or item of the vessel, a horizontal force acting on berth. According to IS: 4851 (Part III)- 1974, this force is affected by eccentricity coefficient.

a) The eccentricity coefficient (C_e) may then be expressed as follows-

$$C_e = \frac{1+(l/r^2)\sin^2\theta}{1+(l/r^2)}$$ (from IS: 4851 (Part III) - 1974)

where,

$l \Rightarrow$ Distance from the centre of gravity of the vessel to the point of contact projected along the water line or the berth in m,
$r \Rightarrow$ Radius of gyration of rotational radius on the plane of the vessel from its centre of gravity in m,
$\theta \Rightarrow$ Approach angle of vessel

b) The approach angle θ with known with accuracy should be taken as 10°. In case of smaller vessels approaching wharf structures, the approach angle should be taken as 20° .
c) The rotational radius of a vessel may be considered as L/4 and, in normal case, the point of contact of the berthing vessel with the structure may be taken at a point about L/4 from the bow or stern of the vessel, which is known as a quarter point contact. Also, when the approach angle θ is closes to 0°, then

For large tankers, r = 0·2L, then C_e = 0·4.

- **Softness coefficient -** This softness coefficient (C_s) defines the relation between the rigidity of the vessel and that of the fender, and hence also the relation between the energy absorbed by the vessel and by the fender. Since the ship is relatively rigid as compared to the usually yielding rendering systems, the value of C_s of 0.90 is generally applied for this factor, or 0.95 if higher safety margin is desirable as per the recommendation of IS: 4651 (Part III)-1974.

The following table shows normal velocities of vessels as per IS:4651(Part III)-1974

Site condition	Berthing condition	Berthing velocity normal to the berth in m/s			
		Upto 5000 DT	Upto 10000 DT	Upto 100000 DT	More than 100000 DT
Strong wind and swells	Difficult	0.75	0.55	0.40	0.20
Strong wind and swells	Favourable	0.60	0.45	0.30	0.20
Moderate wind and swells	Moderate	0.45	0.55	0.20	0.15
Sheltered	Difficult	0.25	0.20	0.15	0.10
Sheltered	Favourable	0.20	0.15	0.10	0.10

Table 5.1: *Normal velocities of vessels as per IS: 4651 (Part III) -1974*

❑ Mooring Loads

The mooring loads are the lateral loads due to the lines when vessels are pulled into or along the dock or hold it against the current and wind force. The maximum mooring loads are caused by the wind forces on exposed area on the broad side of the vessel in light condition:

$$F = C_w \times A_w \times \mathrm{P} \qquad \text{(from IS: 4851 (Part III) - 1974)}$$

where,

F ⇒ Force due to wind in kg,
C_w ⇒ Shape factor = 1.3 to 1.6,
A_w ⇒ Windage area in m^2,
P ⇒ Wind pressure in kg/m^2 to be taken in accordance with IS: 875 – 1964

The windage area (A_w) can be expressed as follows:

$$A_w = 1.175\, L_P\, (D_M - D_L) \qquad \text{(from IS: 4851 (Part III) - 1974)}$$

where,

L_P ⇒ Length between perpendicular in m,
D_M ⇒ Mould depth in m,
D_L ⇒ Average light draft in m,

When the ships are berthed on both sides of a pier results the total wind force acting on the pier, should be increased by 50 percent to allow for wind against the other ship.

❑ Forces due to Current

Pressure due to current (as per IS: 4851 (Part III) - 1974) will be applied to the area of the vessel below the water line under fully loaded condition. It is equal to $\gamma v^2/2g$ per square metre of area, where v is the velocity in m/s and w is the unit weight of water in tonnes/m^3. The ships are generally berthed with parallel to the current. The likely force should be calculated by any recognized method and taken into account with strong currents and where berth alignment materially deviates from the direction of the current.

❑ Wave Forces

According to analysis and computation of forces exerted by waves on structures are concerned, there are three distinct types of waves, namely: a) Non-breaking waves, b) Breaking waves, and c) Broken waves (as per IS: 4851 (Part III) - 1974).

- ***Non-breaking waves*** - Non-breaking wave conditions occur when the depth of water against the structure is greater than $1\frac{1}{2}$ times the maximum expected wave height.
- ***Breaking waves*** - Breaking waves is caused by both static and dynamic pressures. Determination of the design wave for breaking wave conditions is based on depth of water about seven breaker heights, H_s seaward or the structure, in lieu of the water depth at which the structure is located.
- ***Broken waves*** – it is defined as locations or certain structures like protective structure will be such that waves will break before striking them.

❑ Wind Forces

The design wind speed shall be obtained to include the following effects to get design wind velocity at any height for the chosen structure:

a) Risk level,
b) Terrain roughness, height and size of structure,
c) Local topography.
Design wave speed can be mathematically expressed as follows:

$$V_z = V_b\, k_1\, k_2\, k_3 \qquad \text{(from IS: 4851 (Part III) - 1974)}$$

where,

$V_z \Rightarrow$ Design wind speed at any height z in m/s,
$V_b \Rightarrow$ Basic wind speed at any height z in m/s,
$k_1 \Rightarrow$ Probability factor,
$k_2 \Rightarrow$ Terrain, height and structure size factor,
$k_3 \Rightarrow$ Topography factor

5.3 Hawser forces criteria

The hydraulic design of a lock filling and emptying system results the minimization of time of the filling and emptying operation, followed by so-called hawser forces. Hawser forces criteria provides sufficient grade of safety and comfort navigation during filling and emptying of lock. The hawser force criteria is set to quantify the necessary threshold value of unbalanced hydrodynamic forces on vessel generated during filling/emptying, in order to limit the displacement of the vessel and the associated forces in the vessel-positioning system. Ship movements must be avoided or kept to acceptable limits inside the lock else ship or lock damage might be occured. Therefore, vessels are kept in their location by mooring lines. The vessel movement in the chamber is induced by hydrodynamic and hydrostatic forces acting on the ship, wind and the mooring line forces.

The determination of Hawser Forces on the basis of studies by S.Roux, P.Roumieu, T.De Mulder, M.Ventorre, J.De Regge and J .Wong (PIANC MMX LIVERPOOL UK 2010) defines the Hawser Forces as

1) Forces Exerted on the Mooring Lines.
2) Hydrodynamic Forces on the Ship's Hull.
3) Hydrostatic Forces on the Ship's Hull.
4) Forces deduced from Water Level Slopes.

The longitudinal unbalanced forces which are acting on vessel during filling/emptying may be derived from water surface slope, i.e,

$$F_h = \sin\alpha \times K$$

where,

F_h ⇒ Hawser force,
α ⇒ The angle of the water surface against the horizontal,
K ⇒ The weight of water displaced by the vessel

Water surface slope - Therefore, water surface slope is the one of the limiting factors to be checked during opening or filling the lock. So, the required longitudinal force to keep the vessel in its position is assumed to be the percentage of the weight of the vessel. A rule of thumb is made between rule based on the maximum force and the rule based on a maximum water slope in the lock chamber (for example, 1/1000 for inland navigation vessels). The longitudinal force is derived as a relative value as a percentage of the weight of the water displacement by the vessel. A tabular chart of the hawser force criteria for inland navigation vessels as used in the Netherland and Chinese are reproduced in the following respectively.

Vessel Class	Hawser force criteria (of total ship displacement)	
	In Filling	At Emptying or filling with floating bollards
CEMT Class III	0.15%	0.20%
CEMT Class IV	0.11%	0.15%
CEMT Class Va	0.085%	0.115%

Table 5.2: *Dutch criteria for hawser forces*

DWT of Vessels	3000 t	2000 t	1000 t	500 t	300 t	100 t	50 t
Longitudinal Horizontal Components (kN)	46	40	32	25	18	8	5
Transverse Horizontal Components (kN)	23	20	16	13	9	4	3

Table 5.3: *Chinese code of practice for allowable mooring forces*

DWT of Vessels	3000 t	2000 t	1000 t	500 t	300 t	100 t	50 t
Longitudinal Horizontal Components	0.16%	0.20%	0.33%	0.51%	0.61%	0.82%	1.02%
Transverse Horizontal Components	0.8%	0.10%	0.16%	0.26%	0.31%	0.41%	0.61%

Table 5.4: *Chinese code of practice for allowable mooring forces in percentage of DWT of vessels*

The criteria of hawser forces in terms of percentage of the weight of vessels, i.e., water surface slope (%), in various countries could be abstructed as below:

- In France and Germany, the longitudinal force fraction is about 1/600 (0.167 %).
- In Netherland and Belgium, the allowable forces is about 1/1000 (0.1 %) of the displacement or less than 100 kN.
- In China, the allowable longitudinal forces for different weight of vessels varies between the range of 0.16 % to 1.02 %.

Since, no criteria for hawser forces is available for India, the criteria adopted by Chinese has been considered for the study.

CHAPTER – 6

ANALYSIS OF NAVIGATIONAL LOCK

CHAPTER - 6 ANALYSIS OF NAVIGATIONAL LOCK

The water from Farakka barrage are diverted using a feeder canal. This feeder canal has the capacity to discharge 1,100 cubic metres per second (40,000 cu-ft/s) of water from the Ganges. The present lock under study is planned for navigation between the reservoir of Farakka barrage in the upstream and the feeder canal in the downstream.

Navigation lock is a structure in a waterway provided to enable secure navigation where water level is varied. The variation of water level occurred due to natural reasons such as tidal variations or manmade such as construction of dam or barrage. Also it is important that the operation process of a navigation lock progresses steadily within minimum of time. The design of navigational lock depends on draft and size of design vessel, projection of traffic and variation of water level. Lock operation comprises of lockage time, filling and emptying time, forces during filling and emptying, lift of lock, lock capacity etc.

Design of modern locks for waterway have been influenced by Accelerated growth of Waterway Traffic, the use of larger ships, the need for safe navigation and the use of higher lock lifts. Detailed hydromechanical studies of conditions of lock approaches and traffic management, filling and emptying systems, valve operation and gate operation are required to enable safe and authentic operation of modern locks.

Optimization Goals :

There are many innovations in Lock Design to achieve fast transmission of goods and human resources (Ref: A.12.). The basic concept included are the following-

- ✓ Reliabilitation of the system and operation,
- ✓ Limitation of duration of Lock Navigation Cycle times,
- ✓ Minimization of water & Energy usage,
- ✓ Reduction of Life Cycle Cost,
- ✓ Neglecting the negative environmental impact,
- ✓ Security and Safety

Target Fixation :

The target fixation relates to overall economic development of the country and goods transfer from one point to other. This will also include import and export components.

Preparation of Feasibility Studies :

The initial strategy is the planned development of bulk material transportation, vessel size, waterway to be utilised and the obstructions along the pathway of waterway. A comparative study of various alternatives on traffic management, location of lock and lock height would be presented in the form of feasibility study. A preliminary financial analysis will be included in the feasibility study.

Preparation of Specification and Selection of Features of the Lock :

For high locks designs are close to the feasible physical limits of filling time, rate of flow, allowable waves and currents, cavitation, air entrainment and structural capacity of concrete side wall structures. The specification covers the following items:

- ✓ The type of structure walls,
- ✓ The selection between a simple and multiple block.
- ✓ The configuration of Water Saving Basins,
- ✓ The type of filling system through Gates and Culverts,
- ✓ Type of Gates,
- ✓ Type of valves,
- ✓ Type of Pumps

Collection of Data :

- ✓ Traffic,
- ✓ Transit Time,
- ✓ Velocity of Ships,
- ✓ Operating and maintaining features of Waterway,
- ✓ Geomorphology of Waterway area,
- ✓ Siltation conditions,
- ✓ Topography and satellite imagery,
- ✓ Water Depth,
- ✓ Water Level Variation in Waterway,
- ✓ Navigational Safety,
- ✓ Availability of Construction Material,
- ✓ Physical obstruction to constructional activities,
- ✓ Utilities to be diverted,
- ✓ Wind Speed,
- ✓ Wave Amplitude,
- ✓ Availability of trained construction personnel, maintenance personnel and operational personnel

Engineering Details :

- ✓ Lock capacity,
- ✓ Dimensions of lock,
- ✓ Duration of filling and emptying,
- ✓ Duration of Gate Operation,
- ✓ Duration of ship entrance and exit,
- ✓ Selection of Lock Layout and Gates,
- ✓ Water and Energy Consumption,
- ✓ Operating Time,
- ✓ Lock Structure,
- ✓ Selection of mode of Gate Movement

The two most important items of Planning and Design of Navigational Lock are Transit Time and Loads.

Transit Time :

Transit time covers the following-

- ✓ Time needed for a tow to move from an arrival point to the lock chamber,
- ✓ Time to enter the lock-gate chamber,
- ✓ Time to close the ship entering gate,
- ✓ Time to fill or empty the lock chamber,
- ✓ Time to open and close the water filling/emptying gate,
- ✓ Time to open the ship leaving gates,
- ✓ Time to Tow to Exit of the lock-gate Chamber

Loads :

- ✓ Hydrostatic Loads,
- ✓ Earth Loads,
- ✓ Earthquake & Seismic Loads,
- ✓ Ship Impact load,
- ✓ Hawser loads,
- ✓ Wave Pressure,
- ✓ Wind Loads

6.1 Main components of navigation lock

The major components of Navigation lock consists of approach channels, lock Pit, filling and emptying system and operating gates. These main components have different alternatives based on site condition. In this case the main components are described below:

- **Approach channel**: The orientation of the lock chamber is kept in a way that the vessel can safely enter or exit the lock chamber in a straight way without taking any turn. There is proper space for waiting of vessels near the approach channels. Approach channels are retaining structures and it can be designed as cantilever retaining wall based on height. (Ref: A.8.).
- **Lock pit**: The Lock pit is looking like "U" shaped structure. It is consists of retaining walls and base slab. Lock pit is designed as cantilever retaining walls based on the depth of lock.
- **Filling/emptying arrangement**: The hydraulic design of a lock filling and emptying system quantify the minimization of the filling and emptying time. It is meant as maintaining between minimum time of filling/emptying operation and minimum unbalanced force acted on ship's hull for safe navigation. Maximum and minimum water levels and variation of seasonal water level both in upstream and downstream channels is studied for computing the size of culverts. When a vessel is going towards downstream then before entering in the chamber, it is filled up by water and after entering in the chamber, water level is lowered to make the same level as downstream. There are two sets of valve i.e. filling valve at upper pool and emptying valve at lower pool are used for this operation. The filling and emptying operation comprises of space of the vessels from upstream to downstream or from downstream to upstream imitated by the space of waiting vessels in opposite direction. The total time for one way comprises of area of wet section, initial flow velocity, maximal lock valve lifting velocity, emptying lock filling volume, area of filling influenced section, decisive lock valve lifting velocity, area of lock gate inflow section, area of door opening section, average door lifting velocity, maximal door lifting time(Ref: A.7.).
- **Operating gates**: Gates are major component of lock. Gates are constructed at upstream and downstream section of lock chamber. There are various force like hydrostatic and hydrodynamic force are acting on gate. They are properly analysed for design purposes. The air entrainment force, cavitation are checked to create safe navigation. Gates are constructed to allow the vessel for entering or leaving the lock chamber and to allow water filling and emptying the lock. Mitre gate, Caisson gate, Radial gate and Bulkhead gate are operated in new navigational lock at Farakka. Mitre gates are constructed at upstream and downstream to enable a vessel for entering and leaving in the lock chamber respectively. Caisson gates are used for maintaining purposes of mitre gate. Radial gates are constructed at upstream and downstream lock chamber to enable the water for filling and emptying the chamber respectively. Bulkhead gates are used during the repairing of radial gate.

6.2 Lock appurtenances

There are few lock appurtenances which are described as follows-

- **Fenders** - Fender system are used as lock appurtenances to provide safety barrier for security of navigation, operation, structure, vessel and people. It is generally made of rubber material for absorbing energy.
- **Bollards and floating bollards** – Fixed bollards are used to tie the vessel in the chamber wall in order to resist unwanted movement caused by flow. Floating bollards are operated when rise of fall of water level is greater than 6m and rise or fall of velocity is greater than 2m/min. They are located at moor at the edge of the lock chamber maintaining the safe distance two vessels.
- **Rung ladder**- Rung ladder used in lock chamber as stair case. It is connected to railing for safety purposes.
- **Rubbing strips** – It is provided along the barel of the lock chamber to prevent contact between vessel and lock wall which may cause damage.
- **Mooring rings**- It is provided to ensure safe navigation through the lock chamber. It helps to stop unwanted moving of vessel in the lock chamber.
- **Capstan**- Capstan is a lock appurtenances which is mounted on lock chamber wall. It is used to pulling the rope to move the vessel inside the lock chamber.

For designing of navigational lock, the study of different types of lock chamber is required.

6.3 Study of different types of navigation lock

There are two types of navigational locks –

A) Movable lock chamber and B) Fixed lock chamber

A) Movable lock chamber

i) ***Moving Basin Chamber -*** Movable lock chambers are generally made up of steel plates which is supported with a steel truss system. Gates are installed at upstream and downstream section of lock chamber. The lock chamber is moved vertically between upstream and downstream section. When the water level is same as the upper pool then the lock chamber is said to be full; and when the water level is same as the lower pool then lock chamber is said to be empty. When it is under maintenance, there lock chamber is kept in empty. Movable lock chambers are costly to construct and maintain.

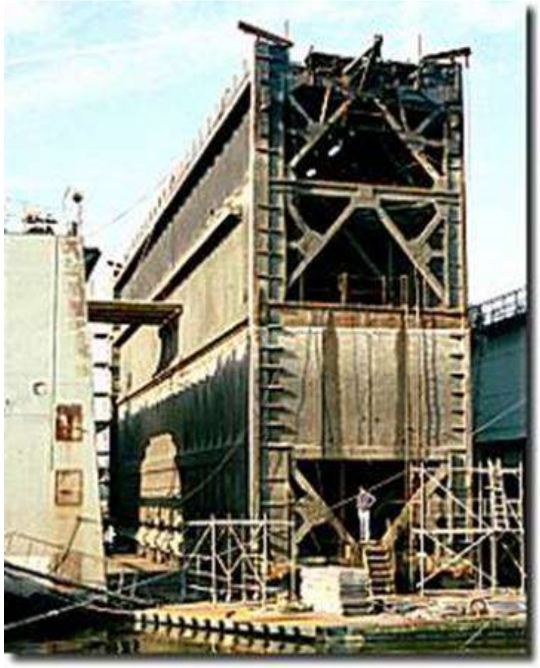

Fig. 6.1: *Moving basin chamber*
(source- **http://osp.mans.edu.eg/tahanany/LOCKS1.html**)

i) Elevator Lock Moving on Inclined Floor –

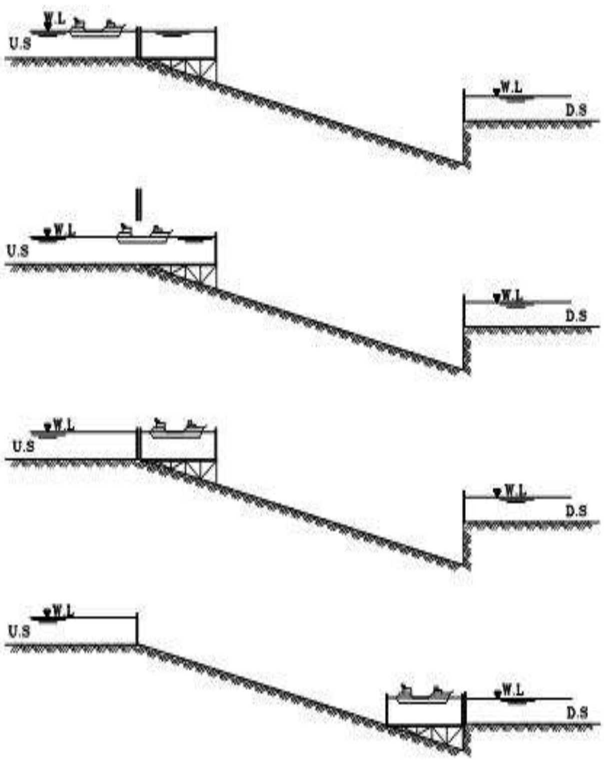

Fig. 6.2: *Elevator lock moving on inclined floor*
(source- **http://osp.mans.edu.eg/tahanany/LOCKS1.html**)

i) Vertical Elevator Locks –

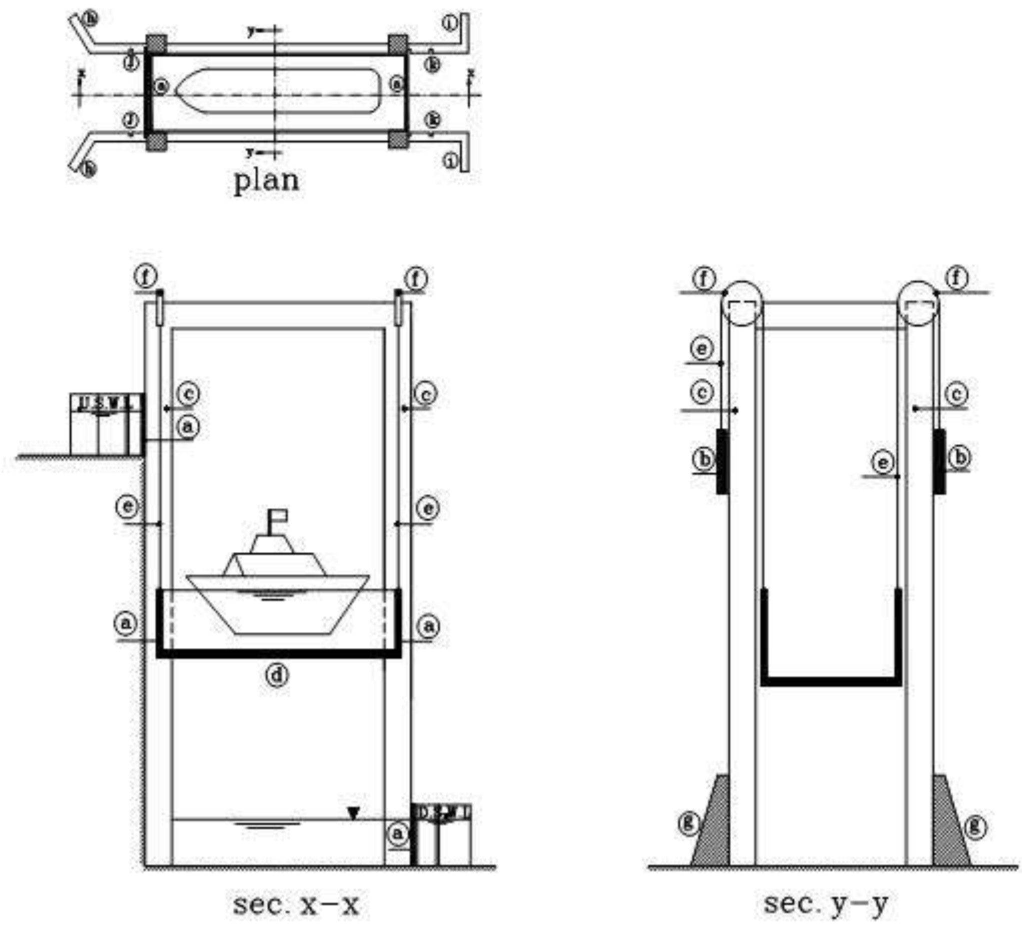

Fig. 6.3: *Vertical elevator locks*

(source- **http://osp.mans.edu.eg/tahanany/LOCKS1.html**)

a) Lock gate

b) Elevator gate

c) Tower column

d) Elevator chamber

e) Chains

f) Fixed ring

g) Retaining wall

h) u/s abutments

i) d/s abutments

j) Grooves for temporary u/s gates

k) Grooves for temporary d/s gates

l) Counter weight

B) Fixed lock chamber

Fixed lock chamber is comprises of fixed constructed elements. There are two gate at upstream and downstream to allow a vessel for entering and leaving the lock chamber and also four gates at upstream and downstream to allow water for filling and emptying the lock chamber. Culvert system are constructed for filling and emptying operations.

There are fixed lock chamber is selected for constructing the new navigational lock at Farakka. So, the study of classification of fixed lock chamber is required.

6.4 Classification of navigation lock with fixed lock chamber

The classification of navigational lock with fixed lock chamber are as following –

A) According to layout

Fig. a) denotes the location of adjacent to Regulator such as Weir or Dam,
Fig. b) denotes the location at a separate canal and at intersection of a waterway with a sea.

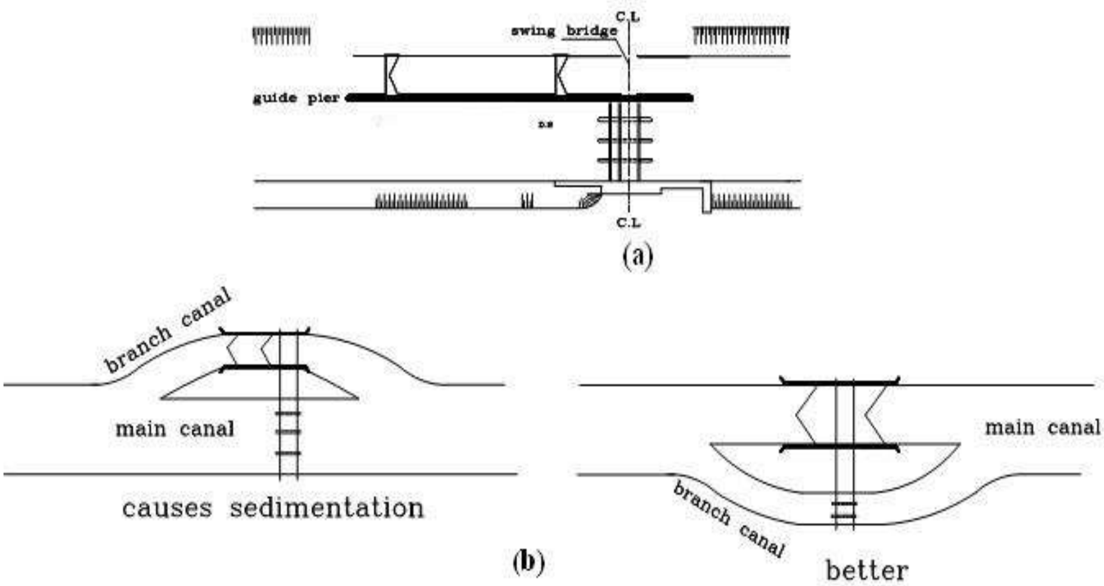

Fig. 6.4: *Navigational lock according to layout*
(source- **http://osp.mans.edu.eg/tahanany/LOCKS1.html**)

B) According to Variation of u/s & d/s Water Levels

This means that locks gates are working when variation of water level occurs at upstream and downstream location.

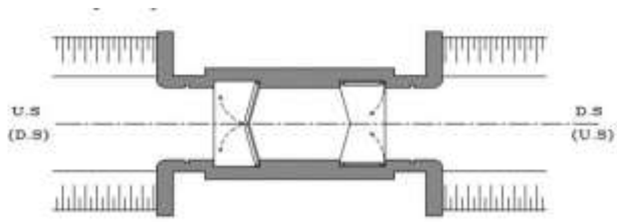

Fig. 6.5: *Navigational lock according to change of u/s & d/s water levels*
(source- **http://osp.mans.edu.eg/tahanany/LOCKS1.html**)

C) According to location relative to regulator or weir

Fig. a) Denotes the location of adjacent to a diversion head work as regulator such as weir or dam,
Fig. b) On a separate canal of a waterway and
Fig. c) At intersection channel of a riverway or canal with the sea.

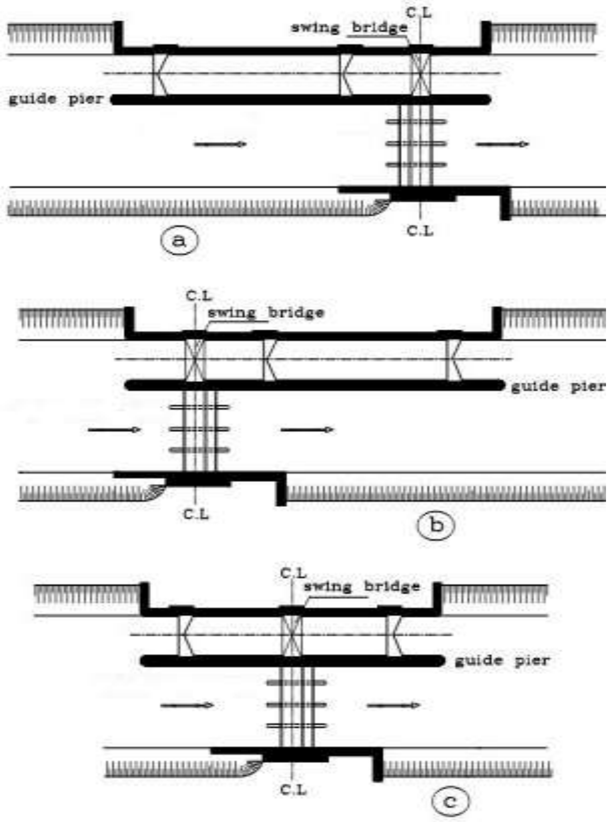

Fig. 6.6: *Navigational lock according to location relative to regulator or weir*
(source- **http://osp.mans.edu.eg/tahanany/LOCKS1.html**)

D) According to density of Navigation

According to density of Navigation, Length of lock chambers may varied according to length of vessel sailing through the lock. For high density navigation, two parallel chambers are used simultaneously either in one or in two direction.

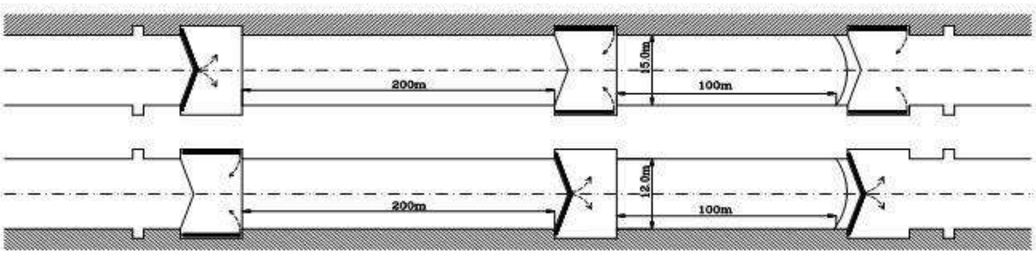

Fig. 6.7: *Navigational lock according to density of Navigation*
(source- **http://osp.mans.edu.eg/tahanany/LOCKS1.html**)

E) According to different lengths of lock chamber

This means that the lock chamber is of suitable length of the sailing vessel for water consuming.

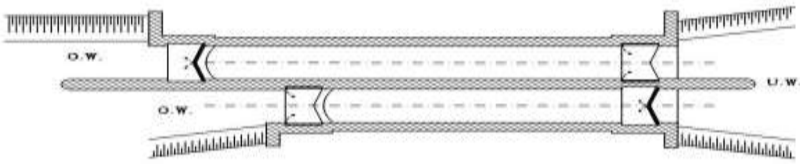

Fig. 6.8: *Navigational lock according to different lengths of lock chamber*
(source- **http://osp.mans.edu.eg/tahany/LOCKS1.html)**

F) According to very light Navigation Density

This means that lock chamber is designed for taking based on many vessels in a trip.

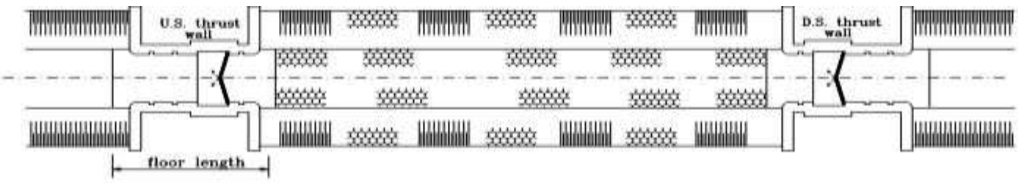

Fig. 6.9: *Navigational lock according to very light Navigation Density*
(source- **http://osp.mans.edu.eg/tahany/LOCKS1.html)**

The fixed lock chamber is selected according to change of u/s & d/s water levels, constructing the new navigational lock at Farakka.

6.5 Navigational lock system

In order to analytical study for a navigational system, it is required to understand the lock system configuration and its operational system. A navigation lock system comprises of gates and valves at the upstream and downstream of the lock. Vessels are wishing to pass through a dam or barrage must lock through the lock chamber. Locking of the chamber is done by using a system of valves to raise and lower the water level and a system of gates for entering/leaving of ship and filling/emptying of water in the lock chamber. It is like an elevator system for raising and lowering the vessels to the equal level as the pool they want to get to. There are two sets of valves, the filling valves which are located at the upper pool and the emptying valves which are located at the lower pool, are used. The filling valves are opened to enable water to enter the chamber for making the chamber the same level as the upstream, and the emptying valves are opened to enable water to drain out for making the chamber the same level as the downstream(Ref: A.11.).

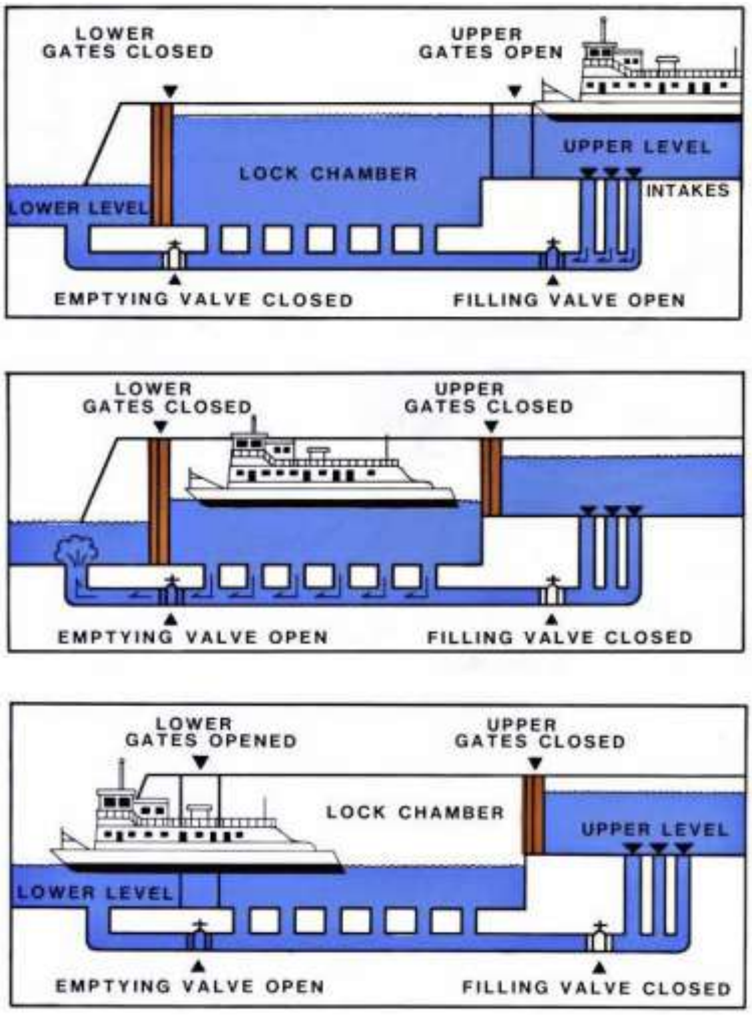

Fig. 6.10: *Navigation lock operation*

(Source- **http://www.mvs-wc.usace.army.mil/arec/LD_27.html)**

In the design of navigational lock, the determination of emptying and filling up parameters like discharge, time, forces, velocity and turbulence inside the lock chamber are key problems from the standpoint of hydraulic engineering.

There are two fundamental requirements to reconcile two conflicting interests: (1)the filling and emptying time should be minimum to avoid penalizing traffic and (2) the resultant forces/turbulence not be too large to cause high hawser stresses and damage vessel, people and the lock chamber etc., therefore, it is of importance that the operation process of a navigation lock progresses steadily within a minimum of time. In order to optimise navigation time and hawser stresses, it is required to carry out study, either numerical or physical (Ref: A.4.). In the present study, it is required to have a analytical study for optimising filling and emptying time and hydrodynamic forces in the chamber.

6.6 New navigational lock at Farakka

The waters from Farakka barrage are diverted using a feeder canal. This feeder canal has the capacity to divert 1,100 cubic metres per second (40,000 cu ft/s) of water from the Ganges. The present lock under study is planned for navigation between the reservoir of Farakka barrage in the upstream and the feeder canal in the downstream.

The existing lock gate at Farakka barrage, which has been operational since 1978 is old and inefficient. With the existing lock, it takes about two hours or more for a vessel to pass upstream or downstream of Farakka barrage. Since the modernisation of the existing lock will entail closing down the lock gate for about 8-10 months, it was decided to first build a new navigational lock and subsequently undertake the modernisation of the existing lock.

- **Operating levels** - The regular operational levels of Farakka barrage i.e. Farakka reservoir in the upstream and feeder canal in the downstream, as tabulated below.

	u/s Water Level (m)	d/s Water Level (m)	Head differences (m)
1:100 Flood	26.30	24.38	1.92
Normal Monsoon	21.95	20.88	1.07
Dry Season (Flow of about 50,000 cusecs)	21.95	18.90	3.05
Dry Season (Flow of about 70,000 cusecs)	21.34	18.288	3.05

Table 6.1: *Farakka barrage operational levels*

From the above table it can be seen that the maximum head difference occurs during the lean season and the maximum head difference during normal operation of the reservoir is 3.05 m. From the above table, it can be seen that the head difference in the lock varies from 1.07 m to 3.05 m as per normal operational criteria.

The observed levels of Farakka barrage during 2014-2015 in the lock i.e., Farakka reservoir in the upstream and feeder canal in the downstream is collected and is tabulated below.

Water Levels in feeder canal at IWAI Gate Station				
Month	**Monthly Max**		**Monthly Min**	
	u/s Farakka Lock (m)	**d/s Farakka Lock (m)**	**u/s Farakka Lock (m)**	**d/s Farakka Lock (m)**
Aug-14	23.797	20.448	22.037	19.828
Sep-14	22.347	20.448	22.067	19.918
Oct-14	22.437	20.618	21.987	19.958
Nov-14	22.207	20.158	21.977	20.008
Dec-14	22.197	20.148	22.037	19.968
Jan-15	22.187	20.248	22.067	20.008
Feb-15	22.227	20.318	22.057	19.778
Mar-15	22.267	20.628	21.957	19.518
Apr-15	22.127	20.358	21.907	20.188
May-15	22.097	20.368	21.837	20.158
Jun-15	22.087	20.578	21.637	19.828
Jul-15	22.267	20.108	21.745	19.308
Average	*22.354*	*20.369*	*21.943*	*19.872*

Table 6.2: *Observed water levels in the Farakka navigational lock*

From the above table, it can be seen that the head difference in the lock varies from 1.07 m to 3.05 m as per normal operational criteria.

The typical annual head difference (2014-15) is about 2.03 m.

The maximum head difference observed during august 2014 is 3.35 m.

- **Head difference considered for study** - As can be seen from Tables 6.1 and 6.2 that, when the water level u/s of the lock rises, the level d/s of the lock also rises and similarly when the water level u/s of the lock reduces, the level d/s of the lock also reduces.

  From paras above, the typical annual head difference is about 2.03 m during 2014-15 and the maximum head difference observed during august 2014 is 3.35 m.

Case	Condition	u/s Water Level (m)	d/s Water Level (m)	Head differences (m)
Case – 1	Typical Head	22.15	20.12	2.03
Case – 2	Maximum head	23.80	20.45	3.35

Table 6.3: *Various cases of head difference considered*

For the present study, the typical annual head difference of 2.03 m and the maximum head difference of 3.35 m are considered.

6.7 Lock approach and traffic management

A lock approach be fulfilled a number of functions as part of traffic management. Generally, the lock approach be considered as the navigation area between the connecting waterway and the lock complex. In the lock approach, approaching vessels have the opportunity to reduce velocity and moor to a guiding structure. The lock approach should not be situated in a bend and be free of resistance. Also, longitudinal and transverse currents in the lock approach should be neglected as much as possible, in view of the decreased manoeuvrability of the vessel when decreasing speed and closing.

The lock approach is functionally divided into(Ref: A.8.):

A) ***The Line Up Area -*** This area is arrayed with proper mooring facilities. It is located as such that moored vessels are not an interruption to departing vessels. The line up area is intended for vessels that would be locking in the way of next locking process. All vessels should be able to enter the chamber rapidly through the leading jetties from the mooring area. The line up area per chamber per side is necessary. The dimension of the mooring area is assembled with a completely filled chamber.

B) ***The waiting area -*** This area is also arrayed with proper mooring facilities and is located at locks where the expected navigation intensity is such that the mooring area will be too small for all the waiting vessels. The waiting area is intended for vessels that would not be able to lock in a way of the next locking process after arrival. The waiting area is required per chamber per side. It is the area which required for navigation zone between connecting waterway and lock complex. In the waiting area, the normative vessel might at least be abled to moor.

C) ***Free Area –*** The free area is denotes to provide to approaching vessels to have the opportunity to reduce velocity and moor to a guiding structure. Again, the free area provides the opportunity to adjust the profile of the waterway to the profile of the lock approach.

D) ***Stop over harbour -*** Stop over harbour be also considered as lock approach for inland navigation. Dissimilation are made in the lay out and dimensions of waiting areas in this case for locking.

6.8 Lift of lock

The lift of a lock is defined as the difference in elevation or head of the upstream and downstream water levels.

The classification of lift of lock is depends on their height. The following designations have been adopted for design purposes(Ref: A.8):

- **Low lift - Lifts under 9 m**
- **Intermediate lift - Lifts from 9m to 16 m**
- **High lift - Lifts over 16 m**

This classification reflects to certain grade the complexity which is involved in design of navigation locks. For example, a wall culvert-side port system could be constructed with lifts from 3m to 9m for low-lift locks but more well-performed and improved designs are needed for lifts in the range of 9m to 16m. For the 9m to 16m range i.e. intermediate lift lock, a design is required to utilize bottom longitudinal manifolds for connecting to the main wall culverts through a cross culvert at the midpoint of the lock chamber. So, an approximate equal flow division to the upstream and downstream portions of the lock chamber by means of a vertical wall in the cross culvert are provided by this system. In case of high lift i.e. lifts over 16m a design criterion is adopted to provide a bottom longitudinal manifold system for satisfactory operation time and negotiation of hawser stresses.

6.9 Design calculation of Lock capacity

Locks should be designed to attune the traffic which can reasonably be anticipated during the life of the structures. Usually the expected design life of navigation locks is considered to be 50-60 years for planning of economic purposes. To establish the required lock capacity, Projections of annual tonnage are take from the date of project completion. At the time of initial planning studies of a project, such projections are usually made by economic units to fulfil the criteria (Ref: A.4.). therefore, proper design of lock capacity are required to making long design life of navigation lock . So, various plans including lock dimension, number of chambers, number of gates, number of valves and other lock appurtenance and operational characteristics can be analysed to develop a basis for final design during establishing of the required capacity by economic studies.

Lock capacity expressed in vessels per hour (VPH) and tonnages per hour (TPH) are presented in the calculation below. Capacity is one of the most important parameters of transportation system. Before starting of lock design, estimation of lock capacity are required in terms of annual tonnages or numbers of vessels per year. The capacity of a lock defines that highest number of traffic that can be locked per unit time in the prevailing conditions if the lock operates continuously with full chambers. Lock capacity is an average value which is derived from a large number of lockage with full chambers . There are few technical and operating conditions which are involved in design of lock capacity. So, the technical condition of the design of lock capacity consists of the dimension and number of lock chambers, opening and closing time of gate, filling and emptying time, force during filling and emptying, the size and layout of the navigational approach channels, lock pit, berthing structures, navigation flow condition and the operating conditions of the lock capacity consists of traffic density, random arrival, the unbalance between upstream and downstream traffic, the unbalance in loaded or unloaded vessels, types and sizes of vessels or tows, vessels dispatching, control policy, adjacent ports capacity, type of waterway and weather conditions . The management conditions of the lock capacity comprises of the quality and number of personnel, the ability of handling accidents and maintenance, communication and finance. To design the lock capacity, simplification of all conditions are required. Thus, practically lock capacity is not constant value and varies with the operating conditions and technical condition. In order to design the lock capacity reasonably, those complex conditions are simplified or analysed and that is presented below.

1. VPH (Vessel Per Hour) = $(N \times 60)/T_c$
2. TPH (Tonnage per Hour) = VPH × G
3. ALT (Average Locking Tonnage) = N × G
4. ANDL (Average No. of Daily Tonnage) =$(t \times 60)/T_c$
5. C (Lock Capacity in Annual Total tonnages of Vessels Passed Through a lock in Up & Down Direction) = ANDL × D_t × ALT

where,

N = Average Values of No of Vessels (Two one up & one Down)= 2
G = Average Tonnage Per Vessel = 3000 T.
T_c = Cycle time in Minutes = 56.3
t = Lock Operating Time per day in Hours = 20 Hours
D_t = Value of Operating Days per year = 350 Days

Farakka Lock Capacity Calculation :

Starting Position :

1. Ship Goes Upstream through Lock Comes from Downstream.
2. Doors have opened
3. Ship is resting its bow in front of Lock Entrance
4. A single cycle assumes one ship upstream and one ship downstream.
5. A continuous supply of ships assumed.

Sl. No.	Ship Direction	Action	Time, minutes
1.	UP	Sailing time into lock	4.9
2.	UP	Closing downward doors	3.0
3.	UP	Filling lock	12.5
4.	UP	Opening upward doors	3.0
5.	UP	Sailing out of lock	2.0
6.	UP	Clearing lock area for next ship	2.0
7.	DOWN	Sailing time to lock	1.0
8.	DOWN	Sailing time into lock	2.0
9.	DOWN	Closing upward doors	3.0
10.	DOWN	Emptying lock	12.0
11.	DOWN	Opening downward doors	3.0
12.	DOWN	Sailing out of lock	4.9
13.	DOWN	Clearing lock area for next ship	2,0
14.	DOWN	Sailing time to lock	1.0
		Total cycle time	*56.3*
	Total		**Capacity**
1.	*Theoretical maximum capacity*		*2.13 Ship/Hour*
2.	*Practical capacity*		*1.71 Ship/Hour*

Table 6.4: *Tabulation of lock capacity*

$$VPH = \frac{2 \times 60}{56.3} = 2.13 \text{ ships/hour}$$

TPH = 2.13 × 3000 = 6390 tonnes /hour

ALT = 2 × 3000 = 6000 T

ANDL = (20 × 60)/56.3 = 21.31

C = 21.31 × 350 × 6000 = 44,760 tonnes /year

So, Lock Capacity in Annual Total tonnages of Vessels Passed Through a lock in Up & Down Direction is 44,760 tonnes/year

6.10 Forces during filling and emptying

The hydraulic design of a lock filling and emptying system results the minimization of time of the filling and emptying operation, followed by so-called hawser forces. Hawser forces criteria provides sufficient grade of safety and comfort navigation during filling and emptying of lock. The hawser force criteria is set to quantify the necessary threshold value of unbalanced hydrodynamic forces on vessel generated during filling/emptying, in order to limit the displacement of the vessel and the associated forces in the vessel-positioning system. Ship movements must be avoided or kept to acceptable limits inside the lock else ship or lock damage might be occured. Therefore, vessels are kept in their location by mooring lines. The vessel movement in the chamber is induced by hydrodynamic and hydrostatic forces acting on the ship, wind and the mooring line forces.

The longitudinal unbalanced forces which are acting on vessel during filling/emptying may be derived from water surface slope, i.e,

$$F_h = sin\alpha \times K$$

where,

$F_h \Rightarrow$ Hawser force,

$\alpha \Rightarrow$ The angle of the water surface against the horizontal,

$K \Rightarrow$ The weight of water displaced by the vessel

So, water surface slope is the one of the limiting factors to be checked during opening or filling the lock. So, the required longitudinal force to keep the vessel in its position is assumed to be the percentage of the weight of the vessel. A rule of thumb is made between rule based on the maximum force and the rule based on a maximum water slope in the lock chamber (for example, 1/1000 for inland navigation vessels). The longitudinal force is derived as a relative value as a percentage of the weight of the water displacement by the vessel. A tabular chart of the hawser force criteria for inland navigation vessels as used in the Netherland and Chinese are reproduced in the following respectively.

Vessel Class	Hawser force criteria (of total ship displacement)	
	In Filling	At Emptying or filling with floating bollards
CEMT Class III	0.15%	0.20%
CEMT Class IV	0.11%	0.15%
CEMT Class Va	0.085%	0.115%

Table 6.5: *Dutch criteria for hawser forces*

DWT of Vessels	3000 t	2000 t	1000 t	500 t	300 t	100 t	50 t
Longitudinal Horizontal Components (kN)	46	40	32	25	18	8	5
Transverse Horizontal Components (kN)	23	20	16	13	9	4	3

Table 6.6: *Chinese code of practice for allowable mooring forces*

DWT of Vessels	3000 t	2000 t	1000 t	500 t	300 t	100 t	50 t
Longitudinal Horizontal Components	0.16%	0.20%	0.33%	0.51%	0.61%	0.82%	1.02%
Transverse Horizontal Components	0.8%	0.10%	0.16%	0.26%	0.31%	0.41%	0.61%

Table 6.7: *Chinese code of practice for allowable mooring forces in percentage of DWT of vessels*

The limiting criteria of hawser forces in terms of % of the weight of vessels, i.e., water surface slope (%), in various countries could be summarized as below:

- In France and Germany, the longitudinal force fraction is 1/600 (0.167 %).
- In Netherland and Belgium, the allowed forces is 1/1000 (0.1 %) of the displacement or less than 100 kN.
- In China, the allowed longitudinal forces for different weight of vessels varies from 0.16 % to 1.02 %

Since, no criteria for hawser forces is available for India, the criteria adopted by Chinese has been considered for the study.

6.11 Calculation of Filling and emptying time of navigational lock

1. **General parameters regarding lock and ship dimension:**

i) Positive longitudinal force, f_p = 0.8 promille

ii) Low water level/empty lock level, h_l = 18m

iii) Filled lock level /upstream water level, h_f = 26m

iv) Lock bottom level, z_0 = 13m

v) Lock width, w = 25m

vi) Lock length, L = 180m

vii) Intake width, i_w = 8m

viii) Discharge coefficient, C_d =0.7

ix) Maximum opening height, h_m = 2m

x) Bottom level of discharge gutter, z_0 = 13m

xi) Ship beam, B = 22m

xii) Ship draft, D =4m

xiii) Ship length, l_s =100 m

xiv) Ship block coefficient, $C_b = \dfrac{\text{Displacement of ship or underwater volume}}{\text{Volume of a rectangular block i.e. } l_s \times B \times D}$ = 0.9

xv) Area of ship section, $A_s = B \times D = 22 \times 4 = 88\ m^2$

xvi) Distance of ship to lock gate, x = 8m.

2. **Calculation of lock filling time** :

Wet section along the ship side :

Area of Wet section, $A_{ws} = [(h_l - z_0)w - A_s] = [(18 - 13)\ 25 - 88] = 37\ m^2$

Fall = $\delta h_0 = h_f - h_l = 26 - 18 = 8$ m

Gravitational acceleration, g = 9.81 m/sec^2

Initial flow velocity, $V_i = \sqrt{2 \times g \times \delta h_0}$

$= \sqrt{2 \times 9.81 \times 8}$

= 12.525 m/sec

i) **First condition : maximal lock valve lifting velocity regarding longitudinal lock waves -**

Maximal Lock Valve Lifting Velocity regarding longitudinal lock waves,

$$V_{ml} = \frac{f_p \times g \times A_{ws}}{1000 \times C_d \times i_w \times V_i}$$

$$= \frac{0.8 \times 9.81 \times 37}{1000 \times 0.7 \times 8 \times 12.525}$$

$$= \frac{290.376}{70140}$$

= 0.00414 m/sec

ii) **Second condition: maximal lock valve lifting velocity regarding longitudinal momentum reduction -**

$F_n = -f_p = -0.8$ promille

Wet section along the side of ship at maximal discharge :

Area of Wet section along the side of ship, $A_{wsm} = [h_l + \{(5/9) \times \delta h_0\} - z_0] \times w - A_s$

$= \{18 + (5/9)\times 8 - 13\}\times 25 - 88$

$= \{(18 + 4.44 - 13) \times 25\} - 88$

= 235 – 88

= 147 m^2

Empty lock filling volume:

Emptying lock filling volume, $v_{ef} = w \times L \times \delta h_0 = 25 \times 180 \times 8 = 36{,}000\ m^3$

Filling influenced section for culvert:

Area of Filling influenced section, $A_{fis} = w \times h_m = 25 \times 2 = 50\ m^2$

Geometry coefficient:

$$C_1 = \left(\frac{L - x}{L}\right)^2$$

$$= \left(\frac{180 - 8}{180}\right)^2$$

$$= 0.913$$

$$C_2 = \left(\frac{L - l_s - x}{L}\right)^2$$

$$= \left(\frac{180 - 100 - 8}{180}\right)^2$$

$$= 0.16$$

Shape factor, $C_{sf} = 0.59$

Maximum Lock Valve Lifting Velocity Regarding Longitudinal Momentum Reduction,

$$V_{mr} = \frac{-f_n \times A_{wsm} \times C_b \times g \times l_s}{[\{C_{sf} \times 1000 \times C_d \times i_w \times V_i \times v_{ef}\} \times \left\{\left(\frac{C_1}{A_{fis}}\right) - \left(\frac{C_2}{A_{wsm}}\right)\right\}]}$$

$$= \frac{0.8 \times 147 \times 0.9 \times 9.81 \times 100}{\left[\{0.59 \times 1000 \times 0.7 \times 8 \times 12.525 \times 36000\} \times \left\{\left(\frac{0.913}{50}\right) - \left(\frac{0.16}{147}\right)\right\}\right]}$$

$$= \frac{103829.04}{[\{41382 \times 36000\} \times \{(0.01826) - (0.001088)\}]}$$

$$= \frac{103829.04}{(41382 \times 36000 \times 0.017172)}$$

$$= \frac{103829.04}{25582021.344}$$

$$= 0.00405\ m/sec$$

iii) Decisive Lock Valve Lifting Velocity:

Decisive Lock Valve Lifting Velocity, V_{hl} = minimum (V_{ml} , V_{mr})= 4.05 ×10^{-3} m/sec

iv) Lock Valve Lifting Duration : T_{h0} = Nominal ,T_{ha} = Actual

$$T_{h0} = \sqrt{\frac{2w \times L \times V_i}{3 \times g \times C_d \times V_{hl} \times i_w}}$$

$$= \sqrt{\frac{2 \times 25 \times 180 \times 12.525}{3 \times 9.81 \times 0.7 \times 4.05 \times 10^{-3} \times 8}}$$

= 410.95 seconds

T_{ha} = 1.175 × 410.95

= 482.866 seconds

∴ Lock valve lifting duration = 482.866 seconds

Maximum lock gate opening dimension :

Opening height, $h_o = V_{hl} \times T_{ha}$ = (4.05 × 10^{-3}) × 482.866 =1.955 m ≈ 2m

Maximal lock gate inflow section :

Area of lock gate inflow section, $A_k = h_o \times i_w$

= 2 × 8

= 16 m^2

∴ **Lock filling time,**

$$T_{lf} = (0.5 \times T_{ha}) + \left(\frac{w \times L \times V_i}{g \times C_d \times A_k}\right)$$

$$= (0.5 \times 482.866) + \left(\frac{25 \times 180 \times 12.525}{9.81 \times 0.7 \times 16}\right)$$

$$= 241.443 + \left(\frac{56362.5}{109.872}\right)$$

= 241.443 + 512.983

= 754.426 sec

3. <u>Calculation of lock emptying time</u> :

<u>Wet section along the side of ship at the end of emptying</u> :

Area of Wet section along the side of ship at the end of emptying,

$A_{wse} = [(h_l - z_0)w - A_s]$

$= [(18 - 13)\times 25 - 88]$

$= (125 - 88)$

$= 37\ m^2$

i) <u>Optimal door opening section</u> :

Area of door opening section, $A_{os} = \sqrt{\dfrac{f_p \times A_{wse} \times w \times L}{1000 \times {C_d}^2}}$

$$= \sqrt{\frac{0.8 \times 37 \times 25 \times 180}{1000 \times 0.7^2}}$$

$$= \sqrt{\frac{133200}{490}}$$

$= 16.487\ m^2$

Thus, actual opening section of 16 m^2 is accepted = A_{os} actual

ii) <u>First condition : For longitudinal lock waves maximal lock valve lifting velocity V_{mw} is calculated as below -</u>

$$V_{mw} = \frac{f_P \times g \times A_{wse}}{1000 \times C_d \times i_w \times V_i}$$

$$= \frac{0.8 \times 9.81 \times 37}{1000 \times 0.7 \times 8 \times 12.525}$$

$$= \frac{290.376}{1000 \times 70.14}$$

$$= \frac{290.376}{70140}$$

$= 4.1399 \times 10^{-3}$ m/sec

iii) <u>**Second condition : V_{mfd} is the maximal lock valve lifting velocity under fluent discharge condition**</u> **-**

The maximal discharge is achieved in time T_{md} and the end of valve lifting T_{vl} happens after 1.1 T_{md}

∴ $T_{vl} = 1.1\ T_{md}$

$$V_{mfd} = \left\{ \frac{3 \times C_d \times (A_{os}{}^2) \times V_i}{4 \times \left(\frac{T_{vl}}{T_{md}}\right)^2 \times i_w \times v_{ef}} \right\}$$

$$= \left(\frac{3 \times 0.7 \times 16^2 \times 12.525}{4 \times 1.1^2 \times 8 \times 36000} \right)$$

$$= 4.831 \times 10^{-3}\ \text{m/sec}$$

Thus, average door lifting velocity, $V_{dl} = \left(\frac{4.1399 + 4.831}{2}\right) \times 10^{-3}$ m/sec

$= 4.485 \times 10^{-3}$ m/sec

Maximal door lifting time, $T_{dl} = \left(\frac{Aos}{V_{dl} \times i_w}\right)$

$$= \frac{16}{4.485 \times 10^{-3} \times 8}$$

$= 445.93$ sec

<u>Maximum door opening dimension</u>:

Maximum door opening height, $h_o = (4.485 \times 10^{-3}) \times 445.93 = 1.99\ \text{m} \approx 2.0\ \text{m}$

∴ **Lock emptying time ,**

$$T_{le} = \left\{ \frac{1}{2} \times T_{dl} + \left(\frac{w \times L \times V_i}{g \times C_d \times A_k} \right) \right\}$$

$$= \left(\frac{445.93}{2}\right) + \left(\frac{25 \times 180 \times 12.525}{9.81 \times 0.7 \times 16}\right)$$

$= 222.965 + 512.983$

$= 735.94$ sec

Calculation for lock filling and emptying time is done for a ship in a lock opening dimension given above.

The above calculation takes into account of several forces due to inflow and related wave phenomenon.

To avoid exhaustant stresses on the ship, door valve have to be opened slowly.

Filling and emptying time is calculated according to changing discharge due to the changing door opening,

Maximum valve door lifting speed during filling has to be,

$$V_{hl} = 4.05 \times 10^{-3} \text{ m/sec}$$

Maximum valve door lifting speed during emptying has to be,

$$V_{dl} = 4.485 \times 10^{-3} \text{ m/sec}$$

Filling time, T_{lf} = 754.426 sec = 12.57 min

Emptying time, T_{le} = 735.94 sec = 12.26 min

This is assuming double gutters having opening of $16m^2$

CHAPTER – 7

OPERATIONAL SEQUENCE OF NAVIGATIONAL LOCK

CHAPTER - 7 OPERATIONAL SEQUENCE OF NAVIGATIONAL LOCK

A navigation lock requires closure gates at both ends of the lock so that the water level in the lock chamber can be varied to coincide with the upstream and downstream approach channels. The sequence of "locking" a vessel upstream is: (i) lower the water level in the lock to the downstream water level; (ii) open the lower gate and move the vessel into the lock chamber; (iii) close the lower gate and fill the lock chamber to the level of the upper pool; and (iv) open the upstream gate and move the vessel out of the lock. Lockage of a vessel downstream involves a similar sequence in reverse order.

- Two (2) Nos. Mitre Gates are proposed one at upstream and another at downstream of the lock to facilitate the opening and closing operation.
- Two (2) Nos. floating type of Caisson Gates are proposed for replacement/ repair/ maintenance of Mitre Gate. Gates will be installed vertically at both end of the lock for stopping water flow from upstream and downstream of lock chamber only when Mitre gates are required to be attended for repairs.
- Four (4) Nos. Radial gates are proposed, 2 Nos. at upstream and 2 Nos. at downstream at both side of lock for filling and emptying of the lock chamber to facilitate navigation of IWT vessels.
- Eight (8) Nos. Bulkhead gates are required for repair of Radial gates. There will be bulkhead gates in front of each radial gate so that water flow from the lock basin is arrested.

7.1 Operation system

1) **Caisson gate:** By filling up top buoyancy tanks from river water by gravity and draining the same from end tanks during floating operation through drain value.
   Caisson gates shall be capable of being ballasted or deballasted in 30 minutes or less.
   Normal raising and linking operation shall be carried out using suitable valve arrangement without the operation of pumps.
   However for emergency provision of pumping water from lower tanks to top tanks by means of electric pump (submersible pump) shall be made.

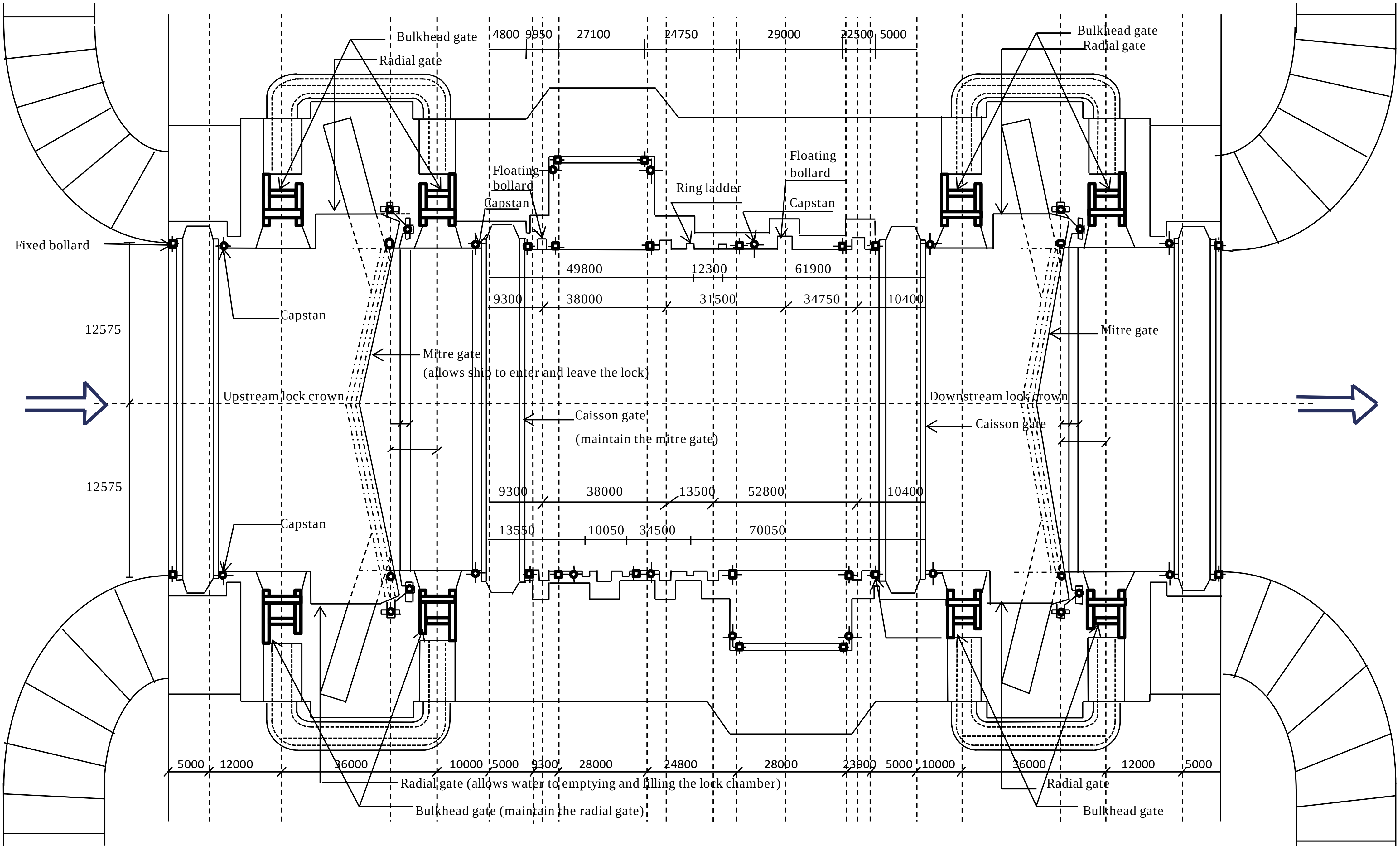

Fig. 7.1: *Typical Navigational Lock With Mitre Gates And Radial Gates As Operational Gates And Caisson Gates And Bulkhead Gates As Maintenance Facilitating Gates*

2) **Mitre gate :** To be operated through electro hydraulic system to achieve opening and closing time preferably in 3 minutes (not more than 5 minutes).
3) **Radial gate :** To be operated through electro-hydraulic system to achieve opening and closing time preferably in 1 minutes(not more than 2 minutes).
4) **Bulkhead gate :** To be operated by rope drum hoists.

7.2 Sequence of operation of navigation lock

A. Vessel sailing upstream (from low water level to high water level)
   A_1 Vessel Enters the Lock
   A_2 The downstream Mitre gate is closed
   A_3 The upstream Radial gates are opened to allow water from upstream to flow to lock and fill up the chamber
   A_4 The vessel rises in the chamber
   A_5 Upstream Mitre gate opened
   A_6 Vessel leaves the at higher level
B. Vessel sailing downstream (from high water level to low water level)
   B_1 Vessel Enters the Lock
   B_2 The upstream mitre gate is closed
   B_3 The downstream Radial gates are opened to allow water from chamber to flow to downstream to empty the lock
   B_4 The Vessel comes down in the chamber to downstream level
   B_5 Downstream Mitre gate opened
   B_6 Vessel leaves the at lower level

Mitre allows the vessel to enter and leave the lock
Radial gate allows water to enter the lock and also allows water to empty the lock through a culvert attached to lock
Two caisson gate allows mitre gate to be repaired/maintained
Four Radial gates are maintained through eight bulkhead gate.

CHAPTER – 8

DESIGN OF GATE OF NAVIGATIONAL LOCK

CHAPTER - 8 DESIGN OF GATE OF NAVIGATIONAL LOCK

A navigational lock is made operative through a number of gates. The gates allow water to enter the lock or go out of the lock. The most important item is the Mitre gate which allows entry of ship inside the lock and travel of the ship out of the lock. Caisson gate is provided to isolate the Mitre gate during maintenance period. Radial gates are provided for filling and emptying the lock through entry of water through culvert. Bulk head gates are provided for isolating Radial gates during maintenance.

8.1 Design criteria

- **Codes and standard** –

All material, testing and execution shall be in conformity with these codes and standard. Indian standard (IS code) shall generally be followed.

1) British standards
2) American standards
3) General standards

Wherever details for part of works are not defined adequately in IS code, relevant acceptable International Standards shall be adopted. Codes and standards covering the major part of the works are included in the some of them are listed below:

Codes and standards	Subject
BS: 6349-Part 3	Designing of dry docks, locks, slipways and shipbuilding berths, ship lifts and dock and lock gates.
IS: 4623	Recommendation for standard design of radial gates.
IS: 4622	Recommendations for structural design of fixed wheel gates.
IS: 7718	Recommendations for inspection, testing & maintenance of fixed wheels and slide gate.
IS: 6938	Code of practise for design of rope drums and chain hoists for hydraulic gates.
IS: 3029	Structural steel for construction of hulls of ships.
IS: 14177	Guidelines for painting system for hydraulic gates.
ISO: 12944	Corrosion protection of steel structures by protective paint system.
PIANC Guidelines	Design and Operation of gates, ship impact on lock gates.

Table 8.1: *Codes and standards*

❑ Lock gate size and numbers –

Types of gate	u/s		d/s		Nos.
	Height (m)	Width of lock opening (m)	Height (m)	Width of lock opening (m)	
Mitre gate	13.64	25.15	13.94	25.15	2
Caisson gate	13.94	25.15	13.94	25.15	2
Radial gate	2	4	2	4	4
Bulk head gate	2.2	4	2.2	4	8

Table 8.2: *Lock gate size and numbers*

❑ Design life –

The gate shall be designed as per the following design life considering the proper maintenance.

- Gate structure – 30 years
- Electro hydraulic and mechanical components – 15 years
- Pumps, valves and piping – 10 years

❑ Range of differential water levels –

All the gates should be designed for the differential water head considering maximum water level i.e. 26.3 m on one side and other side considering empty.

❑ Load considered for Structural Design –

Gates shall be designed for the following loading conditions:

• All hydrostatic and hydrodynamic loads due to differential water levels mentioned above.

• All loads due to dead weight and frictional forces.

• Accidental impact from 3000 DWT fully loaded barge on Caisson and Mitre gate.

• Seismic wind load as per IS:800-2007.

• All temperature loads as per IS:800-2007.

• Loadings from small forklift trucks of 1 T capacity on the top deck of caisson gate.

• Induced pressure during de-ballasting operation of the caisson gate on the water ballast tank plate work and piping system. The stresses for the design of mitre, radial and bulkhead gates shall be as per IS: 4622, IS: 5620 and IS: 9349.

❑ Structure and Scantling –

The envelope plating and all primary and secondary structural members of mitre gates and caisson gates shall be designed as per Rules of any IACS member Classification Society. However, thickness of envelope plating and all primary structural members shall be 25% over rule requirement. Scantling of all secondary members to be 15% over rule requirement.

❑ Design Method–

The sizing of structural plating and stiffening of the gate shall be based on the above mentioned loading criteria and hydrostatic pressure. The buckling resistance and yielding of each plate panel, slenderness, stiffener and beam members shall be evaluated for finalising the structural design. The rules and regulations of any IACS member of classification society will have to be followed in addition to BS: 6349-Part 3. Maximum combined stresses shall be checked to be less than the allowable stresses given in BS: 5400-Part 3 or any equivalent Indian Standards. A minimum load factor of 1.2 shall be used as per BS: 5400 in conjunction with water levels mentioned above.

❑ Corrosion Protection and Corrosion Allowance–

The gates shall be coated with anti-fouling and anti-corrosive paint system to achieve minimum guarantee life to first maintenance of 15 years as per ISO: 12944.

It is proposed to provide aluminium alloy sacrificial cathodic protection which shall have a planned life of 15 years to supplement the coating protection.

A corrosion allowance of 1 mm per wetted face shall be taken in normal thickness of all steel plate and sections of the gates.

❑ Fatigue and Fracture Criteria–

All possible modes of failure should be considered for designing of lock gates.

Possible failure modes are:

- General yielding or excessive plastic deformation,
- Buckling or general instability.
- Subcritical crack growth leading to loss of cross section or unstable crack growth.
- Unstable crack extension leading to failure of a member.

Failure modes 1 and 2 are addressed by Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD) principles whereas failure modes 3 (fatigue) and 4 (brittle fracture) can be addressed using fatigue and fracture mechanics principles.

Welded construction with its emphasis on monolithic structural members has led to the increased desirability of including fracture criterion in addition to strength and buckling criteria when designing a structure. Stress range detailing and the number and frequency of load cycles control fatigue, while geometry, toughness, and stress levels control fracture. In these aspects, Appendix B of Engineer Manual (EM) 1110-2-2105 and IS: 800 shall be followed for fatigue consideration of gates.

- **Fatigue requirements -** Fatigue can be controlled by stress range and the number of frequency of load cycles. While the number and frequency of load cycles are usually controlled by the structure's purpose, for control of stress range, AISC -2016 Appendix 'K' (which covers concentrated forces, ponding and fatigue pertaining to design for cyclic loadings) shall be considered.
- **Fracture control requirements -** The fracture of critical members is defined as members and their associated connections subjected to tensile stresses and whose failure would cause the structure to be inoperable. In this connection for minimum Charpy V-Notch impact test values, EM-1110-2-2105 and relevant IS Codes shall be considered.

❑ <u>Material</u>–

Material	Codes and standard
Lock gate envelope plating and primary	Ship building quality steel (IS: 3039)
Secondary structural members	Hot Rolled Medium & High Tensile Structural Steel (IS: 2062)
Seals	Rubber (IS: 11855 & IS: 15466)
Polished Building Stones Specifications	Granite (IS: 14223 - Part I)
Seal Seats and fasteners	Stainless steel (IS: 1570 - Part V)
Bushings	Bronze (IS: 305, IS: 318)
Guide Roller	Cast steel (IS: 1030/IS: 2014)
Guide Roller pin	Corrosion resistant steel (IS: 1570 Part V)
Wheels	Cast steel / forged steel (IS: 1030, IS: 2004)
Wheel pin	Corrosion resistant steel (IS: 1570 – Part V)
Ballast	Cast Iron (IS: 210) or concrete
Components of Hydraulic System	IS: 10210 & DIN 19704
Valves	2% Ni-Cast Iron
Piping	G.I. (IS: 1239)

Table 8.3: *Material used as per given code*

❑ <u>Water-tightness of Gates</u>

The allowable average water leakage tolerance of gates under any head and without the use of any additional sealing material per metre length of seal shall be 0.10 l/s.

8.2 Hydromechanical specifications

A navigation lock requires closure gates at both ends of the lock so that the water level in the lock chamber can be varied to coincide with the upstream and downstream approach channels. Two mitre gates and four radial gates have to be constructed at upstream and downstream. Two caisson gates and eight bulkhead gates have to be built to maintain mitre gates and radial gates respectively.

➲ Mitre gate

- ***Structure*** **-** The opening and closing of lock entrance and exit points are controlled by Mitre Gate structure by using two leaves. There are two types of framing in mitre gate like horizontal framing and vertical framing. For new navigational lock at Farakka, Mitre Gate structure shall be designed based on horizontal framing. The skin plate of a horizontally framed gate are supported by horizontal members which would be straight girders acting as beams. Each such horizontal members are supported by the vertical quoin post at one end and the mitre post at the other end. All water load will be transmitted through the girders and quoin blocking into the gate monoliths.

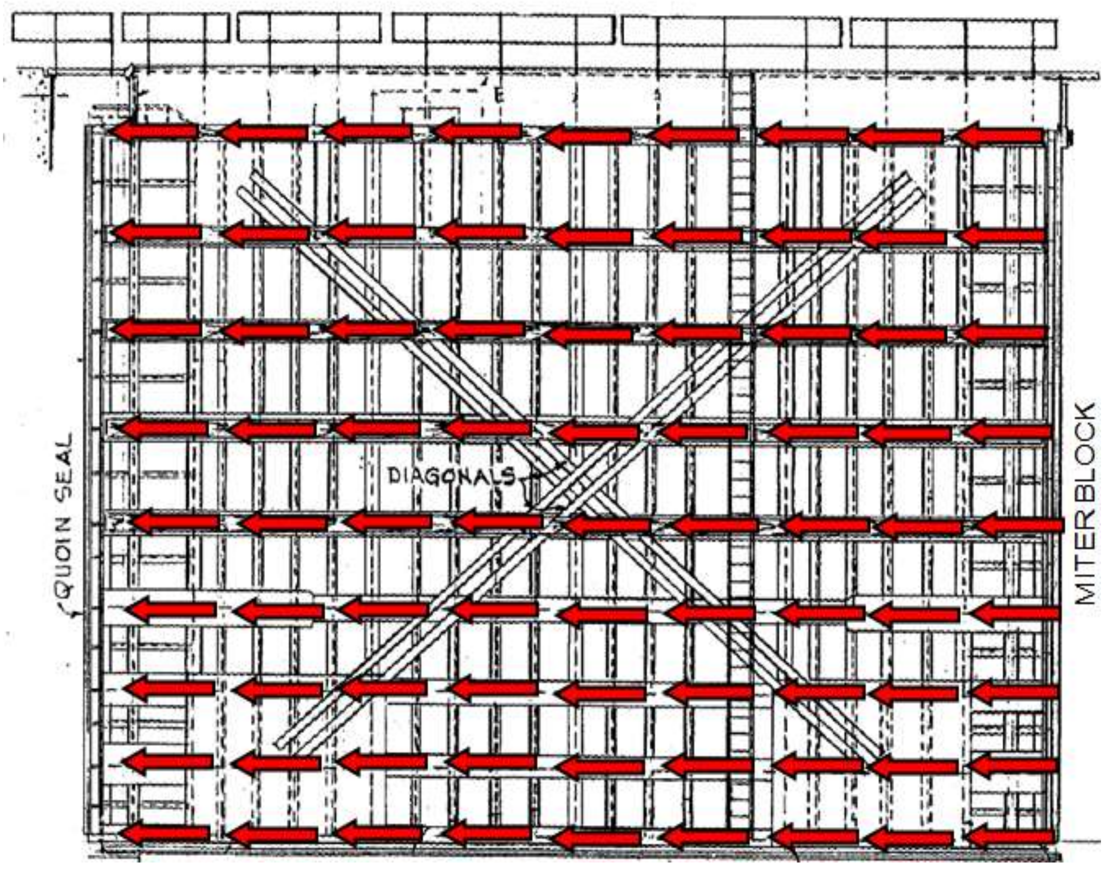

Fig. 8.1: *Horizontally framed mitre gate*
(source- **http://slideplayer.com/slide/13524883**)

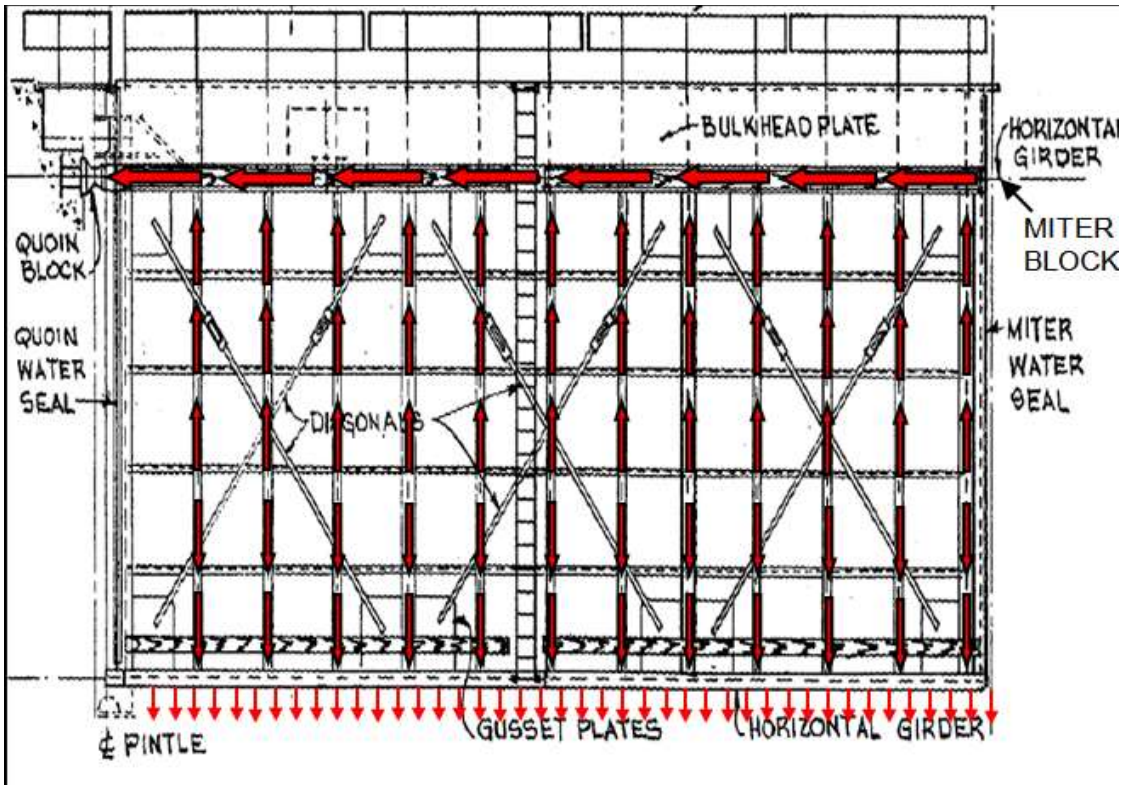

Fig. 8.2: *Vertically framed mitre gate*
(source- **http://slideplayer.com/slide/13524883**)

Mitre gates are a pair of two standard hinged leaves each having a width slightly greater than half of the width of the dock. Both the leaves are meet in the middle, so they are looking like a chevron style shape in plan view. They are opened and closed by rotating around a vertical axis during entering and leaving of ship. The resultant forces known as hydrostatic forces due to water on the both leaves of gate are acting right to the gate. Reaction forces on the lower and upper hinge are same as resultant force on gate. Reaction forces at the common contact surface of the gates are acting perpendicular to the contact surface. The mitre gate is the most common type of lock gate used in waterway (Ref: A.2.).
There is no need of high superstructure for these gates. There are few mechanical components of this gate which are not complex. The design of mitre gate should be very accurate in order to resist leakage.

- ***Construction -*** The entire gate shall be weld fabricated with shipbuilding quality steel plate as per IS: 3039 for skin plate and primary structural members. For secondary structural members IS: 2062 quality steel shall be used.

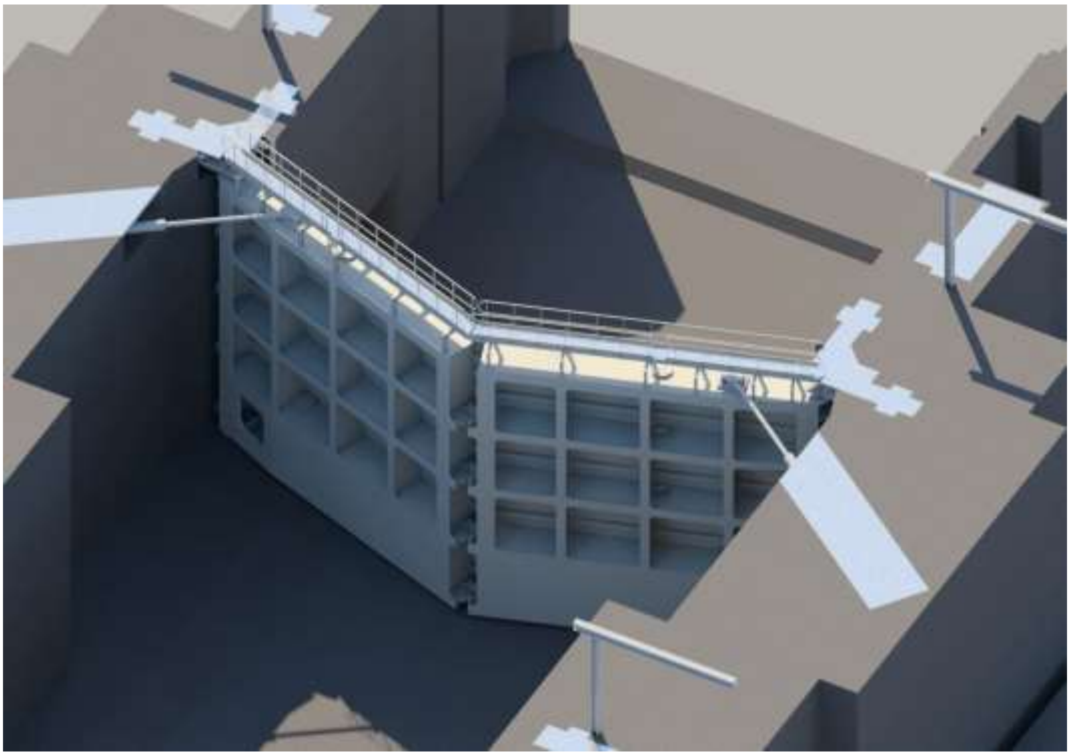

Fig. 8.3: *Three dimensional view of mitre gate*
(source- **http://www.sbe.be/en/reference/navigational-lock-farakka**)

Fig. 8.4: *Front view of mitre gate*
(source- **http://www.sbe.be/en/reference/navigational-lock-farakka**)

- ***Components –*** Mitre gate has various components , which has been discussed as following-
  - Skin Plate: It is a membrane through which water load is transferred on a mitre gate to other components.
  - Horizontal Girder: The water pressure is transferred from skin plate and vertical stiffeners to end arms of the mitre gate by horizontal spanning of horizontal girder. It is the main structural members of a mitre gate.
  - End Arms: It is the member through which the reactions are carried from horizontal girder to the gate trunnion.
  - Trunnion Hub: The converging arms of a mitre gate are rigidly connected to trunnion hub. It houses the trunnion bushing or bearing. It is rotated about the trunnion pin.
  - Trunnion Assembly: It is being consists of trunnion hub, trunnion bush or bearing, trunnion pin and trunnion bracket.
  - Yoke or Trunnion Girder: Trunnion bracket is being supported by this member and is held in place by load carrying anchors or tension members embedded in piers or abutments.
  - Anchor flats/Anchors: It is a structural member through which water load is transferred from trunnion girder of a mitre gate to the piers or abutments.
  - Anchor Girder: Load from a mitre gate to its surrounding structure is transferred by this structural member.
  - Thrust Pad or Thrust Block: It is an embedded structural member through which water thrust on a mitre gate, caused by lateral force generated due to inclination of end arms, transferred to the pier or abutment.
  - Trunnion Tie: Trunnion tie is designed to connect the two trunnion assemblies of a mitre gate to cater to the effects of lateral force induced due to inclination of end arms.
  - Wall Plate: A track for the seal and guide rollers of the mitre gate is provided by this embedded flush plate in a pier or abutment.

- ***Control system -*** The gate shall be operated through electro-hydraulic system to achieve opening and closing time.

  It is proposed to install the hydraulic power packs at both side of the lock near the each leaf of the gate. A remote control operation of the gate is envisaged from central control and also local control from the room where hydraulic power packs will be located.

  The hydraulic system shall include hydraulic power units using variable displacement, axial piston pumps, manifolds, stainless steel reservoirs, hydraulic cylinders, piping etc. as well as safety and instrumentation system.

The speed of the mitre gate will be determined by the output flow of the pump controlled by an electrically operated valve.

The cylinders will be directly attached to the Mitre gate. As the cylinder extends, water level is adjusted when mitre gates close. This seals the lock chamber from upstream or downstream approach channel. Once the water levels are equal, the cylinder retract to open the mitre gates so that the barges can pass.

The control system shall be PLC based. Fibre optic technology is proposed as communication mode for the lock operating system. The preferred protocol for the control system shall be suitable for the operations and shall be selected by the manufacturer/supplier of the control system.

- ***Fixing Arrangements* –** Adequate space shall be provided in the lock wall to accommodate the components of the hydraulic units. For fixing the hinges of the gate in the lock wall, a suitable provision shall be kept. Sill and side walls at gate grooves should be made of polished granite as per IS codes 14223 (Part-I) as mentioned in Design Criteria, keeping suitable provision in civil works. The rubber/timber seal of suitable grade as required shall be placed properly for water tightness of structure.

- ***Painting* -** Before fabrication all steel shall be shot blasted to SA $2\frac{1}{2}$ quality standard and primed immediately after blasting with one coat of approved shop primer. Thereafter the skin plate, structural/frames, fittings shall be coated with anticorrosive and antifouling paint system to achieve minimum guarantee life to first maintenance of 15 years based on ISO 12944.

➲ Caisson gate

- ***Structure* -** The entire gate shall be weld fabricated with shipbuilding quality steel plate as per IS:3039 for skin plate and primary structural members. For secondary structural members IS: 2062 quality steel shall be used.

  It shall comprise of deck, bulkheads, face plates so that various tanks and chambers can be arranged for ballasting and de-ballasting required for sinking and raising operations of the gate. The structural arrangement of the gate shall be such so that adequate strength and stiffness shall be achieved during sinking and raising operation under the specified load condition(Ref: A.16.). The shape of the gate shall be designed in such a manner so that the structure can be floated at a required light ship draft with adequate stability for manoeuvring and maintained sufficient stability during sinking and raising operation(Ref: A.16.).

  The profile of the keel should properly match with the contour of the lock floor. Proper sealing arrangements shall be provided with vertical and horizontal face of the lock chamber for the placement of the caisson gate in the grooves. The meeting face shall be provided with rubber seal of suitable grade and shall be placed in an epoxy grout and fitted properly using bolts for tight tolerance. Sill and side walls at gate grooves should be made of polished granite as per IS: 14223 (Part-I) as mentioned in Design Criteria, keeping suitable provision in civil works. Any modification/addition of tanks or chambers if required from stability point of view the same can be considered without changing the clear opening width of the lock based on which gate dimension has been planned.

- ***Components and Material of construction –*** It has miscellaneous items for fitting and fixtures.
  - Fixed Ballast : Steel I concrete block
  - Loose Ballast : Cast iron blocks

    The requirements of the ballast for operation of the caisson gate shall be made properly while designing the caisson and stability of the gate.
  - Bollards : At four corners of the top deck suitable beyond the operating platform tieing up the gate with lock wall or shore structure.
  - Fair Leads/Mooring Bits : Near the end of the top deck in four corners.
  - Fixed Hard Ralls : At each side of the top deck over full length in 3 tiers duly supported by galvanised steel stanchions. Handrails around bollards or fairleads shall be removable type.
  - Vertical Ladders : At both side in both ends upto the gate securing place.
  - Ring Plates : Suitable ring plates shall be provided for handling the caisson when afloat.
  - Cathodic Protection : Aluminium anodes shall be provided on the skin plate and inside tanks or chambers to achieve design life mentioned in design criteria.
  - Draft Marks : It shall be made from M.S. Roman numbers and welded on each side of the caisson near each stem and also printed in white denoting the draft in meters.

- ***Stability and floatation*** - Downstream lock approach channel has water depth of 5.28m. There is no tide effect in the approach channel. Gate shall be designed to be floated in and out of the lock entrance. The gate shall float with sufficient stability at light ship draft such that it can be safely maneuvered in out of the entrance. The gate shall also remain stable during sinking and raising operation.

  The following floatation and stability criteria shall be considered:
  - A minimum metacentric height of 0.6 m during sinking and raising operation.

- A positive preponderance shall be achieved when the gate is on the sill during all states of lock water levels.
- Minimum freeboard during floating condition - 0.6 m.
- Minimum under keel clearance at lightship draft - 0.5 m.
- The gate shall be capable of being ballasted for de-ballasted in 30 minutes or less.

So, the design should be accurate and the tanks are located to accommodation sufficient ballast weight for the sinking of the gate during all states of lock water levels with a positive preponderance. The sequence of the valve operations and the conditions of various tanks or compartments (full or empty) before starting the raising or lowering operation of caisson depends on the detailed design to be carried out.

- ***Control System -*** The sinking and raising operation of the gate shall be carried out through suitable valve arrangement without requiring any external assistance. The sequence of valve operations and the conditions of various tanks or chambers (full or empty) before starting the raising of lowering of the caisson is depending on the design. Each valve or cock shall have a separate control to operate from the top deck as well as from local. The valve controls shall be operated by electrical mode and manually from the top deck. All controls shall have suitable indicators showing the position of level for the valve or cock. Suitable piping arrangement shall be provided to connect these valves.

- ***Capstan -*** Two (2) nos. electrically operated capstan including starters, cables, fuse sockets etc. shall be fitted with necessary foundation for positioning and shifting the caisson on both side of lock floor. The capacity of the capstan shall be adequate for the intended operation.

- ***Submersible Pumps and Blowers -*** As an alternative arrangement for pumping due to any emergency, electric driven submersible pumps shall be provided in the tanks/chambers for emptying river water to achieve required buoyancy.

  Blowers of required capacity shall be provided for proper ventilation of enclosed space with wirings, switch and socket.

- ***Electricals -*** Control panel for operation of ballasting system, valves etc. shall be attached to the handrail on the top deck. The panel shall be within a weather proof enclosure. Sufficient lights with watertight fittings suitable under water application with all the cables and gears etc. shall be provided below main deck. The cables shall be enclosed in watertight GI pipes.

- ***Testing for Air/Water Tightness* -** The entire caisson gate shall be tested for water or air tightness as the case may be separately for individual compartment and jointly as a complete gate as specified by classification society. All water pipes and valve bodies shall be also tested in accordance with the manufacturer's specification and relevant IS codes.

- ***Inclining Test* -** The metacentric height of the gate at lightship draft shall be calculated by means of an inclining test during commissioning.

- ***Trials* -** A demonstration trial shall be carried out at the project site to prove that the gate along with the ballasting or de-ballasting system is in good condition and to familiarize the operation to the lock operators.
  The following trials will be carried out before acceptance:
  - The gate shall be placed and position in the landing face of the lock basin be to check the perfect sealing of the gate. There should not be any leakage from the gate i.e. in between the lock face and caisson seals.
  - The above trial shall be shown for both the side of the caisson one after another.
  - Ballasting/de-ballasting time in 30 mins or less.
  - Emergency lifting of the gate by using submersible pumps.

- ***Painting System* -** Before fabrication all shall be shot blasted to SA $2\frac{1}{2}$ quality standard and primed immediately after blasting with one coat of approved shop primer. Thereafter the skin plate, tanks, frames, fittings shall be coated with anticorrosive and antifouling paint system to achieve minimum guarantee life to first maintenance of 15 years based on ISO 12944.

➲ Radial gates

- ***Structure* -** The filling and emptying of lock chamber are controlled by Radial Gate structure by using two leaves. Radial gates are hinged gates with centre of gravity at the hinge or trunnion Gate sill is positioned at downstream of crest as close to the crest as possible to economise on the dimension of the pier and gate. Trunnion is placed above the upper nappe of water along piers to resist damage to trunnion due to variation of water level.

- ***Components* –** Radial gate has various components, which has been discussed as following-
  - Vertical Stiffeners or horizontal girders : The horizontal girders shall be so spaced that the bending moments in the vertical stiffeners at the horizontal girders as a continuous beam are about equal. When more than three girders are provided, the bending moment in the vertical stiffener at

the top most girder, of a higher value than at the other girders may be allowed so as to adequately stress the skin plate. The girders shall be designed considering the fixity at arms support. In case of inclined arms used, the girder shall be designed per compressive stress induced. Girder shall be checked for shear at the points where they are supported by arms. The spacing and design of the bearing and intermediate stiffeners shall be governed by relevant portion of IS: 800-1984.

- Arms : The arms shall be designed under combined axial compression and bending in accordance with the provisions contained in IS: 800-1984 and taking into consideration the type of fixity to the girder.
  The total compressive stress shall no exceed values of l/r where 'l' is the effective length a e east arms and horizontal girders shall be designed for the side thrust due to the inclination of the arm.
  Arms shall be suitably braced. The bracings connecting the arms that shall be so spaced, that the slenderness ratio of the arms in both the longitudinal and transverse directions is nearly equal.
- Trunnion hubs : The arms of the gate shall be rigidity connected to hubs to ensure full transfer of loads. The hubs shall be sufficient long so as to allow arms of the gate to be fixed to the respective limbs of the hub without having to cut and shape the flanges of the arms. The limbs of the hubs shall be on the apex of a cone with the base of the cone along the joints of the arms and horizontal girders. The thickness of the webs and flanges of each of the limbs of the hub shall be greater than that of arms to the extent so as to provide adequate space for the weld. Sufficient ribs and stiffeners shall be provided in between its webs and flanges to ensure rigidity of the Trunnion hubs.
- Trunnion pins : The Trunnion pin shall be supported at both ends on the Trunnion brackets which are fixed to the support girders. The Trunnion pins shall be designed for bending for the total load transferred through the Trunnion hub. The load shall be taken as uniformly distributed over the length of the pin bearing against the hub. The provision for periodical greasing of the bearing shall be made on the outer surface. The Trunnion shall be medium fit in the bearing lugs of the support and shall be locked against rotation. Suitable arrangement for greasing the outer surface of Trunnion pins shall be made. The Trunnion pin shall be made of Corrosion Resistant Steel Gr. 20 cr 13/ 30 cr 13 conforming to IS: 6603/IS: 1570 Part (V).
- Trunnion bush/bearing : Trunnion bush/bearing shall be of self-lubricating plain bearings type. These shall be force fit in the Trunnion hub and running fit on the Trunnion pin.

- Trunnion brackets : The Trunnion brackets shall be rigidly fixed to the support yoke girders by bolts or welding and shall transfer the total load from the Trunnion to the anchorages. The arm of the bracket shall be designed to transfer the load from each Trunnion bearing. The arms of the bracket shall also be designed to resist any bending which may be encountered by them due to the component of the load parallel to the base of the Trunnion bracket. Ribs and stiffeners shall be provided on the Trunnion bracket to ensure sufficient structural rigidity.
- Seals : The seals shall be fixed to the gate leaf by means of counter sunk screws made of stainless steel/corrosion resistant steel. The screws shall be designed to take up full shear likely to develop during raising or lowering of the gate under maximum head of water between the seal and bearing plates. The screws shall be adequately tightened to a constant torque and locked by punch mark. Minimum threaded length equivalent to one -and- half times the diameter of screws shall be screwed to ensure against their loosening under vibrations during operations.
  Fluorocarbon cladded rubber seals for sides and top shall only be used. Suitable chamfer shall be provided at the bottom of the skin plate/clamp plate to accommodate the bottom wedge seal in compressed position.
- Guide Plates and Guide Rollers **–** Guide roller shall be provided to the sides of radial gate to limit the lateral motion or side sways of the gate to not more than 6mm in either direction. Rollers shall be adjustable and removable. These shall travel on wall plate but the portion of wall plates on which they travel shall be made of structural steel. Roller shall be provided with plain Aluminium Bronze Bushings, turning on fixed steel pins. Suitable provision for greasing shall also be made.
- Gate Anchorage System - The gate anchorage system shall consist of steel Trunnion girders, anchor girder, load bearing anchor rods. The anchorage system shall be designed to withstand the total water load on the gate and transfer it to the piers and abutments either by bond stress between anchors and concrete or in bearing as bearing stress between concrete and the embedded girder at upstream end of the anchors.
- Trunnion Girder or Yoke Girder **-** The Trunnion girders shall about the downstream face of the piers. It shall be of structural steel fabrication. Trunnion girder and its design shall be determined by the magnitude of the bending shear and maximum torsion occurring when the gate is partially raised and the lock chamber is on the maximum water level.
- Anchor Bolts or Anchor Plates - The anchorages shall be provided in the 1st stage concrete, with suitable block out openings to hold the 2nd stage embedded parts. The anchor bolts in 2nd stage concrete shall be with double, nuts and washers.

- ***Material of construction* -** The radial gates shall consist of curved skin plate as per IS:2062 steel quality cladded with corrosion resistant steel conforming to IS:1570 - Part V. The skin plate shall be supported on suitably spaced vertical stiffeners which are supported on horizontal girders. The horizontal girders shall be supported by radial arms emanating from the Trunnion hubs located at the axis of the skin plate cylinder. The arms shall transmit the water thrust to yoke girder. Suitable sealing arrangement shall be fixed with the help of stainless steel screws so as to ensure positive water pressure to prevent leakage.

***Control System* -** The gate shall be operated through electro-hydraulic system to achieve opening and closing time.
It is proposed to install the hydraulic power packs at both side of the lock near the each leaf of the gate. A remote control operation of the gate is envisaged from central control and also local control from the room where hydraulic power packs will be located.
The hydraulic system shall include hydraulic power units using variable displacement, axial piston pumps, manifolds, stainless steel reservoirs, hydraulic cylinders, piping etc. as well as safety and instrumentation system.
The speed of the radial gate will be determined by the output flow of the pump controlled by an electrically operated valve.
The control system shall be PLC based. Fibre optic technology is proposed as communication mode for the lock operating system. The preferred protocol for the control system shall be suitable for the operations.

- ***Painting* -** Before fabrication all steel shall be shot blasted to SA $2\frac{1}{2}$ quality standard and primed immediately after blasting with one coat of approved shop primer Thereafter the skin plate, structural/ frames, fittings shall be coated with anticorrosive and antifouling paint system to achieve minimum guarantee life to first maintenance of 15 years based on ISO 12944.

➲ Bulk head gates

- ***Structure* -** The gate frame consists of bearing plate/roller tracks, seal seats, girder and guides and the structure shall be welded construction. The gate frames, gate leaf and embedded parts shall be fabricated from structural steel as per IS: 2062.
- ***Components* -** Bulkhead gate has various components , which has been discussed as following-
  - <u>Seals</u> : Rubber seals shall be provided as per relevant IS codes and the sealing arrangement should be such as to make the gate watertight.

Provision shall be made to pressurize the back of the top and side seals with water in order to obtain water tightness.

- Guide Rollers : Guide rollers shall be provided at the sides of the gates both near the top and bottom. The guide rollers shall be effective in both longitudinal and transverse directions. Bottom guide roller shall be provided with shear screws and top roller shall be provided with non-shearing screw capable of withstanding the load arising due to tilting of the gate.
- Track/ Bearing Plates : It shall be provided on downstream side of the gate slot
- Seal Seat : Side seal seat face shall be in common plane without off sets or gaps at joints. The bottom seal seat shall be flush with adjoining concrete surface. The arrangements of fixing should be such to ensure water tightness.
- Sill Girders : The bottom seal seat shall be provided on a suitable girder of structural steel to safety withstand the gate loads and impacts due to sudden closure of the gate.

➢ ***Material of construction -*** The entire gate shall be weld fabricated with shipbuilding quality steel plate as per IS: 3039 for skin plate and primary structural members. For secondary structural members IS: 2062 quality steel shall be used.

➢ ***Painting -*** Before fabrication all steel shall be shot blasted to SA $2\frac{1}{2}$ quality standard and primed immediately after blasting with one coat of approved shop primer. Thereafter the skin plate, structural/ frames, fittings shall be coated with anticorrosive and antifouling paint system to achieve minimum guarantee life to first maintenance of 15 years based on ISO 12944.

8.3 Flow through culvert

The lock is filled or emptied by using two culverts of size 4m wide × 2m high. The culverts are operated by a radial gate of height 2 m. The sill level of the gate/ invert of the culvert is 14.3 m. The culverts are submerged both on the upstream as well as on the downstream side.

The flow through a submerged culvert is calculated by,

$$Q = C_d A\sqrt{2gh}$$

where,

C_d ⇒ Discharge Coefficient,

A ⇒ Flow area
H ⇒ the head difference between u/s and d/s water levels

The discharge coefficient, C for a culvert which is submerged both in u/s and d/s is given by,

$$C_d = \frac{1}{\sqrt{K_b + K_e + K_o}}$$

Bend loss coefficient = 0.5
No of bends in each culvert = 2
Total bend loss coefficient, K_b = 2.0
Exit loss coefficient, K_e = 1.0
Gate loss coefficient, Friction loss and Entrance loss, K_o = 1.0
Total loss coefficient = 3.0

$$\therefore C_d = \frac{1}{\sqrt{K_b + K_e + K_o}}$$

$$= \frac{1}{\sqrt{2+1+1}}$$

$$= 0.58$$

Hence coefficient of discharge, C_d = 0.58

8.4 Air entrainment and Forces on gates

❑ Air entrainment

Water intake structures of different types are sometimes subjected to air-entraining vortices formation. An intake vortex can cause a swirling flow to enter the machine, resulting in off-design operation, loss of efficiency and cavitation, surging and vibration. An air-entraining vortex can also decreases the discharge into the intake.

A) ***Culvert/Tunnel levels -*** The new Farakka lock is connected in the u/s with the Farakka reservoir with two inlet culverts and in the d/s with feeder canal with two outlet culverts. The u/s of the inlet culvert is fed from the Farakka reservoir and d/s of the inlet culvert is drained to the lock. The u/s of the outlet culvert is fed from the lock and the d/s of the outlet culvert is drained to the feeder canal. All the culverts are rectangular in shape and 2.0 m high and 4.0 m wide.

The top and bottom levels of the u/s of the inlet culvert = 14.3 m (bottom) & 16.3 m (top)

The top and bottom levels of the d/s of the inlet culvert = 14.3 m (bottom) & 16.3 m (top)
The top and bottom levels of the u/s of the outlet culvert = 14.3 m (bottom) & 16.3 m (top)
The top and bottom levels of the d/s of the outlet culvert = 14.3 m (bottom) & 16.3 m (top)

B) ***u/s & d/s levels in lock -*** The regular operational levels of Farakka barrage i.e. Farakka reservoir in the upstream and feeder canal in the downstream is tabulated below.

	u/s Water Level (m)	d/s Water Level (m)	Head differences (m)
1:100 Flood	26.30	24.38	1.92
Normal Monsoon	21.95	20.88	1.07
Dry Season (Flow of about 50,000 cusecs)	21.95	18.90	3.05
Dry Season (Flow of about 70,000 cusecs)	21.34	18.288	3.05

Table 8.4: *Farakka barrage operational levels*

C) ***Flow condition through culverts -*** From the table above, It can be seen that,

The minimum u/s level = 21.34 m

The minimum d/s level = 18.28 m

The top of both the inlet and outlet culverts as 16.3 m. hence it can be said that the culverts are always in submerged condition.

The minimum water cushion = 21.34 − 16.3 = 5.04 m

$$\therefore \frac{V^2}{2g} = 5.04$$

$$V = 9.94 \text{ m/s}$$

The maximum velocity in the culvert = 4.4 m/s < 9.94 m/s.

Hence, no air entrainment occurs in the pipes.

The culverts are always submerged both in the u/s and d/s and the flow through these culverts is always pressure flow. Hence air is not entrained in the culverts during normal operational levels of the lock.

D) ***Vortex induced air entrainment -*** Air entraining vortices are a typical concept at intakes of hydroelectric power plants. A free surface vortex are initiated from the surface of the water, enabled the entrainment of air and angular momentum, called swirl. The origin of a subsurface vortex is located at a boundary, e.g. the wall or the bottom. Here are only swirl, but no air can be entrained. Furthermore, dissolved air could be contained by the core. They form at high intake velocities and/or low submergence.

IS 9761 stipulates the minimum submergence required to prevent air entrainment in the pipes/ culverts.

Clause 5.2; IS 9761, stipulates the minimum water cushion required above the central line of the pipe required as,

$$\frac{h}{d_p} = 0.5 + 2F_r$$

where,

h ⇒ the minimum submergence required above central line of the pipe
d_p ⇒ the height of the pipe/culvert = 2.0
F_r ⇒ the Froude number = 0.87

Thus the minimum submergence required above central line of pipe is 4.46 m (as per IS 9761).

The WL in the reservoir is 21.34 m and the central line of culvert is 15.3 m. hence a cushion of about 6.04 m exists above the central line of culvert.

Hence, no air entrainment due to vortices occurs in the system.

❑ Forces on radial gate

There are several forces which are acted on hydraulic gates with large cross-sectional area during their operation. Generally, these forces on a hydraulic gate consists of frictional force, hydrodynamic forces, dead weight, buoyant forces, transit loads and driving forces.

A fully closed radial gate is balanced in horizontal forces and is only subjected to buoyant forces by means of vertical forces. If a radial gate is partially opened and the flow inwardly the gate reaches high velocities and decreases the pressure, which causes a non-uniform distribution of piezometric head around the gate, then the hydrostatic balance is disturbed. As these velocities reaches higher values, higher value of hydrodynamic forces occur and hence leading an increase in the pressure difference.

- ***Hydrostatic force*** – The hydrostatic force acting on the gate is as shown in figure below

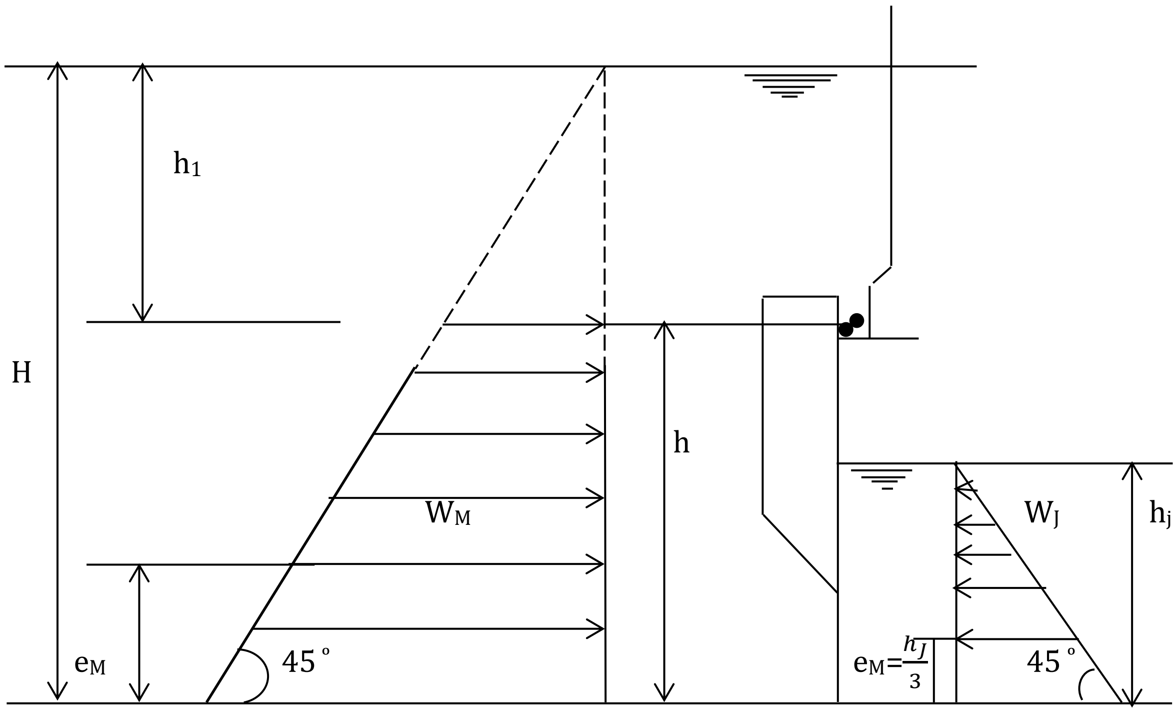

Fig. 8.5: *Forces on culvert gate*

Hydrostatic force on the gate for new Farakka navigational lock with maximum operating head of 4m is estimated below.

<u>Hydro-Static force on Gate</u> –

<u>Input:</u>

i) Floor level = 14.3 m
ii) Gate top level = 16.3 m
iii) u/s Water Level = 21.95 m
iv) d/s Water Level = 17.95 m
v) Height of Culvert = 2 m
vi) Density, ρ = 1000 kg/m^3
vii) Acceeleration due to gravity , g = 9.81 m/s^2
viii) Specific weight, γ = 9.81 kN/m^3

<u>Case: Gate fully Closed</u> :

Hydrostatic force, $P_a = \frac{\gamma(H^2 - h^2)}{2}$

Hydrostatic force u/s of gate, P_U = 130.47 kN/m

Force acting at = 0.95 m

Hydrostatic force d/s of gate, P_D = 51.99 kN/m

Force acting at = 0.87 m

Resultant force on gate = 78.48 kN/m

Taking moments of all the forces, about sill, Resultant Force acting at = 1.00 m

The maximum force on the gate is observed with full gate closing condition. The maximum force on the gate is 78.48 kN/m. The width of the gate is 4 m. Hence total force on the gate is 313.92 kN. For any other case of partly opened gate position, the force is less than this value.

8.5 Cavitation

- ### Cavitation in pipes

Cavitation expresses to the formation of air bubbles in fluid in the condition of low-pressure which is lower than the saturation pressure. It is a potentially damaging condition in which the fluid is at high velocities in pipes or sewers. The pressure head of fluid is decreased at high flow velocities according to Bernoulli's Equation. Dissolved gases are released from the fluid and these air bubbles will suddenly collapse when the flow enters into a region of higher pressure, as the fluid pressure is less than saturation pressure. Then a high dynamic pressure is produced by this and that high dynamic pressure is the cause of damage to the pipelines due to its high frequency.

When the pressure of a fluid becomes the same as its vapour pressure, Cavitation occurs and this happens a bubble of vaporized fluid forms. The formation of the vapour bubble is like boiling, but without adding heat. Then the vapour bubble is rapidly compressed by the pressure of the surrounding fluid. It creates a lot of localized energy because this process happens very rapidly. It releases the energy in the form of heat, sound and light after compression of the bubble is occurred enough.

When the static pressure is decreased below the vapour pressure corresponding to the liquid temperature or the temperature is increased above the saturation temperature corresponding to the liquid pressure in a flowing liquid, vapour bubbles are generated. When the bubbles are carried down streams by the liquid at a location of lower temperature or at higher static pressure then the bubbles are collapsed. The location of the flow where bubbles exist is the cavitating region, whereas the observed damage is at the region of the bubble collapse.

Cavitation is likely to occur in systems near:

- ✓ Orifices
- ✓ Valves
- ✓ Venturies
- ✓ Pump suction
- ✓ Pipe fittings (elbows, tees, etc)
- ✓ Bumps

There are undesirable effects on piping system and components created due to cavitation. There is undesirable noise produced, erosion might be cause, flow capacity is restricted of the system, and pipe failure might be cause.

So, the erosion is created in the cavitating fluid due to bubble collapse near the pipe wall.

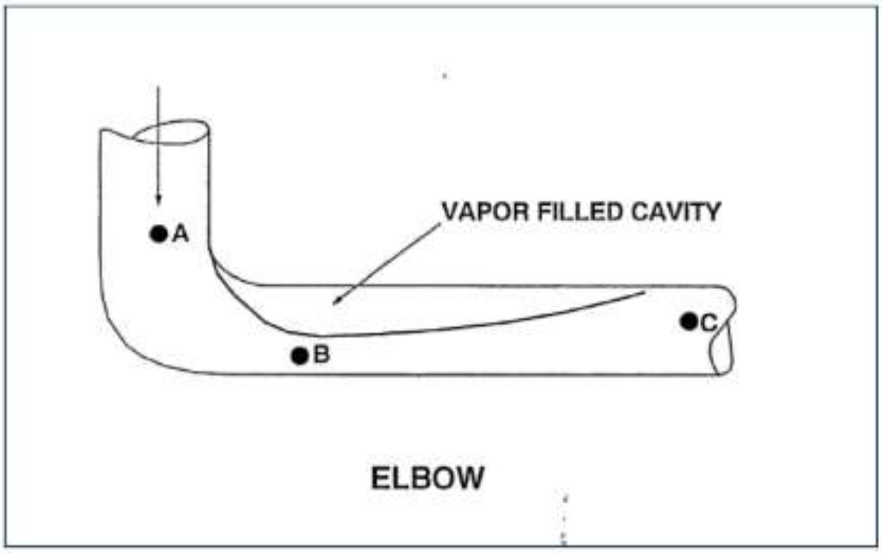

Fig. 8.6: *Cavitation in pipe bend/elbow*

❑ <u>Estimating cavitation</u>

Cavitation in culvert is estimated using Bernoulli's equation, manually.

Head considered for the study is 4.0 m. Since as head reduces, velocity in the pipe reduces and pressure rises. The possibility of cavitation reduces with rise in pressure. Hence the case with head of 4.0 m is the critical condition and for heads lesser than 4.0 m, the cavitation effect is decreasing.

<u>Estimation of piezometric head in the culvert</u> :

u/s Level = 21.95 m
d/s Level = 17.95 m

Operating head = 4.00 m

Invert Level = 14.3 m
Height of culvert = 2 m

Correction for absolute atm pressure = 10 m

Absolute Pressure head on C/L of inlet = 16.65 m
Absolute Pressure head on C/L of outlet = 12.65 m

Total Loss coefficient = 4.0
Velocity Coefficient = 0.5
Velocity, V = 4.43 m/s

$\frac{V^2}{2g}$ = 1.00 m

Discharge through pipe = 35.44 m^3/s

Applying Bernoulli's Equation in u/s reservoir,
Total EGL = 16.65 m

Applying Bernouli's Equation after entrance loss,
K_e = 0.50
Entrance Loss = 0.50 m
$\frac{P}{\gamma} + \frac{V^2}{2g}$ = 16.15 m
$\frac{P}{\gamma}$ = 15.15 m

Applying Bernoulli's Equation after Gate loss,
K_g = 0.50
Gate loss = 0.50 m
$\frac{P}{\gamma} + \frac{V^2}{2g}$ = 15.65 m
$\frac{P}{\gamma}$ = 14.65 m

Applying Bernoulli's Equation after 1st Bend loss,

K_b = 1.00

1st Bend loss = 1.00 m

$\frac{P}{\gamma} + \frac{V^2}{2g}$ = 14.65 m

$\frac{P}{\gamma}$ = 13.65 m

Applying Bernoulli's Equation after 2nd Bend loss,

K_b = 1.00

2nd Bend loss = 1.00 m

$\frac{P}{\gamma} + \frac{V^2}{2g}$ = 13.65 m

$\frac{P}{\gamma}$ = 12.65 m

Applying Bernoulli's Equation after exit loss,

K_e = 1.00

Exit loss = 1.00 m

$\frac{P}{\gamma} + \frac{V^2}{2g}$ = 12.65 m

$\frac{P}{\gamma}$ = 11.65 m

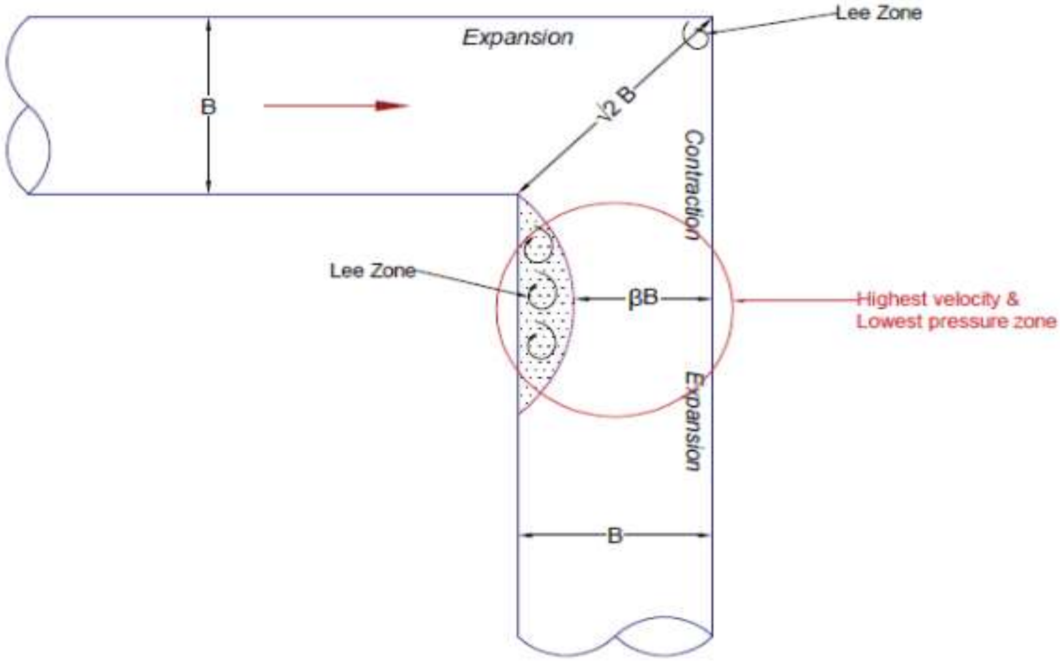

Fig. 8.7: *Flow process due to cavitation near 2nd bend in the pipe*

Estimation of reduced area due to cavitation –

Total Head loss in the bend = $1.1\frac{v^2}{2g}$

However due to cavitation, the following happens in the bend,

i) Turning
ii) Expansion-1
iii) Contraction
iv) Expansion-2

Width of the tunnel = B
Expanded width of culvert at corner = $\sqrt{2}$B
Contracted width due to cavitation = β B

i) loss due to turning = $0.1\frac{v^2}{2g}$

ii) loss due to expansion-1 = $\left(1-\frac{1}{\sqrt{2}}\right)^2\frac{v^2}{2g}$

iii) loss due to contraction = $0.5\left(1-\frac{\beta}{\sqrt{2}}\right)\frac{1}{\beta^2}\frac{v^2}{2g}$

iv) loss due to expansion-2 = $(1-\beta)^2\frac{1}{\beta^2}\frac{v^2}{2g}$

$$\therefore 0.1\frac{v^2}{2g} + \left(1-\frac{1}{\sqrt{2}}\right)^2\frac{v^2}{2g} + 0.5\left(1-\frac{\beta}{\sqrt{2}}\right)\frac{1}{\beta^2}\frac{v^2}{2g} + (1-\beta)^2\frac{1}{\beta^2}\frac{v^2}{2g} = 1.1$$

Solving for β,
β = 0.65
Hence reduced width due to contraction = 0.65 B

Estimation of cavitation at bend

$\frac{P}{\gamma}$ after 2nd bend = 12.65 m

$\frac{v^2}{2g}$ = 1.00 m

Cavitation causes reduced flow area
Ratio of reduced area, $\beta = 0.65$

Velocity of flow for reduced area = 6.81 m/s

Applying Bernoulli's Equation,
P/γ for reduced area = 11.28 m

P for reduced area = 110687.57 N/m^2 = 110.68 kpa

Saturation vapour pressure,

for 30° 4.23 kpa

for 20° 2.34 kpa

for 15° 1.70 kpa

So, No Cavitation occur

Since, pressure at reduced area is much larger than saturation vapour pressure of water. Cavitation does not occur in the pipe/culvert system.

CHAPTER – 9

NAVIGATIONAL LOCK AT FARAKKA

CHAPTER - 9 NAVIGATIONAL LOCK AT FARAKKA

India has a large scale network of water bodies in the forms of rivers, lakes, canals and backwaters. These network of waterways provide transport facilities across the cities like few canals and backwaters of Gujrat, Kerala, Goa, West Bengal and Assam. Still these inland waterways are not utilized in India as compare to other nations in the world. Inland Waterways Authority of India is working on various projects for better waterways transportation in India.

The National Waterway-1 (NW-1) is located in India and runs from Allahabad to Haldia. It is the longest waterway in India of length of 1620 km. It is of prime importance as compared to all other national waterways considering its locational benefits. The National Waterway-1 runs through major towns of West Bengal, Jharkhand, Bihar and Uttar Pradesh.

The discussion of the relevant pointson of historical background of Farakka project is necessary. Farakka Barrage is a barrage across the Ganges River, located in the Indian state of West Bengal. It was constructed in the year of 1975. The existing navigation lock gate at Farakka barrage was constructed in 1978. It is old and inefficient due to operation since forty one years. So, the operation is taking about two hours or more for a ship to pass upstream or downstream of Farakka barrage. Since the modernisation of the existing lock will entail closing down the lock gate for about 8-10 months, it was decided to first build a new navigational lock and subsequently undertake the modernisation of the existing lock.

Fig. 9.1: *Existing Navigation lock gate at Farakka*
(source- **http://www.srllinson.blogspot.com**)

Constructional Features of Farakka:

The Farakka Barrage Project consists of a barrage structure across the river Ganga at Farakka with a feeder canal of length of 38.3 km leading into the river Bhagirathi-Hooghly and make the navigable route through the main Ganga river upstream to the river Bhagirathi downstream. The feeder canal of Farakka barrage and the existing navigation lock is the link between the main Ganga and Bhagirathi-Hooghly. Foundation of the project was began in 1962 and was completed in 1971. Another four years are taken for the excavation of 38.3 km long feeder canal. The formal inauguration of Farakka project was held on 21st May 1975.

Fig. 9.2: *Farakka Barrage*
(source- **http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=Farakka_Barrage**)

The brief particular of Farakka feature are:

i) A barrage across river Ganga at Farakka having a total length of 2240 metre,
ii) A canal 38.3 km. long,
iii) A barrage at Jangipur of 12.19 m clear span,
iv) A regulator on Kalindri spill channel of length of 38 km upstream to prevent spillage of ponded flow,
v) Two navigation locks i.e. one at upstream of Farakka Barrage and the other adjoining to Jangipur barrage for simplifying the navigation from Bhagirathi to Ganga via feeder canal,
vi) Other important particulars include afflux bunds and guide bunds for the barrage, drainage structures on the feeder canal.

Feeder Canal - The feeder canal is an important component of the Farakka. Navigation through Bhagirathi-Hooghly river system, maintenance of regime are depends upon the system of the feeder canal with full supply discharge. Additional benefits of feeder canal are as the following:

i) Improvement of water supply for Calcutta and its industrial hinterlands by decrease in salinity,
ii) Improvement of drainage capacity of the Bhagirathi,
iii) Minimization of flood hazards in the catchment area,
iv) Facilitation of navigability in the Bhagirathi-Hooghly and Ganga from Kolkata port or Haldia port to Uttar Pradesh through feeder canal.

Design features of New Navigation Lock-

i) Length of the canal 38.3 km.
ii) Bed width 150.88 m.
iii) Slide slope 3 : 1
iv) Full supply depth 6.1m.
v) Bed slope 1 : 20,000
vi) Velocity of flow 1.17 m (3.58 ft) per second at FSL
vii) Full supply level discharge 40,000 cusecs
viii) The feeder canal may be operated to the following optimum cycles of withdrawals subject to the confirmation by the model experiments.

Period	Optimum Withdrawals from Feeder Canals
1st January to mid March	40,000 cusec
Mid March to mid May	20,000 cusec
Mid May to mid September	20,000 cusec
Mid September to Mid December	40,000 cusec

Table 9.1: *Optimum Withdrawals from Feeder Canal*

ix) Lock gate size and numbers –

Types of gate	u/s		d/s		Nos.
	Height (m)	Width of lock opening (m)	Height (m)	Width of lock opening (m)	
Mitre gate	13.64	25.15	13.94	25.15	2
Caisson gate	13.94	25.15	13.94	25.15	2
Radial gate	2	4	2	4	4
Bulk head gate	2.2	4	2.2	4	8

Table 9.2: *Lock gate size and numbers*

Site condition - The Bhagirathi River was flowing almost East-West direction near the barrage site. The flow was closed to the right bank and it is comparatively steeper than the left one. The maximum discharge, 560 cumec which was recorded at the site during the monsoons season.

The type of soil of Ganga is alluvium where the barrage site is also located. Both the abutments of the barrage is of silt while the river bed is sandy like the Farakka Barrage site.

The presence of fine and coarse sand mixed with gravel at places has been indicated by drilling of 28 metre deep borehole, on the river bed at Jangipur a few kilometre downstream of the proposed site.

CHAPTER - 10

CONCLUSION

CHAPTER - 10 CONCLUSION

This project has been finalized based on the available construction mechanism, ease of construction and overall economy of the system. Operating gates has been chosen based on the requirement for locking time requirement of the space, site condition, climatic condition and reliability in operation. Considering all these factors and the river morphological characteristics the navigation lock has been designed as latest technology.

The following conclusions are obtained from the study:

- ✓ The typical operational head in the lock during 2014-15 is about 2.03 m and observed maximum in 2014-15 is 3.35 m.
- ✓ Lock Capacity in Annual Total tonnages of Vessels Passed Through a lock in Up & Down Direction is 44,760 tonnes/year.
- ✓ Filling time of lock is 754.426 sec or 12.57 min and emptying time of lock is 735.94 sec or 12.26 min.
- ✓ Two (2) nos. Mitre Gates are proposed one at upstream and another at downstream of the lock to facilitate the opening and closing operation.
- ✓ Two (2) nos. floating type of Caisson Gates are proposed for replacement/ repair/maintenance of Mitre Gate.
- ✓ Four (4) Nos. Radial gates are proposed, 2 Nos. at u/s and 2 Nos. at d/s at both side of lock for filling and emptying of the lock chamber to facilitate navigation of IWT vessels.
- ✓ Eight (8) bulkhead gates are proposed for repair of Radial gates.
- ✓ The maximum hydrostatic force on the gate is 313.92 kN.
- ✓ Air entrainment due to vortices does not happen in the culvert system.
- ✓ Cavitation does not occur in the pipe/culvert system.

Recommendation of future work -

This new navigational lock at Farakka will facilitate the navigation process through Farakka feeder canal. After completion of new Navigation lock, it will be easy to movement of vessel from Allahabad to Haldia or Haldia to Allahabad through Farakka. So, large number of vessel will be passed through this waterway. The control system should be based on modern technology. All the system should be as digital system. There should have alternate system or method to continue service during failure of any system or technical error. SHM(Structural Health Monitoring) system should be developed for collecting water level gages and data from strain to identify the damage in mitre gate structure. More FEM(Finite Element Model) simulations of mitre gate gap at various location are necessary for investigation of damage localization. The road towards the navigation lock needs to be constructed for better communication purposes. The maintenance should be done at specified interval to protect any complex and create safe and secure navigation.

CHAPTER - 11

REFERENCES

CHAPTER - 11 REFERENCES

A. Papers –

1. **Blok, J.J., Brozius, L.H., Dekker, J.N., *(1983).*** *"The Impact Loads of Ships Colliding With Fixed Structures"*, Ship Model Basin Netherlands, Page. 231-240.

2. **Camporese, M., *(2013).*** *"Optimal Design of Horizontally Framed Miter Gates"*, Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 139, Issue- 6.

3. **Dhanuka, A., Agrawal, S.K., and Mehra, H., *(2018)*.** *"Hydraulic and Structural Design of Navigational Locks",* Journal of Civil & Environmental Engineering, Vol. 8, Page. 1-3.

4. **Davis, J.P., *(1989).*** *"Hydraulic design of navigation locks"*, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Page. 9-186.

5. **Daniel, R.A., *(2000).*** *"Mitre gates in some recent lock projects in the Netherlands"*, Department of Hydraulic Engineering, Netherlands, Page. 952-957.

6. **Figular, R.L., *(2017).*** *"Vessel handling in river estuaries"*, Mariners learning system, Princeton, New Jersey, US, Page. 1-3, 12.

7. **Gerritse. A., *(2016)*** *"Load Principles for Drive Mechanisms of Miter Gates"*, Master Thesis report, Delft university of Technology Civil Engineering and Geosciences, Netherlands, Page. 1-10, 24-44, 46-51.

8. **Hufferd, J. A., Isbester, T. J., *(1966)*** *"Hydraulic design of main canal head-gate structure by model study"*, Bureau of Reclamation, United States Department of the Interior Denver, Colorado, Page. 1-15.

9. **Mulder, T.D., *(1966)*** *"Computational fluid dynamics (cfd) in lock design: progress and challenges",* Department of Mobility and Public Works, Flanders Hydraulics Research, Antwerp, Belgium, Page. 1-3.

10. **Mulder, T.D., Verelst. K., Vercruysse. J., Cock, W.D., Haegeman, M., *(2010).*** *"On hawser force criteria for navigation lock design: case study of maritime locks in port of antwerp"*, PIANC MMX Congress Liverpool, Page. 1-2.

11. **Richardson, G.C., *(1964).*** *"Navigation Locks: Navigation Lock Gates and Valves"*, Journal of the Waterways and Harbours Division, USA, Vol. 90, Page. 79-102.

12. **Rigo, P., *(2009).*** *"Innovations in Navigation Lock Design",* International Workshop, PIANC – Brussels, USA, Page. 1-2.

13. **Roux, S., Roumieu, P., Mulder, T.D., Vantorre, M., Regge, J.D., Wong, J., *(2010).*** *"Determination of hawser forces using numerical and physical models for the third set of panama locks studies"*, PIANC MMX Congress Liverpool UK 2010, Page. 5-8.

14. **Stockstill, R. L., Hite, J. E., *(2011).*** *"Innovation in lock filling and emptying systems",* US Army Engineer R&D Center US Army Engineer R&D Center, USA, Page. 1-4.

15. **Verelst, K., Vercruysse, J., Mulder, T.D., *(2013).*** *"On a pragmatic force criterion for the design of a navigation lock filling and emptying system"*, Flanders Hydraulics Research, Belgium, Page. 1-3.

16. **Voorendt, M.Z., Molenaar, W.F., Bezuyen, K.G., *(2016).*** *"Lecture notes on Caissons gate, Hydraulic Structures"*, Department of Hydraulic Engineering, Faculty of Civil Engineering, Delft University of Technology, Netherlands, Page. 6-8, 32-34.

17. **Woelke, P., *(2010).*** *"Ship impact study: Analytical approaches and finite element modelling"*, Weidlinger Associates, Inc., New York, USA, Page. 515-520.

B. <u>Books</u> –

1. **Bansal, R.K., (*2014).*** *"A textbook of Fluid mechanics and Hydraulic machines",* Edition – 9, Page. 69-109, 260-265, 737-744.

C. <u>Codes and standard</u> –

1. **IS : 4851 (Part III) – 1974**. *"Code of practice for Planning and Design of Ports and Harbours".*

2. **IS : 4623 – 2000**. *"Recommendation for Structural Design of Radial Gate".*

D. Dissertations and Manuals –

1. ***Kentucky River And Tributaries, Upper Kentucky River Navigation Project, (1990)***. US Army Crops of Engineers, Louisville, Kentucky, USA, Vol 1, Page. 5-16, 19-22.

2. ***Harbour Approach Channels Design Guidelines, (2014).*** Pianc Report N° 121, Maritime Navigation Commission, USA, Page. 4-21.

3. ***Manual on Design of Locks, (2011).*** Ministry of Transport, Public works and water management, Civil Engineering Division, Netherlands, Page. 4.1–4.11

E. Websites –

- https://en.wikipedia.org/wiki/List_of_National_Waterways_in_India#/media
- https://twitter.com/IWAI_Ship
- https://www.livingtravel.com/asia/india/2015_GangesCruise_04.html
- http://www.sbe.be/en/reference/navigational-lock-farakka
- http://bcompetitive.in/national-waterway-act-2016
- https://india-wris.nrsc.gov.in/wrpinfo/index.php?title=National_Waterways-1
- https://www.mapsofindia.com/maps/inlandwaterways/nationalwaterway2.html
- http://www.iasabhiyan.com/national-inland-waterways-india
- https://en.wikipedia.org/wiki/National_Waterway_4
- https://india-wris.nrsc.gov.in/wrpinfo/index.php?title=National_Waterways-5
- http://www.indiawris.nrsc.gov.in/wrpinfo/index.php?title=National_Waterways-6
- https://www.marineinsight.com/naval-architecture/rudder-ship-turning/html
- http://osp.mans.edu.eg/tahany/LOCKS1.html
- http://www.mvs-wc.usace.army.mil/arec/LD_27.html
- https://slideplayer.com/slide/13524883/
- http://www.sbe.be/en/reference/navigational-lock-farakka
- http://www.srllinson.blogspot.com
- http:// http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=Farakka_Barrage

ANNEXURE

RELATED THEORY

ANNEXURE

RELATED THEORY

Navigation channel is an open channel. The prime motivating force for flow through open channel is gravity. When the ship moves through the channel then various forces are generated due to effect of hydrostatic and hydrodynamic. For designing of navigational lock gate the forces will have to be analysed. The phenomena of open channel flow helps to analysing the forces due to ship movement and also in design process. For this purpose, we have to know basic concept of various types of flow, fundamental equation etc.

A.1 Classification of flow in open channels

The flow in open channel is classified into the following types-

i) Steady flow and unsteady flow,
ii) Uniform flow and non-uniform flow,
iii) Laminar flow and turbulent flow, and
iv) Sub-critical, critical and super-critical flow

❑ Steady Flow and Unsteady Flow

If at any point in open channel flow, the flow characteristics such as velocity of flow, rate of flow, depth of flow do not change with respect to time, the flow is said to be steady flow. Mathematically, steady flow is expressed as,

$$\frac{\partial V}{\partial t} = 0\,, \frac{\partial Q}{\partial t} = 0\,, \frac{\partial y}{\partial t} = 0$$

where, $V \Rightarrow$ Velocity, $Q \Rightarrow$ Rate of flow and $y \Rightarrow$ Depth of flow.

If at any point in open channel flow, the velocity of flow, rate of flow, depth of flow changes with respect to time, the flow is said to be unsteady flow. Mathematically, unsteady flow is expressed as,

$$\frac{\partial V}{\partial t} \neq 0\,, \frac{\partial Q}{\partial t} \neq 0\,, \frac{\partial y}{\partial t} \neq 0$$

❑ Uniform Flow and Non-uniform Flow

If the velocity of flow, depth of flow, slope of the channel and cross-section for a given length of the channel remain constant, the flow is said to be uniform. On the other hand, if the velocity of flow, depth of flow etc., for a given length of the channel do not remain constant, the flow is said to be non-uniform flow. Mathematically, uniform and non-uniform flow are expressed as,

$$\frac{\partial V}{\partial s} = 0\,, \ \frac{\partial y}{\partial s} = 0 \quad \text{for uniform flow}$$

$$\frac{\partial V}{\partial s} \neq 0\,, \frac{\partial y}{\partial s} \neq 0 \quad \text{for non-uniform flow}$$

In open channels, Non-uniform flow is also called varied flow, which is classified in the following two types as

a) Rapidly Varied Flow (R.V.F.), and
b) Gradually varied flow

- ***Rapidly Varied Flow*** **(R.V.F.)** - When depth of flow changes abruptly over a small length of the channel, the flow is said to be rapidly varied flow. In Fig. A.1 if there is any obstruction in the path of flow of water, the water level is rises above the obstruction and then falls and again rises over a small length of channel. Hence the depth of flow is changed rapidly over a short length of the channel.

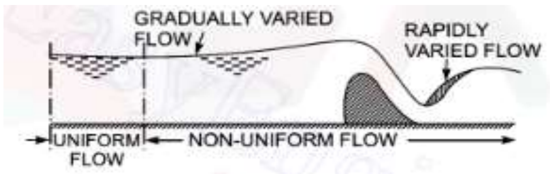

Fig. A.1: *Uniform flow and Non-uniform flow*

- ***Gradually varied flow*** **(G.V.F)** - Gradually varied flow is defined as that the depth of flow in a channel changes gradually over a long length of the channel,

❑ Laminar Flow and Turbulent Flow

The Reynold number, R_e for open channel is expressed as:

$$R_e = \frac{\rho V R}{\mu}$$

where,

$V \Rightarrow$ Mean velocity of flow of water
R $\Rightarrow$ Hydraulic radius or hydraulic mean depth
$\rho \Rightarrow$ Density of water
$\mu \Rightarrow$ Viscosity of water

If the Reynold number is less than 500, the flow in open channel is called to be laminar.

If the Reynold number is more than 2000, the flow in open channel is called to be turbulent.

If the Reynold number lies between 500 and 2000, the flow in open channel is called to be in transition state.

- **Sub-critical, Critical and Super-critical Flow**

The Froud number (F_r) is defined as:

$$F_r = \frac{V}{\sqrt{gD_0}}$$

where,

$V \Rightarrow$ Mean velocity of flow

$D_0 \Rightarrow$ Hydraulic depth of channel = $\frac{A}{T}$

$A \Rightarrow$ Wetted area

$T \Rightarrow$ Top width of channel

$F_r = 1$ for critical flow

$F_r < 1$ for sub-critical flow

$F_r > 1$ for super-critical flow

A.2 Emperical formulas and equation

- **Manning's formula**

Manning's formula is expressed as,

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

where,

$V \Rightarrow$ Mean velocity of flow

$n \Rightarrow$ Manning's constant

$R \Rightarrow$ Hydraulic radius or hydraulic mean depth = $\frac{A}{P}$

$A \Rightarrow$ Wetted area

$P \Rightarrow$ Wetted perimeter

$S \Rightarrow$ Slope of bed

❑ Total pressure and centre of pressure

Total pressure be defined as the force exerted by a static fluid on a plane or curved surface when the fluid comes in contact with that surfaces. Center of pressure is defined as the point of application of the total pressure on the surface.

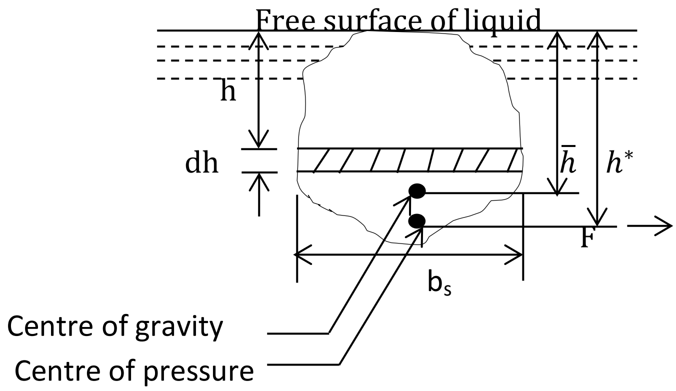

Fig. A.2: *Total pressure and centre of pressure on a vertical surface of liquid*

Consider a plane vertical surface in a liquid as shown in Fig. A.2 where 'A' be the total area of surface and $\bar{h}$ be the distance of C.G. of the area from free surface of liquid.

- **Total pressure (F)** - The total pressure on the surface can be derived by dividing the entire surface into a number of small parallel strips. The force on each small strip is then determined and the total pressure force on the whole surface is determined by integrating the force on each strip.

Considering a strip of thickness 'dh' and width 'b_s' at a depth of 'h' from free surface of liquid as shown in Fig. A.2

Pressure intensity on the strip, $p = \rho g h$

Area of the strip, $dA = b_s \times dh$ ……………i)

Total pressure force on a strip, $dF = p \times dA$

$\therefore dF = \rho g h \times b_s \times dh$ ……………ii)

Total pressure force on the whole surface are,

$$F = \int dF$$

$$\Rightarrow F = \int \rho g h \times b_s \times dh$$

$$\Rightarrow F = \rho g \int b_s \times h \times dh$$

$$\Rightarrow F = \rho g \int h \times dA$$

[We know, Moment of surface area about the free surface of liquid = Area of surface × Distance of C.G. from free surface i.e. $\int h \times dA = A \times \bar{h}$]

$$\therefore F = \rho g A\bar{h} \qquad \text{……………..iii)}$$

So, the total pressure on a surface can be expressed as,

$$\boxed{F = \rho g A\bar{h}}$$

- **Centre of pressure, h^*** - Centre of pressure is determined by following the 'Principle of Moments', which states that the moment of the resultant force about an axis is equal to the sum of moments of the components about the same axis.

The resultant force 'F' is acting at the point of plane vertical surface at a distance of h^* from free surface of liquid as shown in Fig. A.2.

Hence moment of force 'F' about free surface of liquid = $F \times h^*$ …………..iv)

Moment of force 'dF', acting on a strip, $dM = dF \times h$

$= \rho gh \times b_s \times dh \times h$ [$\because dF = \rho gh \times b_S \times dh$ From Equation…ii)]

Total moments of all forces about free surface of liquid, $M = \int dM$

$$\Rightarrow M = \int \rho gh \times b_s \times dh \times h$$

$$\Rightarrow M = \rho g \int b_s\, h^2 \times dh \qquad \text{……….v)}$$

Equation …i) & …v) ⇒

$$\therefore M = \rho g \int h^2 \times dA$$

Here,

$$\int h^2 \times dA = \int b_s\, h^2 \times dh$$

= Moment of Inertia of the surface about free surface of liquid

$= I_0$

$$\therefore M = \rho g I_0 \qquad \text{…………..vi)}$$

Equation …iv) & …vi) ⇒

$$F \times h^* = \rho g I_0 \qquad \text{…………..vii)}$$

Equation ...iii) & ... vii) ⇒

$$\rho g A\bar{h} \times h^* = \rho g I_0$$

$$\Rightarrow \qquad h^* = \frac{I_0}{A\bar{h}} \qquad \text{............viii)}$$

We know from parallel axis theorem,

$$I_0 = I_G + A \times \overline{h^2} \qquad \text{............ix)}$$

I_G = Moment of Inertia of area about an axis passing through the C.G. of the area and parallel to free surface of liquid

Equation ...viii) & ...ix) ⇒

$$h^* = \frac{I_G + A\overline{h^2}}{A\bar{h}}$$

$$\therefore \; h^* = \frac{I_G}{A\bar{h}} + \bar{h} \qquad \text{............x)}$$

So, the centre of pressure on a surface can be expressed as,

$$\boxed{h^* = \frac{I_G}{A\bar{h}} + \bar{h}}$$

- **Total pressure and centre of pressure on lock gates** – lock gates are the device used to limit the changing of water level in a waterway for navigation.

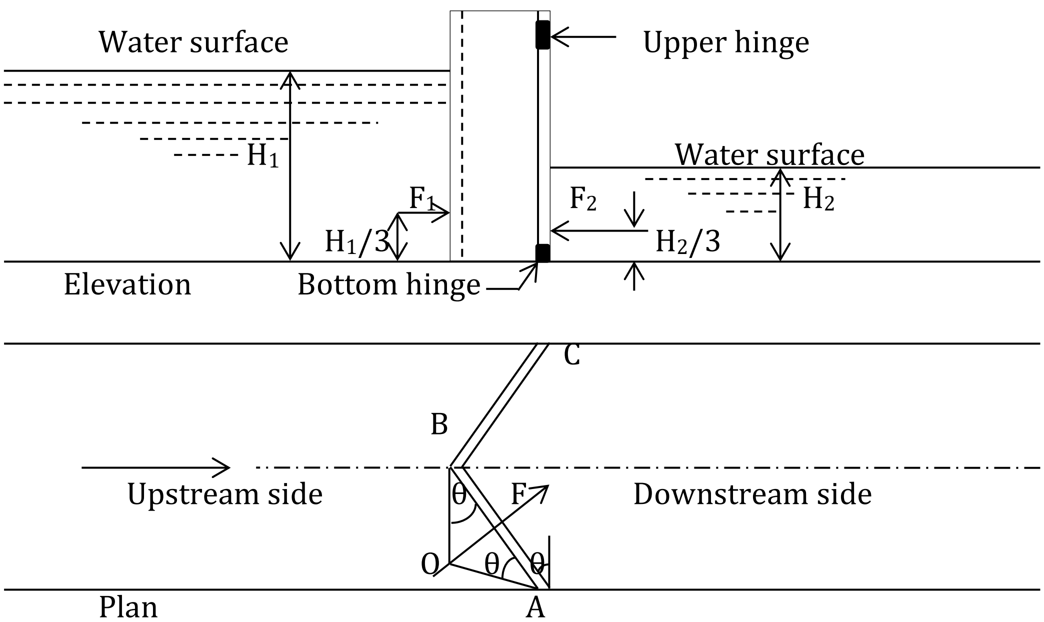

Fig. A.3: *Total pressure and centre of pressure on a lock gate*

There are plan and elevation of a lock gates showing in Fig. A.3. Here AB and BC be the lock gates and each is supported on two hinges at top and bottom. When the gates closed, they meets at B.

Let F ⇒ Resultant force due to water acting right angles to the gate,

Calculation of Total pressure or Hydrostatic force, F

θ can be determined from the angle between lock gates. The angle between lock gate is equal to $180^\circ - 2\theta$

Suppose,

H_1 ⇒ Height of water on upstream side,
H_2 ⇒ Height of water on downstream side,
F_1 ⇒ water pressure on gate at upstream side,
F_2 ⇒ water pressure on gate at downstream side,
l_g ⇒ width of gate

Now,

$$F_1 = \rho g A_1 \overline{h_1}$$

$$\Rightarrow F_1 = \rho g \times H_1 \times l_g \times \frac{H_1}{2}$$

$$\therefore F_1 = \rho g\, l_g \times \frac{{H_1}^2}{2} \qquad \left[\because A_1 = H_1 \times l_g, \overline{h_1} = \frac{H_1}{2}\right]$$

Let,

$$\therefore F_2 = \rho g\, l_g \times \frac{{H_2}^2}{2}$$

∴ Resultant force, $F = F_1 - F_2$

$$\therefore \text{Hydrostatic force, } F = \left[\left(\rho g\, l_g \times \frac{{H_1}^2}{2}\right) - \left(\rho g\, l_g \times \frac{{H_2}^2}{2}\right)\right]$$

F_1 acts at a distance of $\frac{H_1}{3}$ from the bottom and F_2 acts at a distance of $\frac{H_2}{3}$ from bottom.

Calculation of Centre of pressure, h^*

Let, h^* be the height of 'F' from the bottom, so taking moments of F_1, F_2, and F about the bottom,

$$\therefore\ (F \times h^*) - \left(F_1 \times \frac{H_1}{3}\right) + \left(F_2 \times \frac{H_2}{3}\right) = 0$$

$$\therefore\ \text{Hydrostatic force, F acts at a distance of } h^* = \left(\frac{\left(F_1 \times \frac{H_1}{3}\right) - \left(F_2 \times \frac{H_2}{3}\right)}{F}\right)$$

❑ Euler's equation of motion

Euler equation of motion is expressed as,

$$\frac{dp}{\rho} + gdz + vdv = 0$$

where,

$p \Rightarrow$ Pressure of flow,

$\rho \Rightarrow$ Density of water,

v $\Rightarrow$ Velocity of flow,

$g \Rightarrow$ Gravitational acceleration,

z $\Rightarrow$ Potential head

❑ Bernoulli's equation of motion

Bernoulli's equation of motion is expressed as,

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = constant$$

where,

$\frac{p}{\rho g} \Rightarrow$ Pressure head,

$\frac{v^2}{2g} \Rightarrow$ Kinetic head,

z $\Rightarrow$ Potential head