STATUS REPORT

SR-43

SPILLWAY GATE REGULATION

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PREFACE

Spillway is constructed at the dam site to dispose off the surplus water from the upstream of the reservoir to the downstream without causing any harm to the dam structure. Spillway gates (movable crest) are provided to head up the water level for specified purposes like water supply for domestic and industrial use, irrigation, hydropower generation and flood control. So gate operators require gate opening,the straight line distance (cord length) from the gate seat to the downstream side of the gate lip, to serve the purposes.

The purpose of this report is to review different types of spillways and gates, various discharge equations for each type of spillway, different mode of operation, general considerations for selection of spillway and to present a generalised computer program which can give precised ratings table to operate either tainter gate or sluice gate.

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ABSTRACT

Storage structures are constructed to equalize the natural streamflow. Spillway is provided at the dam site to dispose off the surplus water from the upstream of the reservoir to the downstream without causing any harm to the dam structure. Spillway gates (movable crest) are provided to head up the water level for specified purposes like water supply for domestic and industrial use, irrigation, hydropower generation and flood control. So gate operators require gate opening, the straight line distance (cord length) from the gate seat to the downstream side of the gate lip, to serve the purposes. The aim of this report is to review different types of spillways and gates, various discharge equations for each type of spillway, different modes of operation, general considerations for selection of spillway and to present a generalised computer program which can give precised ratings table to operate either tainter gate or sluice gate. The HEC(July 1966) program is modified with the addition of precised sluice gate equations (P.K.Swamee) to prepare ratings table with any number of reservoir level and gate opening intervals according to the prevailing condition in the reservoir.

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INTRODUCTION

1.1 The need of spillways

Over the last forty years, a large number of river valley projects have been constructed in India to tap the available water resources and to allocate the water in accordance with the requirements of mankind. The main objective of a reservoir is to equalize the natural streamflow. In India, reservoirs are constructed to serve multiple purposes like water supply for domestic and industrial use, irrigation, hydropower generation, navigation, recreation and flood control.

In India, more than 80 % of the annual rainfall occurs in the four monsoon months from June to September. Even in this season, the timely distribution pattern of rainfall is not uniform and severe floods are observed frequently. A spillway is a structure constructed at the dam site to dispose off the surplus water from the upstream of the reservoir to the downstream without causing any harm to the dam structure. A spillway is also, sometimes called the essential safety valves for a dam. It is essential for a dam to have appropriate spillway with adequate capacity so as to safeguard the dam against overtopping and subsequent failure.

Once a reservoir attains the uppermost desired level, water is spilled from the reservoir. At the uppermost desirable level, if the inflow rate in the reservoir is more than the outflow rate and the additional water is not spilled from the reservoir, then reservoir level will start building up till there is overtopping of the dam resulting in failure of the dam. So spillways are provided as an integral part of the dam to release surplus water which is in excess of our conservation requirements, as provided in the operation plans. Thus, the primary function of spillways is to prevent the rise of water level beyond a specified limits. In addition to the safety aspect, sometimes, submergence of upstream land is also required to be protected. So spillways are also operated to protect upstream land from submergence. Spillways must be properly designed and must have adequate capacity so as to dispose off the entire surplus water at the time of arrival of worst design flood. The operation of spillways is another important aspect as regards safety of a structure.

1.2 Purpose of providing gates in spillways

Spillways are generally of two types, gated spillway and ungated spillway, according to purposes served by the reservoir, inflow and the soil conditions. Regular gates are installed over the permanent raised crest of the reservoir to act like a movable addition crest and thus the height of the permanent crest can be reduced and the balance can be provided by the movable crest. The storage impounded in the reservoir with permanent raised crest up to the gate top would be equal to the storage of reservoir with gated crest. But the rise in flood level would be much more as compared to what would have been in a gated crest because the gates would be opened during serious floods so as to provide more head and hence larger discharge and consequent lesser rise in flood levels. The storage structure constructed to meet the demand for conservation purposes are always in need of water. It is not possible to store the required water all the time with the designed capacity of storage structure as the inflow into the reservoir is uncertain. Spillway gates (movable crest) are provided to head up the water level for specified purposes within the limits of backwater effect, without seriously curtailing the low water storage or head normally available. The other purpose of movable crest is to receive sudden increase of inflow due to flood and thus it is possible to tone down the outflow so that the downstream area should not be submerged.

1.3 Importance of Regulation of Gates

A natural stream is obstructed by constructing a dam to get advantages. But it will give some disadvantages like sudden rise in head level, shoals in the vicinity of water way, fluctuations in the level of the river etc. The spillway gates are operated in the optimal way to get maximum advantages and to minimize the disadvantages. The spillway gates are to be regulated to achieve the following objectives:

1. To maintain the designed storage level to serve the conservation purposes.

2. To receive the heavy inflow during flood season and to release the water after the flood.

3. To reduce the fluctuations in the level of the river for navigation purposes all the time.

4. To remove shoals in the vicinity of dam to ensure that the waterway is not affected.

5. To avoid cross flow immediately upstream or downstream of the dam which may create undesirable scours close to the dam.

6. To obtain a fairly uniform distribution of discharge along two length of the dam as far as practicable.

7. To allow the flood discharge to pass through the spillway on the downstream side of the river to ensure safety of the structure.

8. To see that the hydraulic jump is not formed beyond the toe of the glacier.

1.4 Purpose and scope of this report

The purpose of this report is to review different types of spillways and gates, various discharge equations for each type of spillway, different mode of operation, general considerations for selection of spillway. The aim of this report is to present a generalised program to operate gates. The scope of this report is to make useful for operators to operate the gates and to give a general view about types of spillway and gate, discharge equations and mode of operations.

CHAPTER 2

SPILLWAYS

2.1 Types of spillways

Essentially, a spillway comprises the following

i) An approach channel

ii) A control structure

iii) A discharge carrier

iv) A terminal structure

v) An outlet channel

The location of the spillway, its shape and size, the arrangement of its components depend on the local site conditions and the hydraulic requirements. The safety of the dam and the life and property of people living on the downstream depend on the safe function of the spillway.

A gated spillway has been the most commonly adopted type now a days. This consists of an overflow section with crest gates at top. The various types of spillways in general use are classified as under

1) Free overfall or Straight drop spillway
2) Ogee shaped spillway
3) Open channel or Trough or Chute spillway
4) Side channel spillway
5) Shaft spillway or Tunnel or Conduit spillway or Glory Hole spillway or Drop inlet spillway or Morning glory spillway
6) Siphon spillway or Saddle or Volute siphon spillway
7) Sluice spillway

The salient features of each type of spillways are presented as follows.

1. Free overfall spillway or straight drop spillway

In free overfall spillway, the flow falls freely from the crest, i.e., the lower nappe is not supported, into the terminal structure. The crest is sometimes extended in the form of an overhanging lip to direct the small discharges away from the face of the overfall section.

Care should be taken of the spray that results from aeration of the jet or from its impact. It can cause damage to the countryside and may adversely affect nearby electrical installations. The underside of the nappe is ventilated sufficiently to prevent a pulsating, fluctuating jet, where no artificial protection is provided at the base of overfall, scour occurs and a deep plunge pod is formed. This type is not generally adopted when the difference in level between the reservoir level and the tailwater level is more than 6 m (20 feet). The free overfall spillway is represented by figure 1.

2. Ogee shaped spillway

This type comprises a structure whose crest is S shaped. It essentially consists of a rounded crest, an inclined glacis and a reverse curve at foot. This shape conforms closely with the profile of the aerated lower nappe falling from a sharp crested weir. The profile of the crest may be made either broader or sharper than the nappe. Since the discharging efficiency of this type of spillway is great, it has been very popular. If the upper nappe is sharper than the lower nappe, subatmospheric pressure might develop as the sheet of water tends to spillway from the crest. But if the crest is wider than required, it supports the nappe and hence there will be positive pressures with a consequent decrease in the discharge coefficient. The inclination of the glacis is fixed from structural considerations in order to obtain adequate base width for the overflow dam. The reverse curve at the toe is necessary to deflect the high velocity jet into the terminal structure. Designing the crest shape to fit the nappe for a head less than maximum head expected often results in economics in construction. The resulting increase in unit discharge may make possible a shortening of the crest length, or a reduction in free board allowance for reservoir surcharge under extreme flood conditions. Because the occurrence of design floods is usually so infrequent, several water control agencies design spillway crest which are fitted to the lower nappe of a head which is 75 percent of that resulting from the actual discharge capacity. Test have shown that the subatmospheric pressures on a nappe shaped crest do not exceed about one half of the design head when the design head is not less than about 75 percent of the maximum head. The minimum crest pressure must be greater than cavitation pressure. The ogee shaped spillway is represented by figure 2

3. Open channel or Trough or Chute spillway

In this type of spillway, water is conveyed from the reservoir to the river or to another natural drainage below the dam through an excavated or built up channel trough with fairly steep slope. The long and the steep discharge carrier is called the Chute. The control structure may be an overflow crest, a side channel spillway, a gated orifice or a flush sill. It may be located either along a dam abutment or through a saddle in the rim of the reservoir. Sometimes, steps are provided in the channel (cascade spillway) to help in dissipation of energy. The site conditions decide the alignment and profiles of the chute. For economy, the profile of the chute generally follows the levels of the supporting substrata. One of the commonest causes of spillway failures has been the improper design of chutes. The flow in a chute is usually supercritical in many cases the velocity is greater than 30 mps. As a result of the large dynamic forces, the structural and hydraulic design of the chute is a critical factor. Criteria governing the profile of the ogee are well known and commonly adhered to, but the necessity of correct shaping of the guide walls in plan is often overlooked. Water flowing down a steep chute and colliding with an improperly aligned guide wall will produce standing waves, piling up of water against walls, overtopping, excessive dynamic impact, cavitation, poor bucket action, and other adverse effects. The width of the chute is limited by topography, construction cost, and width of the river channel into which it discharges. The transition between the control section and the chute should be governed by the following considerations.

1. The convergence should be symmetrical to balance hydraulic forces;
2. The transition should be as far up the chute as practical, since velocities will be least at the upstream end;
3. The transition should be smooth and gradual and should be so proportioned that supercritical flow would be maintained throughout;
4. Where the chute is narrower than the ogee, spillway openings should be arranged radially to eliminate a reverse curve in the guide walls.

The chute spillway is represented by figure 3.

4. Side channel spillway

In this type, the water issuing out of the control structure falls into a narrow trough opposite the weir, turns by 90 and joins the discharge carrier. Flow into the side channel might enter on only one side of the trough in the case of steep hillside locations, or on both sides and over the end of the trough if it is located on a knoll or gently sloping abutment. The cross section and the bed fall of the side channel is fixed such that the momentum for maintaining the flow in the discharge channel is obtained from the bed fall only. Discharge characteristics are similar to an ordinary over flow weir, except that at a high discharge the crest may be partially submerged. The side channel spillway is represented by figure 4

5. Shaft spillway or Tunnel or Conduit spillway or Glory Hole spillway or Drop inlet spillway or Morning glory spillway

This consists of a vertical or sloping shaft connected, at its bottom to a horizontal conduit. Water approaches in a radial direction over the horizontally positioned lip, drops into the shaft and then flows to the terminal structure through a horizontal tunnel or conduit. Where the inlet is like a funnel, the spillway is called Morning glory or glory hole spillway. Since the water drops into the inlet structure it is also called drop inlet spillway. The crest may be ogee type or flat. Considerable turbulence occurs at the bend at the bottom of the vertical shaft. For comparatively low heads this is probably not serious, but the action under high head is uncertain. For high dams, it would seem to be advantageous to begin to incline the tunnel as short a distance as possible below the intake and provide ample access of air to the inclined section. The form of the spillway is longly controlled by the discharge to be accommodated and the depth of overflow permitted, for the length of crest must be sufficient to provide for the required discharge at the maximum head permitted. This large discharge and small depths of overflow give rise to large diameters of the intake section. The size of the outlet tunnel is determined by the discharge and fall and is commonly constructed so that the tunnel will flow full throughout its length but not cause a backwater action on the spillway crest under conditions of maximum discharge. The morning glory spillway is represented by figure 5.

Morning glory shaft spillway may operate under three conditions

i) With Crest control

ii) With tube or orifice flow

iii) With full pipe flow.

6. Siphon spillway or Saddle or Volute spillway

A siphon spillway is a closed conduit system in the shape of an inverted U tube, positioned so that the inside of the bend of the upper passage way is at the normal storage level of the reservoir. The initial discharges are similar to the flow over a weir. As the air over the crest is exhausted, siphonic action takes place.

The important components of a siphon spillway are:

i) Inlet

ii) Upper leg

iii) Throat or control section

iv) Lower leg, and

v) Outlet

Siphon spillways are advantageous where the available space is limited and the spillway design flood is not extremely large. The siphons should be made with gradually contracting entrances and curves of as large radius as possible. They are also useful in providing automatic surface level regulation within narrow limits. The main disadvantages are the cost, the fluctuating flows due to sudden making and breaking of siphonic action, the vibration, inability to pass the floating debris and limitations of discharging capacity. Volute siphon consists of a dome with a funnel underneath leaving an annular space alround connected on to a vertical shaft taken down the funnel. The shaft may be further bent to lead the discharge away from the dam. The lip of the funnel is fixed at full level of the reservoir. Volutes which resemble the blades of a centrifugal pump or turbine are placed on the funnel. These induce a spiral motion to the water passing out. Thus the whilting flows drag away the air in the siphon and siphonic flow starts quickly. The siphon spillway is represented by figure 6.

7. Sluice spillway

The use of large bottom openings as spillways is a relatively modern innovation followingthe greater reliance on the safety and operation of modern control gates under high pressure. A distinct advantage of this type of spillway is that provision can usually be made for its use for the passage of floods during construction. One disadvantage is that, ones built, its capacity is definite whereas the forecasting of floods is still indefinite. A second disadvantage is that a single outlet may be blocked by flood debris, especially where in flow timber does not float. The sluice spillway is represented by figure 7.

2.2 Discharge equations

Discharge equations for free flow condition and submerged flow conditions are furnished as follows:

2.2.1 Free flow condition

The discharge for an overfall spillway can be calculated by the following equation

$$Q = CLh^{3/2}$$

in which Q = total discharge over the spillway, Cumecs

L = net length of spillway,m

h = total head on crest including velocity head, $V^2/2g$,m

C = Coefficient of discharge

The results of model tests show that the discharge coefficient starts at 1.66 and reaches approximately 2.26 at the design head. End contractions at spillway piers reduce the net length between the pierfaces. The modified equation is as follows:

$$Q = C(L-kNh)h^{3/2}$$

in which k = pier contraction coefficient

h = $h_d + V^2/2g$, m

L = net length between piers, m

V = velocity of approach, m/s

N = Number of complete pier contractions (two per pier)

Figure 8 gives the values of Coefficient of pier contraction k

2. The discharge for a gated ogee crest at partial gate openings, in cases where the openings are large, may be computed by the equation.

$$Q = 2/3\sqrt{2g}CL(h_1^{3/2}-h_2^{3/2})$$

in which h_1 = head on upper edge, m

h_2 = head on lower edge, m

C = Coefficient of discharge

L = net length of spillway, m

The orifice discharge coefficient C will differ with different gate and crest arrangements. This coefficient is also affected by the approach and downstream conditions as they influence the jet contractions.

Figure 9 gives the values of Discharge coefficients of orifice discharge.

3. The basic formula for spillway discharge, used in analysing prototype measurements for a spillway, with a vertical leaf gate operating at partial opening, is

$$Q = mL(h_1^{3/2}-h_2^{3/2})$$

in which h_1 = head on upper edge, m

h_2 = head on lower edge, m

L = net length, m

m = coefficient of discharge = $2/3\sqrt{2g}C$

But C in this equation is different with C in other equations.

4. The discharge equation for chute or trough channel is

$$Q = CLh^{3/2}$$

For maximum capacity c is 2.26

For normal capacity c is 1.71

3. The basic equation for the discharge of a nappe shaped circular weir is

$$Q = C_o(2\pi R_s)H_o^{3/2}$$

The details of the equation are in figure 9.

Figure 10 represents the elements of nappe shaped profile for circular weir

C_o must be related to H_o and R_s and, expressed in terms of H_o/R

6. The discharge equations for

i) Orifices

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

where C_d is a discharge coefficient (which varies with relative size, shape of opening and Reynold number)

A is the cross sectional area at the smallest section

H is the head

ii) Sharp crested weirs

$$Q = C_d L_e h_e^{3/2}$$

where

$$C_d = 3.22+0.4h/p$$

in which p is the height of the weir m

and $L_e = L+K_L$

K_L is width adjustment factor given in figure 11

$$h_e = h+0.003$$

h is the piezometric head measured above the crest of the weir.

Figure 11 gives the relation between b/B and K_L

7. Triangular weir

$$Q = C_d \times 8/15\sqrt{2g}(\tan\Theta/2)h^{2.5}$$

$$Q = 2.5h^{2.5} \text{ for } \Theta = 90^\circ$$

8. Sluice gate

$$Q = C_d A\sqrt{2g\Delta y}$$

c_d is discharge coefficient

Δy is difference between y_1 and y_2

y_1 is upstream depth

y_2 is downstream depth

9. Discharge equation for a broad crested weir with sloping faces spanning the entire width of a channel

$$Q = CBk_1k_2\sqrt{2g}H^{3/2}$$

where C and K_2 are functions of geometric parameters K_1 is calculated from model studies.

2.2.2 Submerged flow condition

The submerged flow condition will reduce the value of discharge coefficient and thus it can reduce the discharge over the crest. The reduction in value of discharge coefficient can be calculated by model studies.

2.3 Methods to calculate discharge coefficients

The coefficient of discharge depends upon the geometry of the gate, gate installation, interference of adjacent gates and flow conditions. Two methods are available to calculate the discharge coefficients

1. Field application
2. Model studies.

In field applications the real experiment is carried out and the discharge coefficients are calculated. Through model studies also the discharge coefficients are calculated. The equations developed by P.K. Swamee considering real conditions are

1) Free flow condition

$$Q = 0.864ab\sqrt{gh_o}(h_o\text{-}a/h_o+15a)^{3/2}$$

where Q = Sluice gate discharge

a = the sluice gate opening

b = the sluice gate depth

h_o = upstream water depth

g = gravitational coefficient

2) Submerged flow condition

$$Q = 0.864\ ab\sqrt{gh_o}(h_o\text{-}a)^{0.072}(h_o\text{-}h_2)^{0.7}\{0.32[0.81h_2(h_2/a)0.72$$
$$\text{-}h_o]^{0.7}+(h_o\text{-}h_2)^{0.7}\}^{-1}$$

h_2 = tail water depth

2.4 Factors influencing the spillway profile and discharge coefficients

The important factors which influences the fixation of a spillway profile and discharge coefficients are

i) the head

ii) the inclination of the upstream face of the overflow section

iii) the height of the overflow section above the floor of the entrance channel.

i) Head

The profile of the high coefficient weir has to be made to conform to the lower nappe profile of the flowing water. By presenting access of air to the underside of the nappe, flow over the crest is made to adhere to the face of the profile. At designed head, the flow glides over the crest with no interference from the boundary. Higher heads provide sub atmospheric pressures, but increase the discharge coefficient.

ii) Inclination

It has been found that the slopes below the crest upto half the head affect the discharge coefficient. For small ratios of approach depth to head on crest, the sloping upstream face increases the discharge coefficient whereas for large ratios it decreases.

iii) Height

If the weir is high, the velocity of approach becomes small. As the depth of approach decreases, the velocity of approach increases and the vertical contraction of the underside of the nappe reduces with the result that the coefficient of discharge is reduced.

2.5 Factors affecting selection of spillways

1. General considerations

i) Safety considerations consistent with Economy spillway structures add substantially to the cost of a dam. In selecting a type of spillway for a dam, economy in cost should not be the only criterion. The cost of spillway must be weighed in the light of safety required below the dam.

ii) Hydrological and site conditions

The type of spillway to be chosen shall depend on

a) inflow flood

b) availability of tail channel, its capacity and flow hydraulics

c) power house, tail race and other structures downstream

d) topography

iii) Type of Dam

This is one of the main factors in deciding the type of spillway. For earth and rockfill dams, chute and ogee spillways are commonly provided. Whereas for an arch dam a free fall or morning glory or chute or tunnel spillway is more appropriate. Gravity dams are mostly provided with ogee spillways.

iv) Purpose of Dam and operating conditions

The purpose of the dam mainly determines whether the dam is to be provided with a gated spillway or a non gated one. A diversion dam can have a fixed level crest, that is non gated crest.

v) Conditions downstream of a Dam

The rise in the downstream level in heavy floods and its consequences need careful consideration. Certain spillways alter greatly the shape of the hydrograph downstream of a dam. The discharges from a siphon spillway may have surges and break ups as priming and depriming occurs. This gives rise to the wave travelling downstream in the river, uhich may be detrimental to navigation and fishing and may also cause damage to population and developed areas downstream.

vi) Nature and Amount of Solid Materials Brought by the River

Trees, floating debris, sediment in suspension etc. affect the type of spillways to be provided. A siphon spillway cannot be successful if the inflow brings too much of floating materials. Where big trees come as floating materials, the chute or ogee spillway remains the common choice.

2. Specific considerations

i. Ogee spillway

a) It is most commonly used with gravity dams. However, it is also used with earth and rockfill dams with a separate gravity structures.

b) The ogee crest can be used as control in almost all types of spillways.

c) It has got the advantage over other spillways for its high discharging efficiency.

ii. Chute spillway

a) It can be provided on any type of foundation.

b) It is commonly used with the earth and rockfill dam.

c) It becomes economical if earth received from spillway excavation is used in dam construction.

Following factors limit its adoption.

a) It should normally be avoided on embankments

b) Availability of space is essential for keeping the spillway basins away from the dam paving.

c) If it is necessary to provide too many bends in the chute because of the topography, its hydraulic performance can be adversely affected.

iii. Side channel spillways

a) This type of spillway is preferred where a long overflow crest is desired in order to limit the intensity of discharge.

b) It is useful where the abutments are steep.

c) It is useful where the control is desired by the narrow side channel.

The factor limiting its adoption is that this type of spillway is hydraulically less efficient.

iv. Shaft spillway

a) This can be adopted very advantageously in dam sites in narrow canyons.

b) Minimum discharging capacity is attained at relatively low heads. This characteristic makes the spillway ideal where the maximum spillway outflow is to be limited. This characteristic becomes undesirable where a flood more than the design capacity is to be passed. So it can be used as a service spillway in conjunction with an emergency spillway.

The factor limiting its adoption is the difficulty of air entrainment in a shaft, which may escape in bursts causing an undesirable surging motion.

v. Siphon spillway

a) Siphon spillways can be used to discharge full capacity discharges, at relatively low heads.

b) Great advantage of this type of spillway is its positive and automatic operation without mechanical devices and moving parts.

The following factors limit the adoption of a siphon spillway.

a) It is difficult to handle flows materially greater than designed capacity, even if the reservoir exceeds the design level.

b) Siphon spillways cannot pass debris, ice etc.

c) There is possibility of clogging of the siphon passage way and breaking of siphon vents with logs and debris.

d) In cold climates, there can be freezing inside the inlet air vents of the siphon.

e) When sudden surges occur and outflow stops.

f) The structure is subject to heavy vibrations during its operation needing strong foundations.

g) Siphons cannot be normally used for vacuum heads higher than 8 m and there is danger of cavitation damage.

vi. Overfall or free fall spillway

a) This is suitable for arch dams or dams with downstream vertical faces.

b) This is suitable for small drops and for passing any occasional flood.

The factor limiting its adoption is that the maximum hydraulic drop from head pool to tail pool water should not exceed 20 m

vii. Tunnel or conduit spillway

This type is generally suitable for dams in narrow valleys, where overflow spillways cannot be located without risk and good sites are not available for a saddle spillway. In such cases, diversion tunnels used for construction can be modified to work as tunnel spillways. In case of embankment dams, diversion tunnels used during construction may usefully be adopted. Where there is danger to open channels from snow or rock slides, tunnel spillways are useful.

viii. Saddle spillway

a) It is generally economical

b) It facilitates construction because it is independent of the main dam construction.

c) It can also be used as an auxiliary or emergency spillway.

2.6 Factors governing spillway capacity

The performance of a spillway under a flood situation is affected by the following

a) Inflow flood

b) Reservoir and outflow conditions at the beginning of the flood

c) Hydraulic characteristics of the spillway including those for the approach and the tail channel geometry.

d) Storage characteristics or the reservoir geometry.

e) Rules for operation of the spillway gates.

f) Actual functioning of the spillway including mechanical and human failures.

The acceptability of resulting performance in a flood would then be decided by

a) The highest water level reached in the flood studies i.e., in particular

1) Free board available at this level.
2) Clearance of gates available at this level.
3) Upstream submergence corresponding to this level.

4) Structural safety considerations.

b) The largest outflow during this flood situation and in particular.

1) Behaviour of the spillway, energy dissipation arrangement and downstream channel for this outflow.

2) Acceptability of the outflow from the consideration of downstream damage in the valley.

CHAPTER 3

GATES

3.1 General features

A fixed crest free overfall spillway may be advantageous from the operating point, the great value of property and improvements in many reservoir sites prohibits the back water stages resulting above a dam during flood. The desirable storage or head requirements on projects concerned with the conservation of water or control of floods may often approach the limit that can be obtained at the feasible dam sites. The solution of this problem lies in some form of movable crest, by means of which increases in flood stage above the dam may be materially lessened within the limits of back water effect, without seriously curtailing the low water storage or head normally available. The General features of all gates are as follows:

1. Skin plate to obstruct the water on spillway crest so that head can be raised to required level. Skin plate is arc in case of tainter gates and plain in case of slide gates.
2. Horizontal and vertical girders are arranged to resist and to transfer the forces exerted by skin plate to anchorage structures.
3. Hoist mechanism is provided to hoist the gate.
4. Sealing arrangements are provided to arrest the leakage.

3.1.1 Terms associated with gates

1. Air vent: A passage of suitable size provided for venting/admitting air during filling/draining a conduit or for delivering a continuous supply of air to the flow of water from a gate.
2. Anchor or tension bar: A structural tension member provided for transferring water load from the trunnion girder of a radial gate to the piers/abutments.
3. Anchorage Girder or Anchor Girder: An embedded structural member, transferring load from a gate to its surrounding structure.
4. Back filling of gate: A process of equalizing the water pressure on the two sides of a gate.

5. Balanced Head condition: A condition in which there is equal hydrostatic pressure on both sides of a gate.

6. Ballast: An extra weight added to a gate over and above structural requirements.

7. Bearing plate: A metal plate fixed to the surrounding surface of the frame to transfer water pressure to the gate frame.

8. Block out: A temporary recess/opening left in the surrounding structure of a gate for installing the embedded parts of a gate.

9. Bonnet: A heavily ribbed housing for a gate when it is in the open position.

10. Bonnet cover: A cover fixed over a bonnet.

11. Bottom seal: A seal provided at the bottom of the gate leaf.

12. Brass clad seal: A seal in which the sealing surface is clad with brass.

13. Clad seal: A rubber seal clad with any material (metal or non metal) on its sealing surface.

14. Clamp plate or keeper plate: A metal plate used to keep the rubber seal in proper position and grip.

15. Connectors: A liner connecting two gates in tandem.

16. Counter Guide Roller or Shoe: A device provided on the sides of the gate to restrict its transverse movement.

17. Counter Guide: A guide provided for restricting the transverse movement of a gate during operation.

18. Deflector

a) A projection provided at the top of the skin plate to check the spilling of water over a gate.

b) A projection into the flow to converge or deflect the flow.

19. Depth of Groove: The dimension of a gate groove inside the pier/abutment measured across the direction of flow.

20. Dogging device: A latch for suspending or supporting a gate in its open position when it is disconnected from its hoisting mechanism.

21. Double stem seal: A flexible seal made of rubber or such other material in which the stem extends tangentially on both sides of the bulb.

22. Emergency stop logs: Stop logs which can be lowered under unbalanced condition.

23. End girder: A vertical structural member used at each end of the gate leaf to transfer

the load to the gate frame.

24. Flash board: A temporary barrier, of relatively low height, placed on the crest to allow the water surface to be raised above the crest.

25. Flow Arrester/Slot flow arrester: A device meant for checking the vertical flow in a gate groove.

26. Gate counter weight: A weight used for opposing the dead weight of a gate so as to reduce the hoisting capacity. A counter weight may also be used for making the Gate Self opening.

27. Gate frame or embedded part of embedment: A structural member embedded in the surrounding supporting structure of a gate, which is required to enable the gate to perform the desired function.

28. Gate groove or Gate slot: A groove or slot in the supporting structure of a gate in which the gate rests or seats when in the closed position for special situations.

29. Gate Hanger: A device meant for suspending or supporting a gate in the open position when disconnected from its hoisting mechanism.

30. Gate Hoisting Capacity: The net maximum force required for raising or lowering a gate.

31. Gate leaf: The main body of a gate consisting of skin plate, stiffeners, horizontal girders and end girders.

32. Gate lip: The lower most segment of a gate which is suitably shaped from hydraulic considerations.

33. Gate seal: A device for preventing the leakage of water around the periphery of a gate.

34. Gate sill: The top of an embedded structural member on which a gate rests when in the closed position.

35. Guard sill or Back sill: A sill on the upstream side of the gate chamber of a lock gate.

36. Guide: That portion of a gate frame which restricts the movement of a gate in a direction normal to the water thrust.

37. Guide rollers: Rollers provided on a gate to restrict its movement in a direction normal to the water thrust.

38. Guide shoe: A device mounted on a gate to restrict its movement in a direction

normal to the water thrust.

39. Heel post: A post to which a lock gate is hinged.

40. Hood: A plate fixed at the top of a gate to allow flood water to pass over the gate.

41. Hollow Quoin: Recessed masonry accommodating the heel post of a lock gate.

42. Horizontal girders: The main structural members of a gate, spanning horizontally to transfer the water pressure from the skin plate and vertical stiffeners (if any) to the end girders or end arms of the gate.

43. Hydraulic down pull: A vertical force acting downwards which is caused by the hydraulic conditions that prevail during the operation of a gate.

44. Hydraulic shutter: An inclined shutter that is operated to maintain any desired inclination by means of a hydraulic ram connected to a plunger.

45. Hydraulic uplift: A vertical force acting upwards that is caused by the hydraulic conditions that prevail during the operation of a gate.

46. Lift of gate: The maximum vertical travel of a gate above the gate sill.

47. Lifting beam : A beam (with a grappling mechanism) suspended from a gantry crane or a travelling hoist and moves vertically in a gate groove for lifting or lowering a gate or a stoplog.

48. Lifting lugs: Structural members provided on a gate to facilitate handling of the gate during erection, installation or operation.

49. Liner: Steel lining provided in a conduit for a medium or high head gate installation.

50. Lock Gate Recess: A recess provided in the side walls of a lock in which a lock gate is supported when in the open position.

51. Lock plate or keeper plate: A plate provided on a gate roller assembly to prevent rotation of the roller pin.

52. Metal seal: A metallic gate seal used on slide gates.

53. Mitre post: A vertical member at the free or swinging end of a mitre gate.

54. Music Note Seal or J seal or single stem steel: A flexible seal made of rubber or such other material having a bulb and a tangential stem.

55. Needle: A timber element placed vertically or horizontally against supports on stream bed or weir crest to close an opening for the control of water.

56. Parallel End Arms: The end arms of a radial gate which are parallel to the direction of flow.

57. Pintle: A structural member below a quoin post about which a mitre gate rotates.

58. Pneumatic seal or Retractable (Inflated seal): A rubber seal which comes into operation by means or air or water pressure after the gate has been fully closed. The water pressure on the seal is released before the gate is lifted.

59. Radial Arms: Radially placed beas which connect the trunnion of a hinged radial gate to the leaf.

60. Rest beam/Chain: A structural member which supports the dead load of the trunnion girder or yoke girder of a radial gate.

61. Seal assembly: An assembly consisting of rubber seal, seal base, clamp plate and fastening bolts and nuts.

62. Seal base: A plate on which a gate seal is fixed.

63. Seal friction: The frictional resistance due to the sliding of a seal over the seal seat.

64. Seal Interference/Interference: As applied to hydraulic gate seal, the extent by which the rubber seal bulb interferes with the seal seat.

65. Seal plate: A metal plate mounted on a gate leaf to transfer water pressure to the seal seat and to act as a seal.

66. Seal seat: A plate fixed to the surrounding structure of a gate against which a gate seal bears.

67. Seal Seat Base: A structural member supporting a seal seat.

68. Semi Automatic Shutter, Falling shutter, Falling Crest or Permanent Flash board: A shutter which falls automatically when the normal head water level is exceeded, and raised manually when required.

69. Shield: A plate fixed on the two sides of a radial gate to protect the lifting ropes/end arms from water flowing over the gate.

70. Shutter: A crest gate whose leaf rotates about hinges fixed to the crest.

71. Side seals: Seals fixed to the vertical ends of gate leaf.

72. Skin plate: A membrane which transfers the water load on a gate to the other components.

73. Splitter or separator: A device provided on the hood of a gate to split the flow.

74. Spring point: A point on a gate lip where the flowing water leaves contact with the gate.

75. Stop log: A log, plank, cut timber, steel or concrete beam fitting into end grooves

between walls or piers to lose an opening under unbalanced condition, usually handled or placed one at a time.

76. Teflon clad seal: A seal in which the sealing surface is clad with teflon.

77. Thrust pad or Thrust Block

a) A structural member provided on a gate leaf to transfer water load from the gate to a bearing plate.

b) A structural member designed to transfer to the pier or abutment that component of water thrust on a radial gate, which is normal to the direction of flow.

78. Top seal: A seal provided at the top of a gate leaf or gate frame.

79. Track or Track plate: A structural member on which the wheels of a gate move.

80. Track base: A structural member supporting a track on track plate.

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

82. Trunnion Axis: The axis about which a radial gate rotates.

83. Trunnion Bracket: A bracket which supports the trunnion pin and is rigidly fixed to the trunnion girder.

84. Trunnion Bush/Bearing: A slide type bushing or roller type bearing which transfers the load from the trunnion hub to a trunnion pin.

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

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

87. Trunnion pin: A horizontal axle about which the trunnion hub rotates.

88. Trunnion tie: A structural tension member connecting two trunnion assemblies of a radial gate to cater to the effect of lateral force (normal to the direction of flow).

89. Vertical Stiffeners or vertical Girders: The structural members spanning vertically across horizontal girders to support the skin plate.

90. Wall plate: A plate embedded flush in a pier/abutment to provide a track for the seal and guide rollers of a hinged gate.

91. Wedge seal: A flat rubber seal fixed at the bottom of a gate.

92. Wheel friction: The sum of the axle friction and rolling friction encountered during

the movement of gate wheels.

93. Width of Groove: The dimension of a gate groove in the direction of flow.

3.2 Types of Gates

3.2.1 Low pressure gates

1. Flashboards, stop logs and needles

Flashboards, stop logs and needles are the simplest and probably the oldest types of movable crest devices. Where the size and type of installation are such that they can be readily handled by the operating force available, they are efficient and economical. Where the installation is large or where frequent freshets require continual manipulation, the operation becomes laborious and hazardous.

Flashboards

Flashboards are water retaining devices placed on top of a fixed crest to provide an extra depth of storage, but which may be quickly removed at times of flood. Flashboards have the advantage of providing an unobstructed crest when lowered. Where possible, a regulating gate, of sufficient capacity to pass the normal flow, should be provided so that the head water may be temporarily lowered to allow the flashboards to be set up.

Stop logs

The customary stop logs are dimension timbers spanning horizontally between vertical grooves in adjacent piers. They are built up one on another, a vertical bulkhead being formed from the crest of the spillway to the headwater level. Since the logs must be handled through overflowing water, it is imperative that the grooves in the piers be made amply deep to protect the hoisting device from the current during the fishing operation. Stop logs may prove an economical substitute for more elaborate gates where relatively close spacing of piers is not objectionable and where variation in flow require the removal of only a few logs, except at frequent intervals.

Needles

Needles are set on end side by side to close an opening. They are supported at the top by a runway, from which they are handled, and are supported at the bottom by a ledge on the sill or spillway crest. They are usually made of dimension timbers. Needles are somewhat difficult to place in swift water of considerable depth. Hence, their use is largely confined to emergency spillways where they are seldom raised and where they can readily be replaced after flood waters have receded.

2. Tainter gates

The conventional form of Tainter gate consists of a skin plate formed to a segment of a cylinder, the vertical elements being circular arcs, which is supported by a framework of horizontal or vertical purlins and stiffeners. The skin plate is made concentric to horizontal shaft or pin, and hence the resultant of the water pressure passes through the pin, creating no moment to be overcome in hoisting the gate. Tainter gates are probably the simplest, most reliable, and least expensive type of crest gate for passage of large floods. They require no slots in the piers and have good discharge characteristics. The conventional Tainter gate is not suited for the passage of floating material unless fully open, which may involve waste of water. Tainter gates are usually operated by chains or cables attached near the bottom of gate at each side on either the upstream or downstream side of the skin plate assembly. Some gates also have been made to be operated by trunnion-mounted hydraulic cylinders where piston rods are attached to the gate. Figures 12 and 13 represent types of tainter gates and details of a conventional tainter gate.

3. Flap Gates

This type of gate is a leaf hinged at bearings along its lower edge. The leaf may be flat or curved to give better discharge characteristics when rotated to its open position. The position of the leaf may be controlled by hoisting attachments that pull or push at one or both ends or by hydraulic or screwstem hoists that push at selected locations under the gate. This type of gate can be built to great lengths and is well suited for passing floating material and for close regulation. Counterweights and/or floats may be incorporated in the hoisting mechanisms of relatively small flap gates to provide automatic operation with little or no other source of power. It is recommended that hydraulic model studies simulating all expected opening conditions of the prototype gate be carried out before proceeding with the fabrication of flap gates of any importance. The figure 14 represents Flap gate.

4. Drum Gates

The drum gate fundamentally is an acute circular sector in cross section, formed by skin plates attached to internal bracing. It is hinged at the center of curvature, which may be either upstream or downstream, in such manner that the entire sector may be raised the masonry crest or may be lowered. So the upper surface becomes coincident with the crest line. These gates are controlled by the application of headwater pressure underneath. Drum gates are not adopted to low dams having low substrcutures on account of the deep excavation required and the liability of flooding of the recess in which the gate· float. The operating mechanism for controlling water pressure beneath the gates may be placed in the abutments, or in the piers with access through a gallery, the necessity of an overhead bridge being eliminated and the pier height being reduced to a minimum. Because they are relatively more mostly than Tainter or Flap gates and their operational features may be achieved by judicious combined use of Tainter and Flap gates, the use of drum gates is becoming increasingly rare. The figure 15 represents Drum gates.

5. Vertical lift gates

The designation vertical lift gates is here used to include all rectangular gates supported by vertical guides in which the gates move vertically in their own plane. The hoist is usually mounted on a runway overhead, and the gate is either raised or lowered, depending on the particular design, from its normally closed position by means of cables or stems. The gate proper consists of a frame work to which a skin plate is attached, normally on the upstream face. Vertical lift gates have been generally used where it was necessary to store a high head of water and to obtain large discharges in narrow confines.

i. Sliding gates

In this type, the frame of the gate bears directly on the downstream guide member, the seal being formed by contact between the two. The coefficient of friction in sliding may vary from 0.5 to 0.9, which requires large hoist capacity not only for raising but for lowering as well, for only in the smaller sizes will the weight of the gate exceeded the frictional resistance when the gate is near the position of maximum water loading:

ii. Fixed wheel gates

This type differs from the sliding gate in having a series of fixed wheels mounted along each end to carry the water load to a vertical track on the downstream side of the gate groove. The wheels substitute rolling friction for sliding friction, which allows the gate to be self closing under its own weight. The wheel shafts are located between the main horizontal girders and are supported either by two vertical members of the frame or in pedestal bearings bolted to the frame.

6. Stoney Gates

The fundamental difference between Stoney and fixed wheel gates is that in the former a moving train of rollers is substituted for the fixed wheels in the latter. The roller train, composed of horizontal rollers held in position by shafts bolted into continuous vertical bars on each side, is attached to neither the gate nor the guide, but rolls vertically between the two as the gate is moved. As the rollers transmit the entire load from a bearing strip on the gate to a roller path on the guide, there is no axle friction, and only rolling friction is developed. Since the gate moves on the roller diameter while the roller revolves on its radius, the roller moves only one half the distance of the gate movement and the bottom of the roller train always lags the gate by one half of the distance the gate is opened. The end section of a Stoney Gate is represented by figure 16.

6. Bear trap Gates

A bear trap gate consists essentially of two leaves, an upstream leaf hinged and sealed along its upstream edge and a downstream leaf hinged and sealed along its downstream edge. When the gate is lowered, the leaves are in horizontal position with one leaf lying on top of the other. The two leaves have a sliding seal or hinge at their juncture and are sealed against the piers at each end. When pressure from headwater is applied in the chamber underneath, the gate can be raised to any desired height so long as the two leaves remain in contact. The water pressure under the gate is regulated by an adjustable weir or by the setting of inlet and outlet valves in a control chamber in the abutment of the spillway. This was probably the first gate involving the principle of the application of headwater pressure for its operation. Figure 17 represents bear trap gates

7. Rolling Gates

The conventional rolling gate consists of a cylindrical plate steel roller, approximately as large in diameter as the height of opening to be closed and spanning between piers. Encircling each end of the roller is a heavy annular rim casting with peripheral teeth and a bearing surface which transfer the loads to similar teeth and a bearing surface on a sloping rack supported by a ledge in the piers. The gate is raised or lowered along this rack by means of a heavy chain which winds around and over the top of the gate at one end and pulls upward, parallel to the rack. As with drum gates, the use of rolling gates is becoming increasingly rare because of their high cost. Figure 18 represents rolling gates.

3.2.2 High pressure gates

1. Conduit slide gates

The primary use of slide gates is for the control of discharges from outlet conduits in dams. Slide gates are used for both guard and regulating service. Frequently two practically identical gates are bolted together in tandem. In such cases the upstream gate functions as the guard gate for the downstream regulating gate. Slide gates are also used singly as guard gates. Some gate installations are made on a slope so that the discharge is downward into the stilling basin. This arrangement reduces the required length and cost of the stilling basin. There is an increasing use of metal liners. Slide gates discharge smoothly at all openings but should not be operated at very small openings. The gates can be used either for free discharge into atmosphere or for submerged discharge in water. There appears to be no definite size or head limitation for correctly designed slide gates with few exceptions. Slide gates are operated by hydraulic hoists. Basically, a slide gate consists of a leaf which is either closed by being positioned across the fluid way in the body or opened by being withdrawn into the bonnet by a hoist mounted on the bonnet cover. The mating seats on the gate leaf, body and bonnet serve both as the sliding surfaces for carrying the hydrostatic load on the leaf and as the sealing surfaces when the gate is closed. The body and bonnet are made in halves and are heavily ribbed to minimize distortion when the gate is embedded in concrete. The body and bonnet are not designed to withstand the internal fluid pressure, and the embedding concrete must be suitably reinforced to with stand the pressure. Only the bonnet cover, on which the hoist is mounted, and the top flange of the bonnet are designed to resist the internal water pressure. Figure 19 represents typical tandem slide gate installation.

2. Ring follower gates

Basically, a ring follower gate consists of a leaf, the body and bonnet parts, and a bonnet cover on which the hoist is mounted for moving the leaf to the open or closed positions. The leaf is composed of a bulkhead portion which blocks the fluid way through the body when the gate is closed, and a follower portion having a circular opening which aligns concentrically with the fluidway through the body when the gate is open. The characteristic of having a ring portion which follows the movement of the bulk head portion accounts for the name ring follower gate. As the follower ring on a ring follower gate is essentially the same size and aligns with the pipe when the gate is open, there is practically no hydraulic loss for this type of gate. The gate leaf requires a lower bonnet below the fluid way into which the follower ring on the leaf can move when the gate is closed. The upper bonnet has a similar function for the bulkhead portion when the gate is open. The body and upper bonnet of ring follower gates are made in halves and are heavily ribbed to minimize distortion and avoid misalignment of the seat and guides when the gate is embedded in concrete. Cast steel is most commonly used for gate leaves, but gray iron castings and weldments are also used. Because ring follower guard gates are usually designed to be closed, but never opened, under balanced pressure, a bypass for filling the pipe downstream from the gate is normally provided. Because of the high conduit velocities it is important that the fluidway through ring follower gates be smooth and that no inward offsets into the flow be present when the gate is open. In the installation of ring follower gates it is extremely important that seating surfaces on the gate body and bonnet be held to plane to provide an accurate mating surface for the leaf. Figure 20 represents general assembly and details of ring follower gate

3. Ring Seal gates

A ring seal gate is a ring follower type of gate which has roller trains and wheels to reduce friction and which has no movable, hydraulically actuated seal ring. The primary purpose of these features is to reduce the friction and hoist capacity from that required for sliding type ring follower gates. The first gate designs used twin screen stem mechanical hoists and the movable ring seal was mounted on the leaf. This seal arrangement required complicated telescoping tubes to control the seal actuating water pressure. The hydraulic operation of these gates permits closure in 30 sec. The feature of being able to close a ring seal gate by gravity without power, plus the negligible loss for this type of gate, makes it well suited for a turbine guard gate. The general design and installation requirements are substantially the same for ring seal gates as for ring follower gates. The principal difference is in the wheels, roller, trains and seals which have been added. Figure 21 represents ring seal gate.

4. Jet flow gates

The fundamental features of the jet flow gate are the truncated conical nozzle, a floating seal ring which forms a circular discharge orifice at the downstream end of the nozzle and a flat bottomed leaf which contacts and is moved across the seal ring orifice to regulate flow discharges. The basic features produce a contracted, jet type discharge which is responsible for the name of the gate. Jet flow gates operate very satisfactorily at all openings. In general jet flow gates operate smoothly without vibration or serious cavitation damage at any opening. For partial openings there is considerable air demand under free discharge conditions. The gates have also operated satisfactorily discharging submerged when wide open. It is possible that strength requirements in the design of the seal ring may prove to be the head limiting factor for jet flow gate usuage rather than the flow characteristics. As only the circular upstream fluidway is under reservoir pressure. It is not necessary to provide heavy reinforcement around the body and bonnet in the embedding concrete. The interior spaces of the body and bonnet are rarely subjected to even very low water pressure and usually the pressure will be atmospheric or slightly subatmospheric. As the bonnet cover is not subjected to reservoir pressure, the cover needs to be designed only for the closing thrust capacity of the hoist which is mounted on the cover. It is essential that the upstream face of the gate leaf which is in sliding contact with the seal be made of corrosion resistant material. Steel plate, clad with either monel metal or 18-8 stainless steel, has been used to provide a corrosion resistant surface preference has been given to monel metal because it is closer electrochemically to the bronze seal surface which rubs on the plate and consequently should be less susceptible to electrolytic corrosion. Figure 22 represents jet flow gate.

5. Wheel and Roller mounted gates

Wheel and roller mounted gates normally serve the same function when used in high pressure outlets, namely, that of providing the primary shut off gate for a conduit or penstock. Both gates are also usually designed to close by gravity. Determination of wether to use a wheel a roller mounted gate is basically the result of determining if the weight of the gate is sufficient to overcome friction forces. To ensure gravity closure of such gates, the design is usually made so that the net weight of the gate exceeds the sum of all friction forces by at least 25 percent. As the seal and guide frictions are essentially the same for either type of gate, the type of gate selected is usually determined by the friction of the wheels or rollers. Because wheel mounted gates are somewhat simpler and more economical to build, they are usually given first preference. As the head on such gates increases, the size of the wheel pin must be increased to carry the bearing and bending load. The wheel diameter usually must also be increased to obtain a wheel to pin diameter ratio as large as possible and minimize the vertical force required to overcome the sliding friction on the wheel pin bearing. As heads increase, this combination of factors results in wheel sizes which become excessive in terms of the gate framing. These factors therefore limit the size and head for which wheel mounted gates can be used from a practical and structural stand point. The use of roller bearings or equivalent types of antifriction bearings instead of sleeve bearings increases the feasible heads for wheel mounted gates by reducing frictional resistance of the wheel bearings. The cost and capacity of antifriction bearings impose economic and practical limitations on their use and establish the head limitations for which wheel mounted gates are suitable. The figures 23 and 24 represent wheel mounted gate and roller mounted gate.

6. Cylinder Gates

Cylinder gates are used primarily as shut off gates for conduit and penstock intakes; however, cylinder gates are also used sometimes for regulating discharges. Cylinder gates provide a relatively simple and effective installation for vertical intakes where the controlling gates must operate in a shaft or intake tower. Although cylinder gates not widely used, they are fundamentally a sound type of a gate and merit serious consideration where vertical shaft intakes are required. Basically a cylinder gate is composed of a cylindrical shell which is raised and lowered to control flow through radial openings into a circular vertical intake structure for an outlet works or power plant. Cylinder gates have been located on both the inside and the outside of the circular structure, but an inside location is preferable for maintenance reasons. Seals at the top and bottom of the cylinder contact mating seats when the gate is closed. Three equally spaced stems have usually been used for hoisting, although with proper gate guidance a single hoisting stem should also be satisfactory for gates on the interior of the tower. Except for low heads, most intakes equipped with cylinder gates have had a low level gate and a high level gate. The basic purpose in providing an upper and lower gate has been to limit the maximum unbalanced operating head on the gates. When a cylinder gate is to be used at partial openings for regulation, special care must be used in considering the structural and hydraulic features of the installation. Gates used for regulating under submerged discharge conditions must have defined spring points and adequate fluid recirculation to the discharge orifice boundaries. The figure 25 represents cylinder gate

7. Bulkhead Gates and Stop Logs

Both bulk head gates and stop logs are usually placed over outlets under balanced pressure no flow conditions and function to permit inspection or repair of the downstream fluidway and gate or valve parts. Bulkhead gates and stop logs are located as far to the upstream end of a conduit as possible to permit almost complete unwatering of a fluidway. Modern stop logs and bulkhead gates frequently look very much alike and cannot be differentiated readily on the basis of general appearance. Stop logs no longer resemble the rough-hewn timbers from which the name originated, and the only remaining similarity between modern structural steel stop logs and the original wooden stop logs is the fact that a number of substantially identical parts are placed in a slot at the entrance to a fluidway. The general appearance of modern rubber sealed structural steel stop logs and bulk head gates no longer provides a means of identifying these close devices. It is convenient to have permanent crane facilities available for planning and removing bulkhead gates and stop logs. Because of the infrequent usage, however, it is frequently not economically justifiable to provide permanent hoisting equipment. The fact that bulkheads and stop logs will be used only infrequently should not lead to the neglect of careful design. The figures 26 and 27 represent bulk head Gate and stop log Gate

3.3 Operation of Gates under different conditions

Following are the conditions under which gates must be operated.

1. The foundation is susceptible to serious erosion or is very resistive.
2. Surface turbulence downstream is objectionable .
3. The stream carries heavy drift or logs.
4. Floods are flashy or rise gradually.

5. Floods are frequent throughout the year or are confined to a few occurrences at definite seasons.

6. Intense floods occur frequently or only at long intervals

7. The stream is subject to severe ice flows.

8. The gates will freeze in during the winter and if so, whether they may be expected to be frozen or clear at the time of first spring floods.

9. The pool level must be closely regulated.

10. Water can be wasted or must be conserved.

11. The spillway must be operated and maintained by other personnel or will have its own operating force.

12. Some operating force will be available at all times or only occasionally.

13. The reservoir must be lowered rapidly to provide flood control storage.

3.4 Different modes of operation of gates

The mode of operation of gate is decided by natural condition of the site, purpose to be served by the gate, preciseness of operation. Different modes of operation of gates are given as follows.

1) Automatic

2) Manual

3) Electrical

4) Hydraulic

1 Automatic

Two types of operation of gates are provided normally in dam structures under automatic operating condition

i) Operation due to self weight

ii) Operation through microprocessor

i Operation due to self weight

A sufficient amount of weight is added to a gate to resist the pressure by the water which is headedup in the pool of desired level. Once the pressure of water exceeds the self weight of the gate the gate will be tilted down to release the water from the pool. The gate will be lifted up manually to the exact position after the extra water passed over the spillway. An extra weight called ballast is added to a gate over and above structural requirements to make the gate self closing. Stoney is operated by self weight of the gate.

ii Operation through microprocessor

Computer aided operation of the spillway gates is now widely used as it provides undisputed advantages. The following equipment will be specially required for automatic control of the spillway gates.

a) Gate position sensors

b) Water level indicators

c) Reservoir level indicators

d) Micro computer

e) Printer for printing system reports and events

The automatic gate operation by microprocessor is carried out by preprogrammed strategy. The gate controller takes over when the reservoir level has crossed a preset level and the operation of spillway gates is executed according to function $Q = f(h)$, the total outflow required being a function of reservoir level.

2 Manual

The winch is operated manually to raise or lower the gate. This type of mode of operation is prescribed where the rise in water level due to flood is less.

3 Electrical

The hoist mechanism is operated by high powered electrical motor to raise or lower the gate. Electrical mode of operation is provided when the manual error is required to be neglected.

4 Hydraulic

The lifting drum on which the rope can be rolled is operated by hydraulic pressure. The gate can be lifted with less energy comparatively with other mode of operation.

3.4.1 Advantages and disadvantages of each mode of operation

The following are the main advantages and disadvantages of each mode of operation

i Self weight

Advantages

a) It can be operated without manpower i.e., gate is operated automatically by self weight.

b) The discharge can be passed suddenly after the gate opening.

c) No need of watching the rise in water level

Disadvantages

a) Fluctuations will be produced due to sudden opening of the gate, which may cause damage to earthen embankment.

b) Precise control of gate is not possible

c) Sudden opening may cause damage to downstream section of the dam

ii Microprocessor

Advantages

a) Precised control is possible in this mode of operation

b) Easy to operate the gate

c) Real flood forecasting can be done using the Precised control data

d) Replacement of mechanical mountings are less

Disadvantages

a) Initial cost of installation of equipments will be more

b) Gates can be operated sometimes because of computer and power break down

c) Skilled labour is required to operate the gate

iii Manual

Advantages

a) Operation and maintenance cost is less

b) No skilled labour is required to operate the gate

Disadvantages

a) This mode of operation gives rough and approximate control of gate

b) Waves will be generated due to sudden closure and opening

c) Mechanical mountings replacement are needed

d) Remote control is not possible

iv Electrical

Advantages

a) Manual error will be neglected

Disadvantages

a) The gates can not be operated due to sudden power breakdown. Therefore manually operated arrangements are to be kept always in good condition

b) The gates can not be operated effectively due to voltage fluctuations

v Hydraulic

Advantages

a) The power to operate the gate is less

b) It is advantageous where the rise in water level is slow

Disadvantages

a) Fast operation is not possible to reduce the water level suddenly

b) Operation and maintenance cost will be more

CHAPTER 4

GENERALISED COMPUTER PROGRAM

4.1 Objectives of Program

Gates over spillway crest are to be operated precisely to receive the inflow in flood duration and to serve conservation purposes like water supply for domestic and industrial use, irrigation and hydropower generation. Most project specifications require each gate opening to be straight line distance (cord length) from the gate seat to the downstream side of the gate lip for precised operation. The determination of effective gate opening with related to gate seat and downstream side of the gate lip coordinates is very much needed to pass the desired amount of discharge. A computer program is needed to prepare precise ratings table which is useful for reservoir regulation. HEC(July 1966)program is modified with the addition of precised sluice gate equations (P.K.Swamee) to prepare ratings table with any number of reservoir level and gate opening intervals according to prevailing condition in the reservoir. This program gives ratings table either for partial tainter gate or sluice gate opening on the basis of option.

4.2 Inputs to the program

Two types of inputs are needed on the basis of option. The program will read input data for tainter gate if the option is one. Otherwise it will read inputs for sluice gate. Number of elevation-area-capacity points, design head, crest elevation, number of gates, width of gate, height of gate, radius of gate, trunnion coordinates(XT,YT), maximum opening for the gate, ogee equation constants(CAY,P), elevation-area-capacity-release capacity of spillway table, initial reservoir level, reservoir level increment, initial gate opening , gate opening increment are the inputs in the case of preparation of partial tainter gate ratings table. In case of sluice gate initial upstream reservoir depth, tailwater depth, sluice length(width of gate), gate opening increment, reservoir level increment, maximum gate opening, maximum reservoir level are input data

4.3 Methodology

Two equations are used to get the effective gate opening on the basis of ogee equation $Y_c = kX_c^P$ where k and P are constants

1. $X_L = PX_c^{P-1} Y_L + PkX_c^{P-1}.kX_c^P + X_c$

2. $G_o = \sqrt{(X_L - X_c)^2 + (Y_L - Y_c)^2}$

where

X_L = Horizontal distance from the crest top to the bottom of the gate

Y_L = Vertical distance from the crest top to the bottom of the gate

X_c = Horizontal distance from the weir crest to the intersection of G_o with the ogee

G_o = Effective gate opening

Gate seat coordinates are calculated to get top elevation of gate which will be useful to determine induced surcharge. X_c is calculated by trial to satisfy a known value of X_L. The final value of X_c and X_L is used to calculate gate opening. The equations developed by P.K.Swamee are úsed for sluice gate opening

1) Free flow condition

$Q = 0.864ab\sqrt{gh_o}(h_o a/h_o + 15a)^{3/2}$

where Q = Sluice gate discharge

a = the sluice gate opening

b = the sluice gate depth

h_o = upstream water depth

g = gravitational coefficient

2) Submerged flow condition

$Q = 0.864\ ab\sqrt{gh_o}(h_o - a)^{0.072}(h_o - h_2)^{0\ 7}\{0.32[0.81h_2(h_2/a)0.72$
$-h_o]^{0.7} + (h_o - h_2)^{0.7}\}^{-1}$

h_2 = tail water depth

4.4 Output of model

Elevation of top of gate, effective gate openings and the discharge ratings for each reservoir interval with required number of gate openings are listed in different output files. In case of sluice gate coefficient of discharge and the discharge ratings corresponding to reservoir with required number of gate openings are listed in separate file.

4.5 Listing of variables, program and sample input and output

Some of the important variables used in the program are listed as follows

1 Tainter gate

A1 - An angle used to calculate top elevation of gate,radian

A2 - An angle used to calculate top elevation of gate,radian

A3 - An angle used to calculate top elevation of gate,radian

A4 - An angle used to calculate top elevation of gate,radian

A5 - An angle used to calculate top elevation of gate,radian

A6 - An angle used to calculate top elevation of gate,radian

A7 - An angle used to calculate top elevation of gate,radian

ALFA - An angle used to find the gate position,radian

AMC - Angle the tangent line makes with horizontal,radian

ANGLE - An angle used to check the gate position,radian

ARC - Arc subtended by A4,radian

B - Width of tainter gates,m

BETA - Angles corresponding to coefficient of discharge,degrees

C - Discharge coefficient

CAY - Constant in ogee equation,k

CORD - Straight line distance from gate seat to downstream side of gate lip,m

CREL - Elevation of spillway crest, m

EL - Pool elevation

GATES - Number of tainter gates

GO - Shortest distance from gate lip to ogee

GRAV - 9.81,m/s^2

GX - Horizontal component of G_o

GY - Vertical component of G_o

H - Head,H=EL-YPEL,m

HD - Ogee design head,m

HT - Height of tainter gates,m

JTRIAL - Number of trails required to compute X_c

PI - 3.14159265

PXL - Previous X_c,m

PXL - Previous X_L,m

Q1 - Discharge through all tainter gates,m^3/sec

R - Radius of tainter gates,m

SMC - Slope of tangent line to ogee at intersection G_o

TGEL - Top of gate elevation,m

TXC - Temporary X_c,m

X - Horizontal component of CORD,m

XC - Horizontal distance from weir crest to intersection of G_o with the ogee,m

XC1 - X_c for the previous gate opening ,m

XC2 - X_c for the time-before-last gate opening,m

XCORD - Straight line distance from gate seat to downstream side of gate lip,m

XL - Horizontal distance from weir crest to bottom of gate,m

XT - Horizontal distance from weir crest to gate trunnion,m

XS - Horizontal distance from weir crest to gate seat,m

Y - Vertical component of CORD

YC - Vertical distance from weir crest to intersection of G_o with the ogee,m

YCEL - Elevation of Y_c

YGT - Height of closed gate minus Y_T,m

YGTO - Vertical distance from trunnion to top of gate

YL - Vertical distance from weir crest to bottom of gate,m

YLEL - ELevation of Y_L,m

YPEL - (ELEV Y_L + ELEV Y_c)/2,m

YS - Vertical distance from weir crest to gate seat,m

YT - Vertical distance from weir crest to gate trunnion,m

Z - Used as decimal transfer in computing X_s

ZERO - Trial value of Y_s coordinate

2 sluice gate

CD - Coefficient of discharge

DIS - Discharge,m3/sec

GSTEP - Gate opening increment,m

GAOP - Initial gate opening,m

RSTEP - Reservoir level increment,m

SLENG - Sluice length,m

TWDEP - Tail water depth,m

TAGAOP - Maximum gate opening,m

TUPDEP - Maximum reservoir level,m

UPDEP - Upstream reservoir level,m

```
      SPILLWAY REGULATION - PARTIAL TAINTER AND SLUICE GATE OPENINGS
      DIMENSION BETA(14),C(14),XCORD(100),Q1(100,100), Q2(100,100),
     1 RESL(100),CV(100), GO(100), YPEL(100), H(100,100),EL(100),
     1 AR(100), CAP(100),RELC(100),GAOP(100,100),CD(100,100),
     1 DIS(100,100),UPDEP(100,100)
      CHARACTER*70 TIT
      CHARACTER*70 TITL
      CONS=0.3048**3
      PI=3.14159265
      GRAV=9.81
      FOOT=3.28084
      AMETRE=0.3048
      OPEN(UNIT=1,FILE='DIST.INP',STATUS='OLD')
      OPEN(UNIT=2,FILE='TA1.DAT',STATUS='OLD')
      OPEN(UNIT=3,FILE='EAC.DAT',STATUS='OLD')
      OPEN(UNIT=4,FILE='TAO.OUT',STATUS='NEW')
      OPEN(UNIT=5,FILE='TAA.OUT',STATUS='NEW')
      OPEN(UNIT=6,FILE='TAT.OUT',STATUS='NEW')
      OPEN(UNIT=7,FILE='DIST.OUT',STATUS='NEW')
      READ (2,10) Tit
      WRITE(4,10) Tit
      WRITE(5,10) Tit
 10   FORMAT(A)
      READ(1,10) Titl
      READ(1,*)OPTION,UPDEP(1,1),TWDEP,SLENG,GSTEP,RSTEP,TGAOP,
     1 GAOP(1,1),TUPDEP
      IF(OPTION .GT. 1) GOTO 470
      READ(2,*) HD,CREL,GATES,B,HT,R,XT,YT,GMAXOPEN
      HD=HD*FOOT
      CREL=CREL*FOOT
      B=B*FOOT
      HT=HT*FOOT
      R=R*FOOT
      XT=XT*FOOT
      YT=YT*FOOT
      GMAXOPEN=GMAXOPEN*FOOT
      READ(2,*) CAY, P
      READ(3,*) NN
      DO 20 I=1,NN
      READ(3,*) EL(I), AR(I), CAP(I), RELC(I)
 20   CONTINUE
      DO 25 I=1,NN
      EL(I)=EL(I)*FOOT
      AR(I)=AR(I)*FOOT**2
      CAP(I)=CAP(I)*FOOT**3
      RELC(I)=RELC(I)*FOOT**3
 25   CONTINUE
      BETA(1)=0.
      BETA(2)=50.
      DO 30 J=3,14
 30   BETA(J)=BETA(J-1)+5.
      C(1) = 0.66
      C(2) = 0.6685
      C(3) = 0.67
      C(4) = 0.672
      C(5) = 0.675
      C(6) = 0.678
      C(7) = 0.6826
      C(8) = 0.688
      C(9) = 0.695
      C(10) = 0.705
      C(11) = 0.716
      C(12) = 0.7285
      C(13) = 0.742
      C(14) = 0.755
      Z=10.
      XS=(XT-R)+.01
```

```
      IF(XS.LE.0) XS=.01
40    ZERO=SQRT(ABS(R*R-((XT-XS)*(XT-XS))))-YT-CAY*XS**P
      ITER=ITER+1
      IF(ZERO.LT.1.E-03.AND.ITER.GT.30) GO TO 70
      IF (ZERO) 50,70,60
50    XS=XS+(Z*.1)
      GO TO 40
60    Z=Z*.1
      XS=XS-Z
      GO TO 40
70    YS=-CAY*XS**P
      XS=XS*AMETRE
      YS=YS*AMETRE
      ZERO=ZERO*AMETRE
      WRITE(6,*) 'XS, YS, ZERO', XS, YS, ZERO
      XS=XS*FOOT
      YS=YS*FOOT
      ZERO=ZERO*FOOT
80    A1=ATAN(SQRT(R*R-((XT-XS)*(XT-XS)))/(XT-XS))
      WRITE(6,*) 'A1', A1
      YS=-YS
      JD=1
      WRITE(*,*)'INITIAL RESERVOIR LEVEL(M),RESERVOIR LEVEL INCREMENT
     1 (M)'
      READ(*,*)RESL(1),P
      RESL(1)=RESL(1)*FOOT
      P=P*FOOT
      MM=(EL(NN)-RESL(1))/P
      DO 90 I=2,MM
      RESL(I)=RESL(I-1)+P
90    CONTINUE
      RESL(MM+1)=EL(NN)
      WRITE(*,*) 'INITIAL GATE OPENING (M),GATE OPENING INCREMENT(M)'
      READ(*,*) XCORD(1),Q
      Q=Q*FOOT
      XCORD(1)=XCORD(1)*FOOT
      NO=(GMAXOPEN-XCORD(1))/Q
      NO=NO+1
      WRITE(*,*)NO
      DO  100 J = 2, NO
      XCORD(J)=XCORD(J-1)+Q
100   CONTINUE
      XCORD(NO+1)=GMAXOPEN
      DO 102 J=1,NO+1
      XCORD(J)=XCORD(J)*AMETRE
102   CONTINUE
      DO 105 J=1,NO+1
      WRITE(4,*) XCORD(J)
      WRITE(5,*) XCORD(J)
105   CONTINUE
      DO 110 J=1,NO+1
      WRITE(6,*) 'XCORD(J)', XCORD(J)
      XCORD(J)=XCORD(J)*FOOT
120   A2=ATAN(SQRT(R*R-((XCORD(J)/2.)*(XCORD(J)/2.)))/(XCORD(J)/2.1))
      WRITE(6,*) 'A2', A2
      IF(A1+A2-PI/2.) 130,140,150
130   A3=(PI/2.)-(A1+A2)
      Y=XCORD(J)*COS(A3)
      X=(XCORD(J)*SIN(A3))*(-1.)
      GO TO 160
140   Y=XCORD(J)
      X=0
      GO TO 160
150   A3=PI-(A1+A2)
      Y=XCORD(J)*SIN(A3)
      X=XCORD(J)*COS(A3)
      Y=Y*AMETRE
```

```
      X=X*AMETRE
  160 WRITE(6,*) 'A3, Y, X', A3, Y, X
      Y=Y*FOOT
      X=X*FOOT
      YL=Y-YS
      XL=XS-X
      A4=PI-2.*A2
      A5=PI/2.-A1
      YL=YL*AMETRE
      XL=XL*AMETRE
      WRITE(6,*) 'YL, XL, A4, A5', YL, XL, A4, A5
      YL=YL*FOOT
      XL=XL*FOOT
      ALFA=A4+A5-PI/2.
      YGT=HT-YT-YS
      ARC=R*A4
      A6=ATAN(YGT/SQRT(R*R-YGT*YGT))
      A7=A6+A4
      YGTO=R*SIN(A7)
      TGEL=CREL+YT+YGTO
      YGT=YGT*AMETRE
      ARC=ARC*AMETRE
      YGTO=YGTO*AMETRE
      TGEL=TGEL*AMETRE
      WRITE(6,*) 'ALFA, YGT, ARC, A6, A7, YGTO, TGEL', ALFA, YGT, ARC
     1 , A6, A7, YGTO, TGEL
      YGT=YGT*FOOT
      ARC=ARC*FOOT
      YGTO=YGTO*FOOT
      TGEL=TGEL*FOOT
  170 JTRIAL=0
      IF((J-1).GT.0) GO TO 190
  180 XC=XS-.2
C     FOR FIRST GATE OPENING
      GO TO 250
  190 IF ((J-2).GT.0) GO TO 210
  200 XC=2.*XC1-XS-.0005
C     FOR SECOND GATE OPENING
      GO TO 250
  210 IF(YT-YL) 240,220,230
C     FOR SUCCEEDING GATE OPENINGS
  220 XC=XC1
      GO TO 250
  230 XC=2.*XC1-XC2+.0005
C     BOT GATE BELOW TRUN
      IF(XC) 220,250,250
  240 XC=2.*XC1-XC2-.0005
C     BOT GATE ABOVE TRUN
      IF(XC.LT.0) GO TO 220
  250 CXL=P*CAY*XC**(P-1.)*(YL+CAY*XC**P)+XC
      JTRIAL=JTRIAL+1
      IF(XL-CXL) 260,360,270
  260 IF(XL-CXL+.00001) 280,360,360
  270 IF(XL-CXL-.00001) 360,360,280
  280 IF(JTRIAL.GT.1) GO TO 330
  290 PXC=XC
      PXL=CXL
      IF(CXL-XL) 300,300,320
  300 XC=XC+.005
      IF(XC.GT.0) GO TO 250
  310 XC=.0005
      GO TO 250
  320 XC=XC-.005
      IF (XC) 310,330,250
  330 TXC=XC
      XC=((PXC-TXC)*(XL-CXL)/(PXL-CXL))+TXC
      IF(XC.GT.0) GO TO 350
```

```
 340 XC=TXC/2.
 350 PXC=TXC
     PXL=CXL
     GO TO 250
 360 IF((J-1).EQ.0) GO TO 380
 370 XC2=XC1
 380 XC1=XC
     YC=CAY*XC**P
     GX=XL-XC
     GY=YL+YC
     GO(J)=SQRT(GX*GX+GY*GY)
     CXL=CXL*AMETRE
     XC=XC*AMETRE
     YC=YC*AMETRE
     GX=GX*AMETRE
     GY=GY*AMETRE
     GO(J)=GO(J)*AMETRE
     WRITE(6,*) 'CXL, XC, YC, GX, GY, GO', CXL, XC, YC, GX, GY, GO(J)
     CXL=CXL*FOOT
     XC=XC*FOOT
     YC=YC*FOOT
     GX=GX*FOOT
     GY=GY*FOOT
     GO(J)=GO(J)*FOOT
     SMC=-P*CAY*XC**(P-1.)
     AMC=ATAN(SMC)
 390 ANGLE=PI/2.+AMC+ALFA
C   RADIANS
     ANGLE=ANGLE*57.29578
     WRITE(6,*) 'SMC, AMC, ANGLE' , SMC, AMC, ANGLE
C   DEGREES
     IF(ANGLE-110.GT.0) GOTO 435
 400 N=1
 410 IF(BETA(N).GT.ANGLE) GO TO 430
 420 N=N+1
     GO TO 410
 430 CV(J)=((ANGLE-BETA(N-1))/(BETA(N)-BETA(N-1))*(C(N)-C(N-1)))+
    1 C(N-1)
     YLEL=CREL+YL
     YCEL=CREL-YC
     YPEL(J)=(YLEL+YCEL)/2.
 110 CONTINUE
 435 DO 440 I=1,MM+1
     DO 450 J=1,NO+1
     H(I,J)=RESL(I)-YPEL(J)
     IF(H(I,J).LT.0) H(I,J)=0.
     Q1(I,J)=CV(J)*GO(J)*B*SQRT(H(I,J))*8.025
     Q2(I,J)=GATES*Q1(I,J)
     RECM=FINT(EL,RELC,RESL(I),NN)
     IF(Q2(I,J).GT.RECM) THEN
      Q2(I,J)=RECM
      Q1(I,J)=Q2(I,J)/GATES
     ENDIF
     Q2(I,J)=Q2(I,J)*CONS
     Q1(I,J)=Q1(I,J)*CONS
 450 CONTINUE
 440 CONTINUE
     DO 460 I=1,MM+1
     RESL(I)=RESL(I)*AMETRE
     WRITE(4,*) RESL(I),(Q1(I,J),J=1,NO+1)
     WRITE(5,*) RESL(I),(Q2(I,J),J=1,NO+1)
 460 CONTINUE
     GOTO 560
C   SLUICE GATE
 470 NSTEPR = (TUPDEP-UPDEP(1,1))/RSTEP
     MSTEPG = (TGAOP-GAOP(1,1))/GSTEP
     DO 480 I=1,NSTEPR+2
```

```
      DO 490 J=1,MSTEPG+2
      CONST= 0.81*(TWDEP*(TWDEP/GAOP(I,J))**0.72)
      IF(UPDEP(I,J) .GT. TWDEP .AND. UPDEP(I,J) .LT. CONST) GOTO 500
      CD(I,J)=0.611*((UPDEP(I,J)-GAOP(I,J))/(UPDEP(I,J)+15.0*GAOP(I,J
     1 )))**0.072
      DIS(I,J)=0.864*GAOP(I,J)*SLENG*SQRT(GRAV*UPDEP(I,J))*((UPDEP(I,
     1 J)-GAOP(I,J))/(UPDEP(I,J)+15.0*GAOP(I,J)))**0.072
      GOTO 520
500   WRITE(7,510)
510   FORMAT(2X,'SUBMERGENCE')
      CD(I,J)=0.611*((UPDEP(I,J)-GAOP(I,J))/(UPDEP(I,J)+15.0*GAOP(I,J
     1 )))**0.072*(UPDEP(I,J)-TWDEP)**0.7*(0.32*(0.81*TWDEP*((TWDEP/GA
     1 OP(I,J))**0.72)-UPDEP(I,J))**0.7+(UPDEP(I,J)-TWDEP)**0.7)**(-1)
      DIS(I,J)=0.864*GAOP(I,J)*SLENG*SQRT(GRAV*UPDEP(I,J))*(((UPDEP
     1 (I,J)-GAOP(I,J))/(UPDEP(I,J)+15.0*GAOP(I,J)))**0.072)*(0.32*
     1 (0.81*TWDEP*((TWDEP/GAOP(I,J))**0.72)-UPDEP(I,J))**0.7+(UPDEP
     1 (I,J)-TWDEP)**0.7)**(-1)
520   GAOP(I,J+1)=GAOP(I,J)+GSTEP
      UPDEP(I,J+1)=UPDEP(I,J)
      IF(GAOP(I,J+1) .GT. TGAOP) GAOP(I,J+1)=TGAOP
490   CONTINUE
      UPDEP(I+1,1)=UPDEP(I,1)+RSTEP
      IF(UPDEP(I+1,1) .GT. TUPDEP) UPDEP(I+1,1)=TUPDEP
      GAOP(I+1,1)=GAOP(1,1)
480   CONTINUE
      WRITE(7,10) Titl
      WRITE(7,530)
530   FORMAT(4X'RESERVOIR LEVEL'3X,'GATE OPENING'3X'COEFFI.DISCH',
     1 4X,'DISCHARGE')
      DO 540 I=1,NSTEPR+2
      DO 550 J=1,MSTEPG+2
      WRITE(7,*)UPDEP(I,J),GAOP(I,J),CD(I,J),DIS(I,J)
550   CONTINUE
540   CONTINUE
560   STOP
      END

      FUNCTION FINT(A,B,AVAL,NN)
      DIMENSION A(1),B(1)
      IF(AVAL.LT.A(1)) THEN
      FINT=B(1)
      RETURN
      ENDIF
      IF(AVAL.GT.A(NN)) THEN
      FINT=B(NN)
      RETURN
      ENDIF
      DO 570 I=2,NN
      IF(AVAL.EQ.A(I)) THEN
      FINT=B(I)
      RETURN
      ENDIF
      IF(A(I-1).LT.AVAL.AND.A(I).GT.AVAL) THEN
      FINT=B(I-1)+((B(I)-B(I-1))/(A(I)-A(I-1)))*(AVAL-A(I-1))
      RETURN
      ENDIF
570   CONTINUE
      END
```

INITIAL RESERVOIR LEVEL (M) = 54.5
RESERVOIR LEVEL INCREMENT (M) = 0.5
INITIAL GATE OPENING (M) = 2.0
GATE OPENING INCREMENT (M) = 0.5

INPUT - MAIN SPILLWAY OF MACHHU-II RESERVOIR

6.40 51.210 18.0 9.14 6.90 7.315 8.793 1.83 7.2

0.037591 1.85

INPUT - ELEVATION,WATER SPREAD AREA,CAPACITY OF MACHHU RESERVOIR II

21

43.00	0.110	0.083	0.000
44.00	0.442	0.334	0.000
45.00	0.761	0.981	0.000
46.00	1.134	2.825	0.000
47.00	1.654	7.492	0.000
48.00	2.146	8.743	0.000
49.00	2.648	9.044	0.000
50.00	3.209	10.479	390.742
51.00	3.916	14.113	1226.807
52.00	5.133	18.324	2206.000
53.00	7.536	24.714	3491.082
54.00	10.242	34.365	5026.533
55.00	13.593	46.713	6749.529
56.00	17.301	60.822	8667.062
57.00	23.161	78.337	10765.440
58.00	28.611	102.369	12989.050
59.00	36.347	135.752	15434.150
60.00	44.744	175.672	18023.790
61.00	52.849	278.934	20755.790
62.00	61.532	402.154	23635.760
63.00	70.583	521.651	26656.950

INPUT - VAIGAI DAM - RIVER SLUICE
2.0,7.966,1.044,1.52,0.1,1.0,2.743,1.52,21.64

DISCHARGE RATING TABLE FOR MAIN SPILLWAY OF MACHHU-II RESERVOIR - 18 GATES

2.000000			
2.500000			
3.000000			
3.500000			
4.000000			
4.500000			
5.000000			
5.500000			
6.000000			
6.500000			
7.000000			
7.200000			
54.500000	1430.968000	1748.236000	2032.364000
2273.067000	2461.395000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
55.000000	1567.005000	1932.496000	2272.509000
2578.298000	2843.442000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
55.500000	1692.141000	2100.656000	2489.596000
2851.037000	3179.915000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
56.000010	1808.640000	2256.317000	2689.216000
3099.871000	3484.042000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
56.500010	1918.076000	2401.911000	2875.009000
3330.164000	3763.675000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
57.000010	2021.596000	2539.171000	3049.503000
3545.530000	4023.921000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
57.500010	2120.068000	2669.382000	3214.539000
3748.542000	4268.330000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
58.000020	2214.164000	2793.531000	3371.506000
3941.112000	4499.481000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
58.500020	2304.422000	2912.392000	3521.483000
4124.700000	4719.325000	2217.159000	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
59.000020	2391.275000	3026.589000	3665.329000
4300.458000	4929.374000	5962.141000	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
59.500020	2475.082000	3136.631000	3803.739000
4469.309000	5130.831000	8135.014000	4671.018000
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
60.000020	2556.143000	3242.941000	3937.286000
4632.010000	5324.671000	9839.196000	7796.099000
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
60.500020	2634.711000	3345.875000	4066.449000
4789.187000	5511.697000	11288.980000	9986.986000
6945.167000	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
61.000030	2711.004000	3445.735000	4191.635000

4941.366000	5692.583000	12572.690000	11777.120000
9831.759000	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
61.500030	2785.207000	3542.781000	4313.188000
5088.997000	5867.896000	13736.950000	13328.970000
12045.400000	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
62.000030	2857.484000	3637.240000	4431.409000
5232.463000	6038.121000	14809.970000	14718.090000
13911.140000	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
62.500030	2927.977000	3729.306000	4546.557000
5372.100000	6203.676000	15810.330000	15986.960000
15554.670000	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
63.000000	2996.808000	3819.148000	4658.852000
5508.190000	6364.917000	16750.990000	17162.200000
17040.330000	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			

DISCHARGE RATING TABLE FOR MAIN SPILLWAY OF MACHHU-II RESERVOIR - ONE GATE

2.000000			
2.500000			
3.000000			
3.500000			
4.000000			
4.500000			
5.000000			
5.500000			
6.000000			
6.500000			
7.000000			
7.200000			
54.500000	79.498200	97.124240	112.909100
126.281500	136.744200	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
55.000000	87.055830	107.360900	126.250500
143.238800	157.969000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
55.500000	94.007830	116.703100	138.310900
158.390900	176.661900	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
56.000010	100.480000	125.350900	149.400900
172.215100	193.557900	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
56.500010	106.559700	133.439500	159.722700
185.009100	209.093000	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
57.000010	112.310900	141.065100	169.416800
196.973900	223.551200	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
57.500010	117.781500	148.299000	178.585500
208.252300	237.129400	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
58.000020	123.009100	155.196200	187.305900
218.950600	249.971200	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
58.500020	128.023400	161.799500	195.638000
229.150000	262.184700	123.175500	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
59.000020	132.848600	168.143800	203.629400
238.914300	273.854100	331.230000	0.000000E+00
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
59.500020	137.504600	174.257300	211.318800
248.295000	285.046100	451.945200	259.501000
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
60.000020	142.007900	180.163400	218.738100
257.333900	295.815100	546.622000	433.116600
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
60.500020	146.372900	185.881900	225.913900
266.065900	306.205400	627.165600	554.832600
385.842600	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
61.000030	150.611300	191.429700	232.868600
274.520300	316.254600	698.482500	654.284700

546.208800	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
61.500030	154.733700	196.821200	239.621600
282.722000	325.994200	763.163800	740.498200
669.188800	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
62.000030	158.749100	202.068900	246.189400
290.692400	335.451100	822.775900	817.671600
772.841000	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
62.500030	162.665400	207.183700	252.586500
298.450000	344.648700	878.351400	888.164400
864.148600	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			
63.000000	166.489300	212.174900	258.825100
306.010600	353.606500	930.610800	953.455500
946.685100	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00			

DETAILED RESULTS
XS, YS, ZERO 1.796496 -3.050420E-01 -6.100808E-05
A1 2.961747E-01
XCORD(J) 2.000000
A2 1.433661
A3, Y, X 1.411757 1.974760 3.167402E-01
YL, XL, A4, A5 1.669718 1.479756 2.742698E-01 1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL -2.190483E-02 4.764958
2.006284 7.094222E-01 9.836920E-01 6.090091
59.130090
CXL, XC, YC, GX, GY, GO 1.479756 1.213773 1.105482E-01
2.659830E-01 1.780266 1.800026
SMC, AMC, ANGLE -1.494064E-01 -1.483094E-01 80.247440
XCORD(J) 2.500000
A2 1.399072
A3, Y, X 1.446346 2.480665 3.103226E-01
YL, XL, A4, A5 2.175623 1.486173 3.434491E-01 1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL 4.727447E-02 4.764958
2.512330 7.094222E-01 1.052871 6.355626
59.395630
CXL, XC, YC, GX, GY, GO 1.486173 1.156281 1.020896E-01
3.298922E-01 2.277713 2.301479
SMC, AMC, ANGLE -1.448349E-01 -1.438347E-01 84.467510
XCORD(J) 3.000000
A2 1.364273
A3, Y, X 1.481145 2.987952 2.685945E-01
YL, XL, A4, A5 2.682910 1.527901 4.130461E-01 1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL 1.168715E-01 4.764958
3.021432 7.094222E-01 1.122468 6.592082
59.632080
CXL, XC, YC, GX, GY, GO 1.527901 1.130780 9.842229E-02
3.971215E-01 2.781332 2.809540
SMC, AMC, ANGLE -1.427810E-01 -1.418224E-01 88.570420
XCORD(J) 3.500000
A2 1.329219
A3, Y, X 1.516199 3.494785 1.909953E-01
YL, XL, A4, A5 3.189743 1.605501 4.831548E-01 1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL 1.869801E-01 4.764958
3.534277 7.094222E-01 1.192577 6.798003
59.838010
CXL, XC, YC, GX, GY, GO 1.605501 1.134849 9.900390E-02
4.706520E-01 3.288747 3.322254
SMC, AMC, ANGLE -1.431098E-01 -1.421447E-01 92.568890
XCORD(J) 4.000000
A2 1.293859
A3, Y, X 1.551559 3.999260 7.694468E-02
YL, XL, A4, A5 3.694218 1.719551 5.538745E-01 1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL 2.576998E-01 4.764958
4.051592 7.094222E-01 1.263297 6.971878
60.011880
CXL, XC, YC, GX, GY, GO 1.719551 1.166417 1.035618E-01
5.531340E-01 3.797780 3.837850
SMC, AMC, ANGLE -1.456467E-01 -1.446297E-01 96.478450
XCORD(J) 4.500000
A2 1.258140
A3, Y, X 1.648161E-02 14.761770 -2.433198E-01
YL, XL, A4, A5 14.456730 2.039816 6.253126E-01 1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL 3.291379E-01 4.764958
4.574162 7.094222E-01 1.334735 7.112131
60.152130
CXL, XC, YC, GX, GY, GO 2.039815 6.246684E-01 3.718009E-02
1.415147 14.493910 14.562830
SMC, AMC, ANGLE -9.763733E-02 -9.732884E-02 103.281700
XCORD(J) 5.000000
A2 1.222004
A3, Y, X 5.261812E-02 16.381500 -8.627598E-01
YL, XL, A4, A5 16.076450 2.659256 6.975856E-01 1.274622

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ALFA, YGT, ARC, A6, A7, YGTO, TGEL  4.014109E-01    4.764958
    5.102839   7.094222E-01     1.407008       7.217101
   60.257100
CXL, XC, YC, GX, GY, GO     2.659256   8.055209E-01   5.642317E-02
    1.853735    16.132880     16.239030
SMC, AMC, ANGLE  -1.149042E-01  -1.144024E-01     106.444400
XCORD(J)      5.500000
A2      1.185385
A3, Y, X   8.923623E-02      17.972820       -1.608098
YL, XL, A4, A5      17.667780      3.404593   7.708218E-01      1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL  4.746472E-01     4.764958
    5.638562   7.094222E-01      1.480244      7.285030
   60.325030
CXL, XC, YC, GX, GY, GO      3.404592      1.024808   8.375083E-02
    2.379786     17.751530     17.910340
SMC, AMC, ANGLE  -1.340608E-01  -1.332662E-01     109.559700
XCORD(J)      6.000000
A2      1.148215
A3, Y, X   1.264069E-01      19.527980       -2.481703
YL, XL, A4, A5      19.222940      4.278199   8.451631E-01      1.274622
ALFA, YGT, ARC, A6, A7, YGTO, TGEL  5.489885E-01     4.764958
    6.182368   7.094222E-01      1.554585      7.314039
   60.354040
CXL, XC, YC, GX, GY, GO      4.278199      1.283226   1.211137E-01
    2.994974    19.344050     19.574530
SMC, AMC, ANGLE  -1.548266E-01  -1.536069E-01     112.653700
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VAIGAI DAM - RIVER SLUICE - DISCAHRGE RATING TABLE

RESERVOIR LEVEL	GATE OPENING	COEFFI.DISCH	DISCHARGE
7.966000	1.520000	5.459703E-01	15.768250
7.966000	1.620000	5.434900E-01	16.729280
7.966000	1.720000	5.410956E-01	17.683700
7.966000	1.820000	5.387785E-01	18.631700
7.966000	1.920000	5.365310E-01	19.573430
7.966000	2.020000	5.343464E-01	20.509030
7.966000	2.120000	5.322188E-01	21.438620
7.966000	2.220000	5.301428E-01	22.362310
7.966000	2.320000	5.281137E-01	23.280170
7.966000	2.420000	5.261272E-01	24.192280
7.966000	2.520000	5.241791E-01	25.098680
7.966000	2.619999	5.222660E-01	25.999430
7.966000	2.719999	5.203846E-01	26.894530
7.966000	2.743000	5.199560E-01	27.099620
8.966000	1.520000	5.503999E-01	16.864440
8.966000	1.620000	5.480407E-01	17.896900
8.966000	1.720000	5.457643E-01	18.922720
8.966000	1.820000	5.435628E-01	19.942110
8.966000	1.920000	5.414293E-01	20.955260
8.966000	2.020000	5.393577E-01	21.962320
8.966000	2.120000	5.373425E-01	22.963450
8.966000	2.220000	5.353788E-01	23.958750
8.966000	2.320000	5.334623E-01	24.948340
8.966000	2.420000	5.315889E-01	25.932310
8.966000	2.520000	5.297551E-01	26.910740
8.966000	2.619999	5.279576E-01	27.883690
8.966000	2.719999	5.261934E-01	28.851220
8.966000	2.743000	5.257921E-01	29.073000
9.966000	1.520000	5.541784E-01	17.902110
9.966000	1.620000	5.519217E-01	19.002190
9.966000	1.720000	5.497445E-01	20.095570
9.966000	1.820000	5.476394E-01	21.182500
9.966000	1.920000	5.456002E-01	22.263160
9.966000	2.020000	5.436211E-01	23.337740
9.966000	2.120000	5.416973E-01	24.406390
9.966000	2.220000	5.398241E-01	25.469260
9.966000	2.320000	5.379974E-01	26.526450
9.966000	2.420000	5.362138E-01	27.578100
9.966000	2.520000	5.344697E-01	28.624280
9.966000	2.619999	5.327623E-01	29.665090
9.966000	2.719999	5.310887E-01	30.700600
9.966000	2.743000	5.307083E-01	30.938040
10.966000	1.520000	5.574533E-01	18.889780
10.966000	1.620000	5.552859E-01	20.054250
10.966000	1.720000	5.531943E-01	21.211970
10.966000	1.820000	5.511722E-01	22.363170
10.966000	1.920000	5.492135E-01	23.508080
10.966000	2.020000	5.473131E-01	24.646880
10.966000	2.120000	5.454662E-01	25.779740
10.966000	2.220000	5.436688E-01	26.906810
10.966000	2.320000	5.419171E-01	28.028220
10.966000	2.420000	5.402075E-01	29.144100
10.966000	2.520000	5.385371E-01	30.254560
10.966000	2.619999	5.369031E-01	31.359700
10.966000	2.719999	5.353028E-01	32.459590
10.966000	2.743000	5.349393E-01	32.711850
11.966000	1.520000	5.603282E-01	19.834040
11.966000	1.620000	5.582399E-01	21.060130
11.966000	1.720000	5.562242E-01	22.279400
11.966000	1.820000	5.542749E-01	23.492100
11.966000	1.920000	5.523868E-01	24.698450
11.966000	2.020000	5.505548E-01	25.898650
11.966000	2.120000	5.487747E-01	27.092870
11.966000	2.220000	5.470425E-01	28.281290
11.966000	2.320000	5.453549E-01	29.464040
11.966000	2.420000	5.437086E-01	30.641260
11.966000	2.520000	5.421006E-01	31.813060
11.966000	2.619999	5.405285E-01	32.979560
11.966000	2.719999	5.389896E-01	34.140850
11.966000	2.743000	5.386401E-01	34.407230
12.966000	1.520000	5.628782E-01	20.749140
12.966000	1.620000	5.608612E-01	22.025410

12.966000	1.720000	5.589135E-01	23.303800
12.966000	1.820000	5.570295E-01	24.575550
12.966000	1.920000	5.552042E-01	25.840900
12.966000	2.020000	5.534330E-01	27.100050
12.966000	2.120000	5.517119E-01	28.353180
12.966000	2.220000	5.500373E-01	29.600480
12.966000	2.320000	5.484058E-01	30.842080
12.966000	2.420000	5.468146E-01	32.078130
12.966000	2.520000	5.452609E-01	33.308760
12.966000	2.619999	5.437422E-01	34.534080
12.966000	2.719999	5.422562E-01	35.754200
12.966000	2.743000	5.419189E-01	36.034110
13.966000	1.520000	5.651597E-01	21.612320
13.966000	1.620000	5.632077E-01	22.954630
13.966000	1.720000	5.613219E-01	24.289970
13.966000	1.820000	5.594970E-01	25.618620
13.966000	1.920000	5.577285E-01	26.940810
13.966000	2.020000	5.560120E-01	28.256750
13.966000	2.120000	5.543439E-01	29.566630
13.966000	2.220000	5.527208E-01	30.870620
13.966000	2.320000	5.511395E-01	32.168890
13.966000	2.420000	5.495972E-01	33.461580
13.966000	2.520000	5.480915E-01	34.748830
13.966000	2.619999	5.466200E-01	36.030750
13.966000	2.719999	5.451804E-01	37.307460
13.966000	2.743000	5.448537E-01	37.600390
14.966000	1.520000	5.672162E-01	22.454100
14.966000	1.620000	5.653238E-01	23.851510
14.966000	1.720000	5.634947E-01	25.241890
14.966000	1.820000	5.617240E-01	26.625510
14.966000	1.920000	5.600073E-01	28.002610
14.966000	2.020000	5.583408E-01	29.373400
14.966000	2.120000	5.567209E-01	30.738090
14.966000	2.220000	5.551444E-01	32.096850
14.966000	2.320000	5.536084E-01	33.449840
14.966000	2.420000	5.521103E-01	34.797230
14.966000	2.520000	5.506477E-01	36.139140
14.966000	2.619999	5.492184E-01	37.475700
14.966000	2.719999	5.478204E-01	38.807040
14.966000	2.743000	5.475031E-01	39.112530
15.966000	1.520000	5.690816E-01	23.268420
15.966000	1.620000	5.672445E-01	24.719180
15.966000	1.720000	5.654678E-01	26.162850
15.966000	1.820000	5.637470E-01	27.599700
15.966000	1.920000	5.620782E-01	29.029980
15.966000	2.020000	5.604575E-01	30.453890
15.966000	2.120000	5.588819E-01	31.871650
15.966000	2.220000	5.573481E-01	33.283440
15.966000	2.320000	5.558535E-01	34.689410
15.966000	2.420000	5.543957E-01	36.089740
15.966000	2.520000	5.529723E-01	37.484570
15.966000	2.619999	5.515813E-01	38.874020
15.966000	2.719999	5.502207E-01	40.258210
15.966000	2.743000	5.499119E-01	40.575850
16.966000	1.520000	5.707831E-01	24.057750
16.966000	1.620000	5.689973E-01	25.560280
16.966000	1.720000	5.672694E-01	27.055660
16.966000	1.820000	5.655950E-01	28.544170
16.966000	1.920000	5.639706E-01	30.026040
16.966000	2.020000	5.623925E-01	31.501500
16.966000	2.120000	5.608577E-01	32.970750
16.966000	2.220000	5.593634E-01	34.433990
16.966000	2.320000	5.579069E-01	35.891370
16.966000	2.420000	5.564861E-01	37.343070
16.966000	2.520000	5.550988E-01	38.789220
16.966000	2.619999	5.537428E-01	40.229970
16.966000	2.719999	5.524166E-01	41.665430
16.966000	2.743000	5.521156E-01	41.994860
17.966000	1.520000	5.723426E-01	24.824240
17.966000	1.620000	5.706049E-01	26.377090
17.966000	1.720000	5.689225E-01	27.922730
17.966000	1.820000	5.672915E-01	29.461440
17.966000	1.920000	5.657084E-01	30.993470
17.966000	2.020000	5.641699E-01	32.519040

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APPENDIX

DETAILS OF GATES IN SELECTED INDIAN RESERVOIRS

1 Nagarjunasagar dam

Location	: Nandikonda village, Dist. Nalgonda Andhra Pradesh
Purpose	: Irrigation and Hydropower
River	: Krishna
Spillway type	: Ogee
Type and number of gates	: Radial gates 26 nos 13.72X13.41m
Maximum discharge capacity	: 53450 m^3/sec

2 Chandan reservoir

Location	: District Bhagalpur, Bihar
Purpose	: Irrigation
River	: Chandan
Spillway type	: Chute (saddle)
Type and number of gates	: Nongated
Maximum discharge capacity	: 3115 m^3/sec

3 Kadana reservoir

Location	: Near Kadana village, Panchmahals District Gujarat
Purpose	: Irrigation and hydropower
River	: Mahi
Spillway type	: Ogee shaped for main Chute for additional
Type and number of gates	: Radial 21 Nos for main and 6 Nos for additional
Maximum discharge capacity	: 49600 m^3/sec

4 Bhakra dam

Location	: Near village Bhakra, Bilaspur District Himachal pradesh
Purpose	: Irrigation and hydropower
River	: Sutlej
Spillway type	: Centrally located overflow
Type and number	: Radial 4 Nos of size

	of gates	15'.24x14.48m
	Maximum discharge capacity	: 8212 m^3/sec
5	Tungbhadra dam	
	Location	: Near Hospet town,Karnataka
	Purpose	: Irrigation and hydropower
	River	: Tungbhadra
	Spillway type	: Ogee
	Type and number of gates	: Verticaal lift 33 Nos
	Maximum discharge capacity	: 18408 m^3/sec
6	Malampuzha dam	
	Location	: Near Olavakkot,Kerala
	Purpose	: Irrigation
	River	: Malampuzha
	Spillway type	: Ogee
	Type and number of gates	: Verticaal lift 4 Nos
	Maximum discharge capacity	: 368 m^3/sec
7	Khadakwasala dam	
	Location	: Pune Maharastra
	Purpose	: Irrigation and water supply
	River	: Mutha
	Spillway type	: gated
	Type and number of gates	: Tainter 11 Nos of size (12.19x4.26)
	Maximum discharge capacity	: 2762 m^3/sec
8	Hirakud dam	
	Location	: Hirakud,Sambalpur district, Orissa
	Purpose	: Irrigation, hydropower and Flood control
	River	: Mahanadi
	Spillway type	: Ogeegated
	Type and number of gates	: 34 crest bays with radial gates and 64 under sluices with vertical gates
	Maximum discharge capacity	: 4595 m^3/sec in each crest bay and 465.25 m^3/sec in each undersluice

9 Rana pratap sagar dam

Location	:	51 km south of Kota,Rajasthan
Purpose	:	Irrigation and hydropower
River	:	Chambal
Spillway type	:	Ogee
Type and number of gates	:	Verticaal lift 17 Nos
Maximum discharge capacity	:	18408 m^3/sec

10 Mettur(Stanley)dam

Location	:	Near Salrm,Tamil nadu
Purpose	:	Irrigation and hydropower
River	:	Cauvery
Spillway type	:	Saddle suplus escape
Type and number of gates	:	Verticaal lift 16 Nos of size 18.36x6.10m
Maximum discharge capacity	:	12914 m^3/sec

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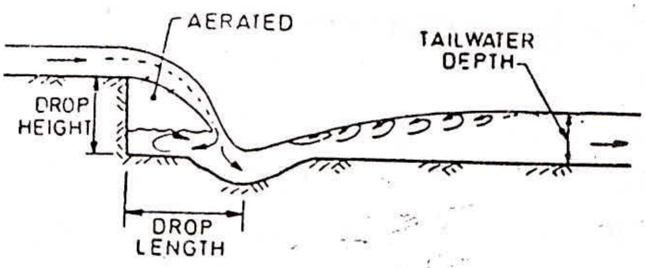


Fig. 1 Free overfall spillway

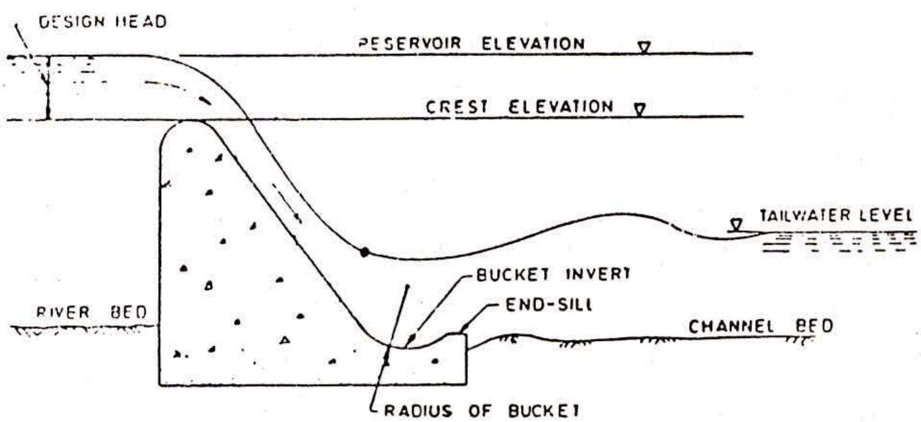


Fig. 2 Ogee shaped spillway

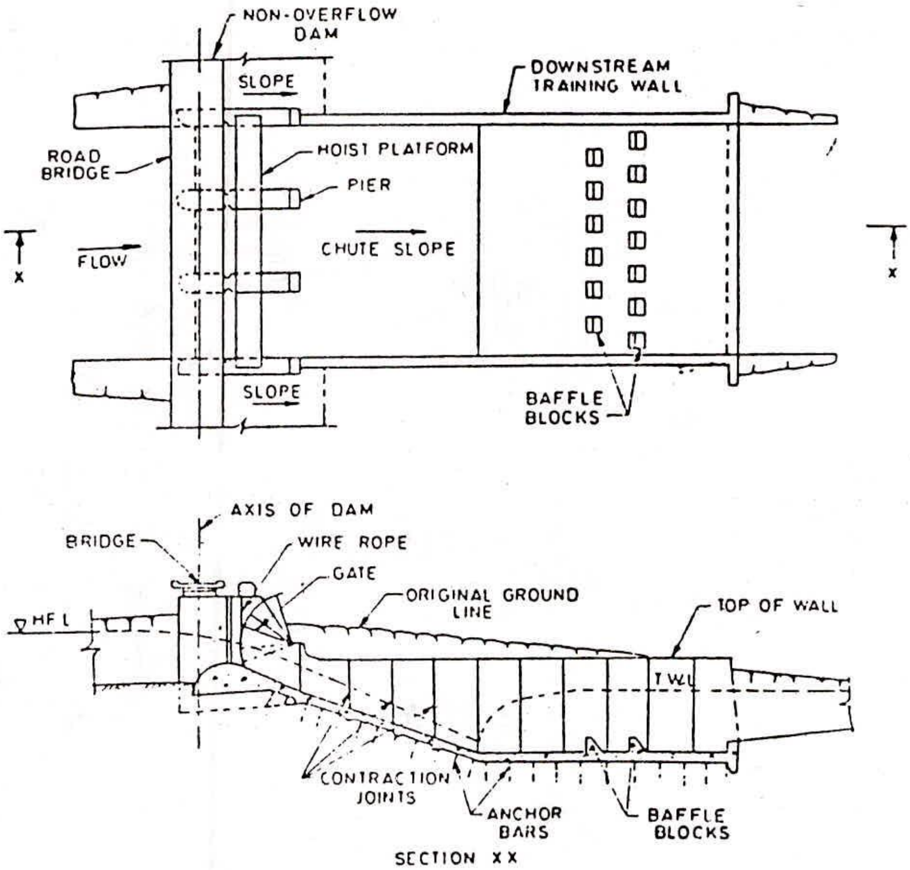


Fig. 3 Chute Spillway

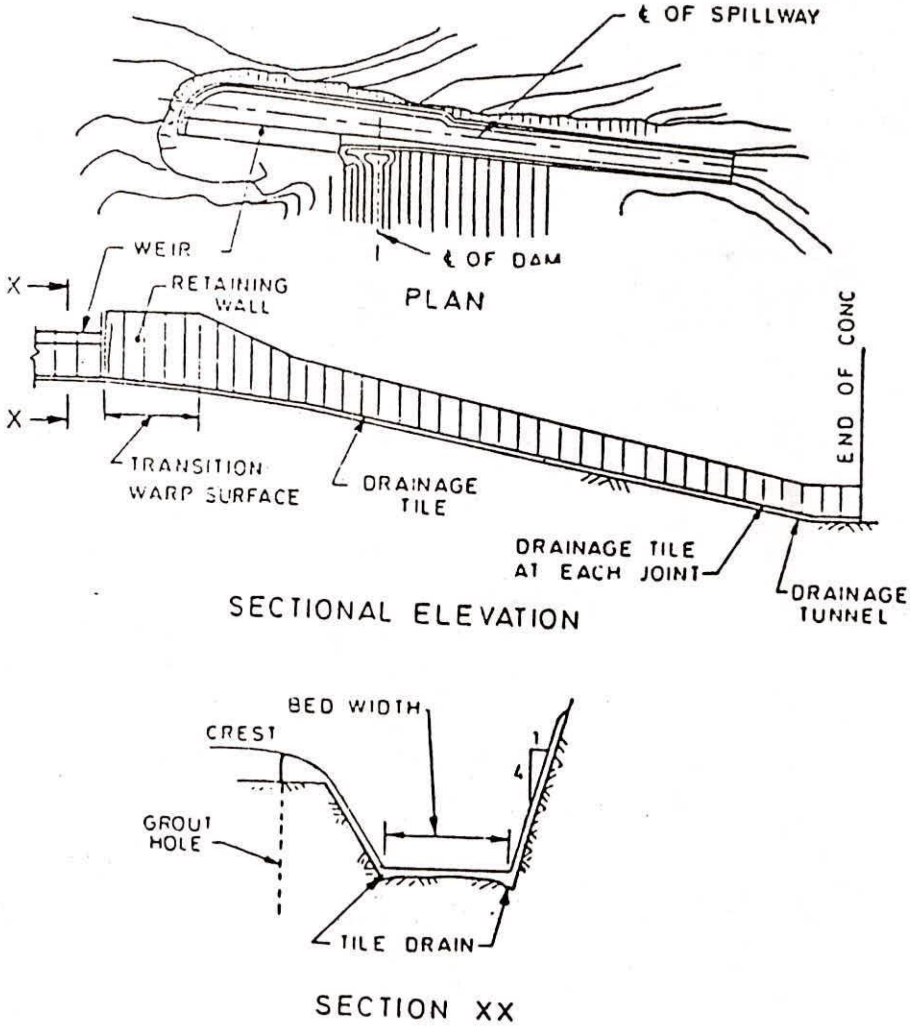


Fig. 4 Side channel spillway

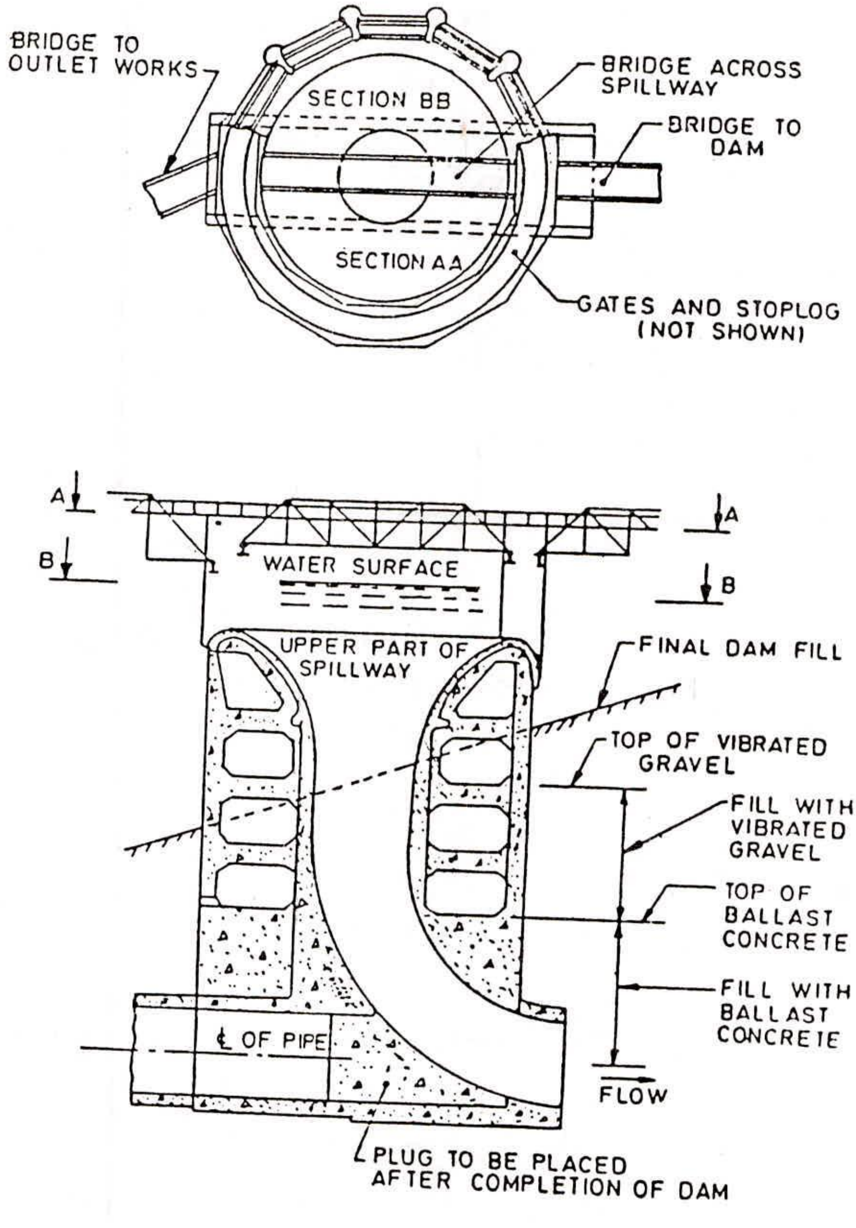


Fig. 5 Morning glory spillway

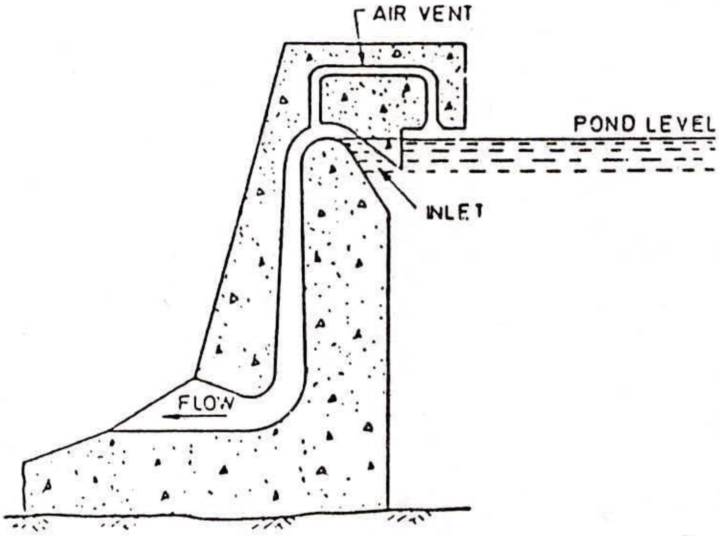


Fig. 6 Siphon spillway

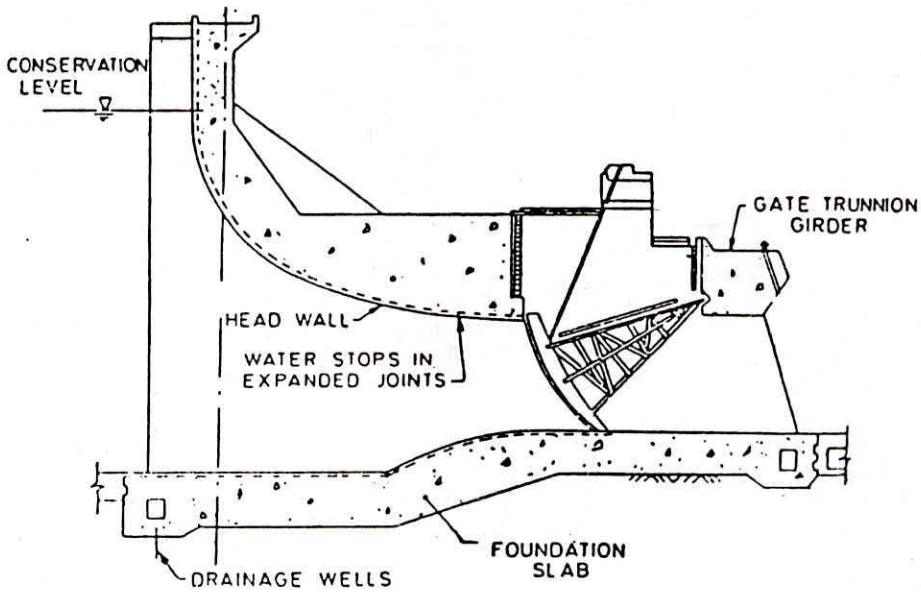


Fig. 7 Sluice spillway

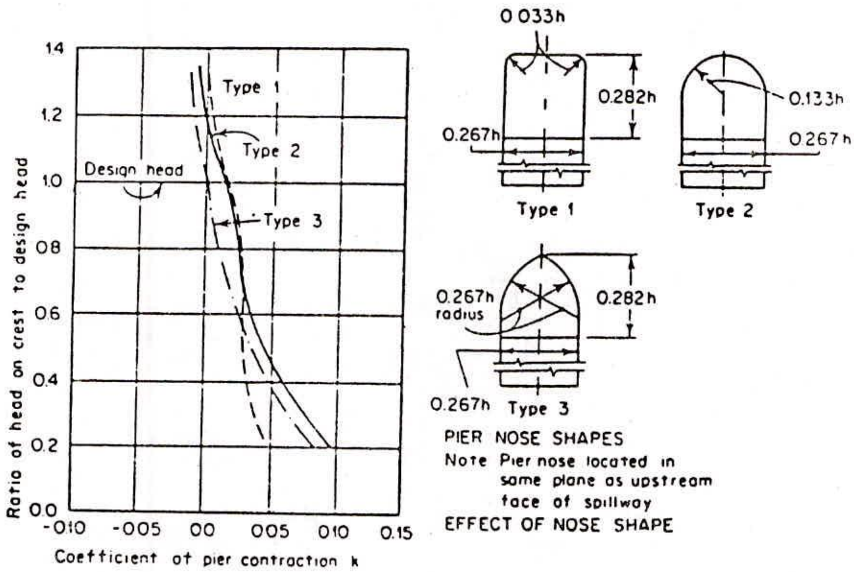


Fig. 8 Coefficient of pier contraction

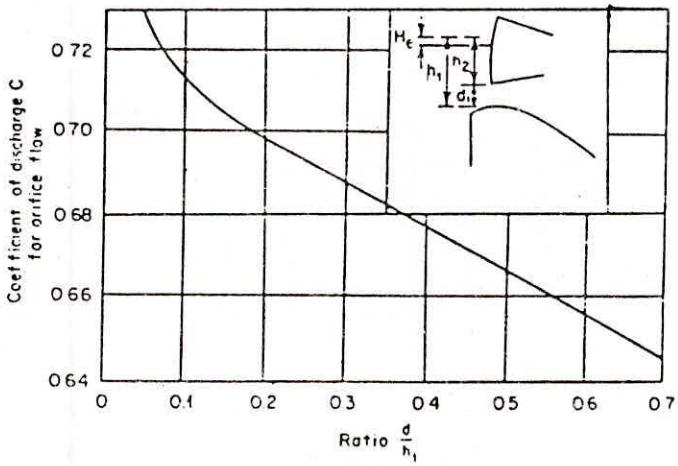


Fig. 9 Discharge coefficients of orifice discharge

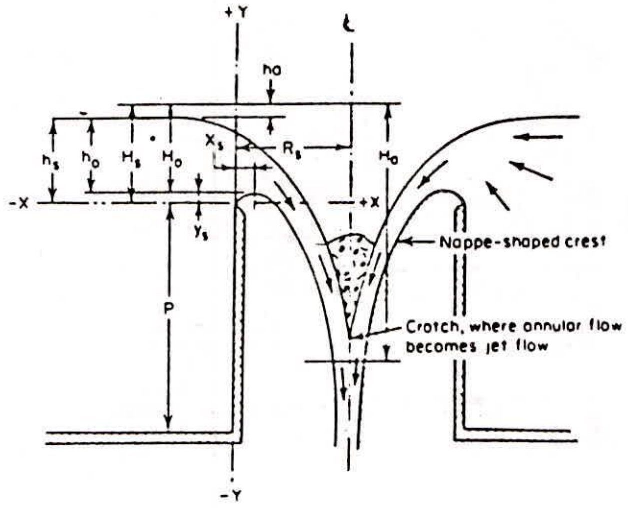


Fig. 10 Elements of nappe shaped profile for circular weir

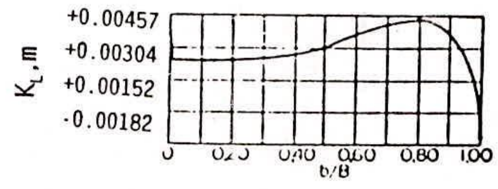


Fig. 11 Relation between b/B and K_L

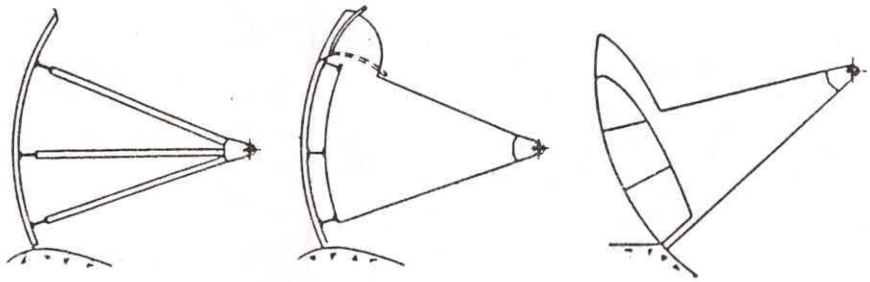


Fig. 12 Types of Tainter gates

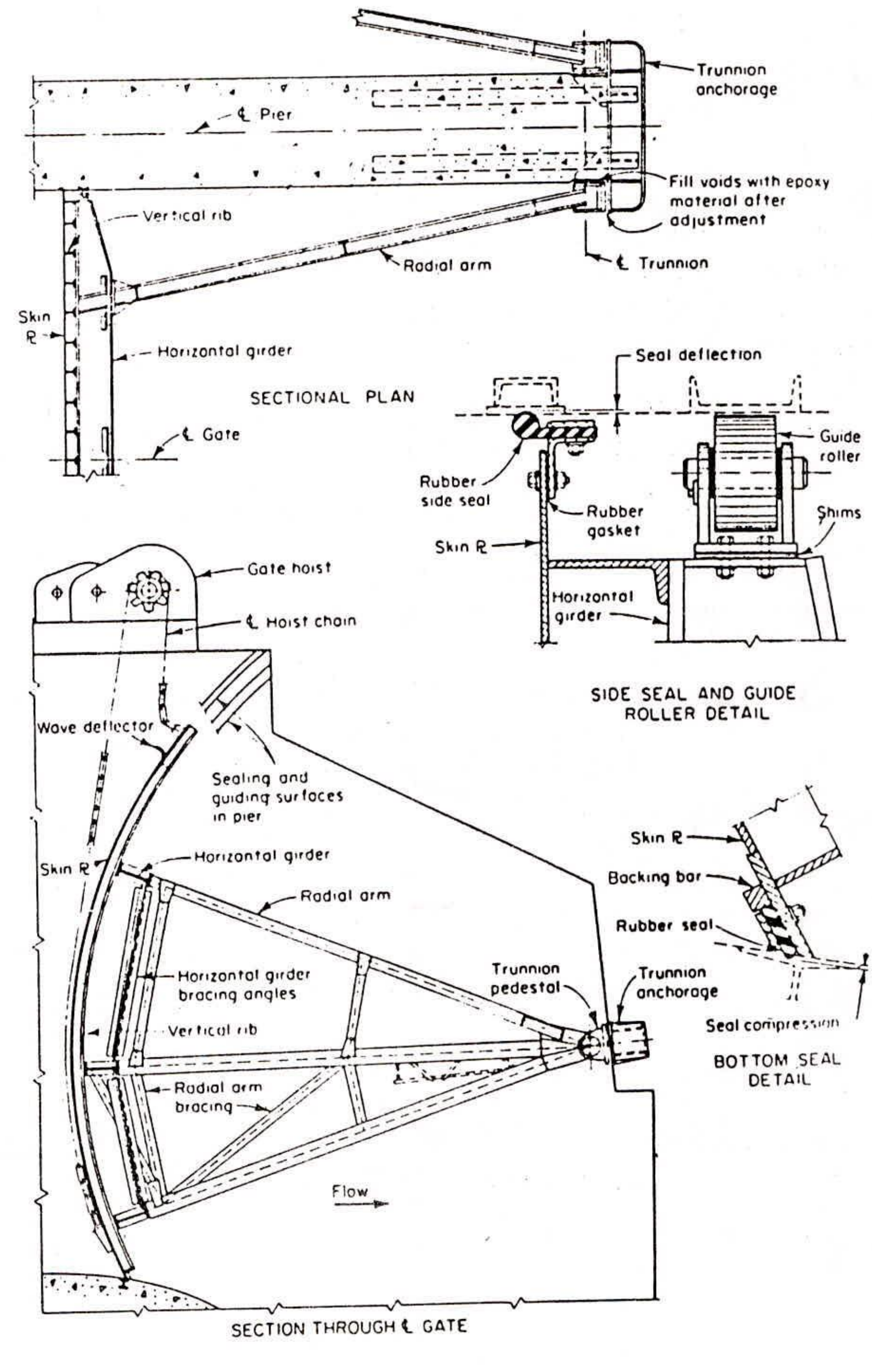


Fig. 13 Details of a conventional Tainter gates

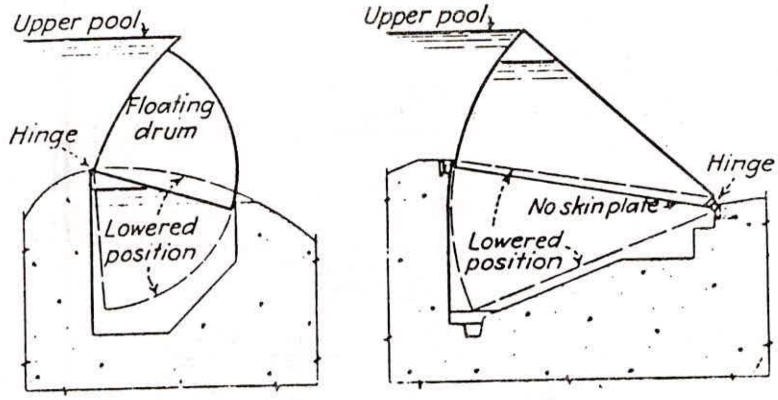


Fig. 14 Drum gates

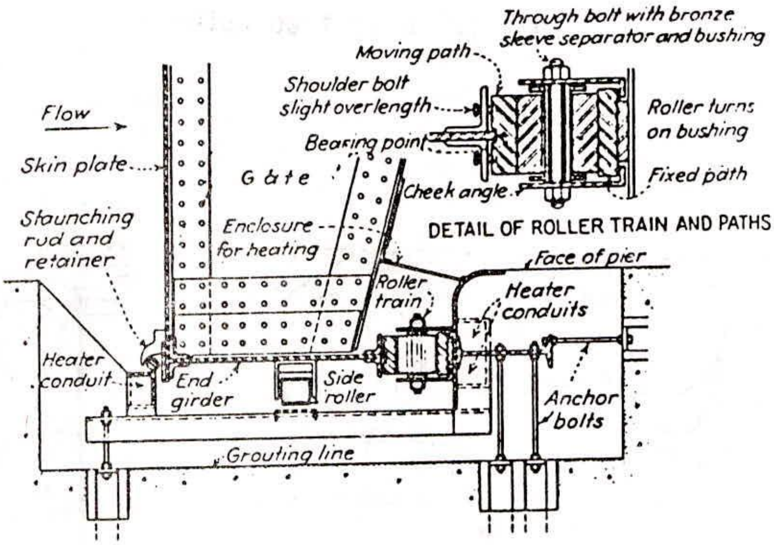


Fig. 15 End section of a stoney gate

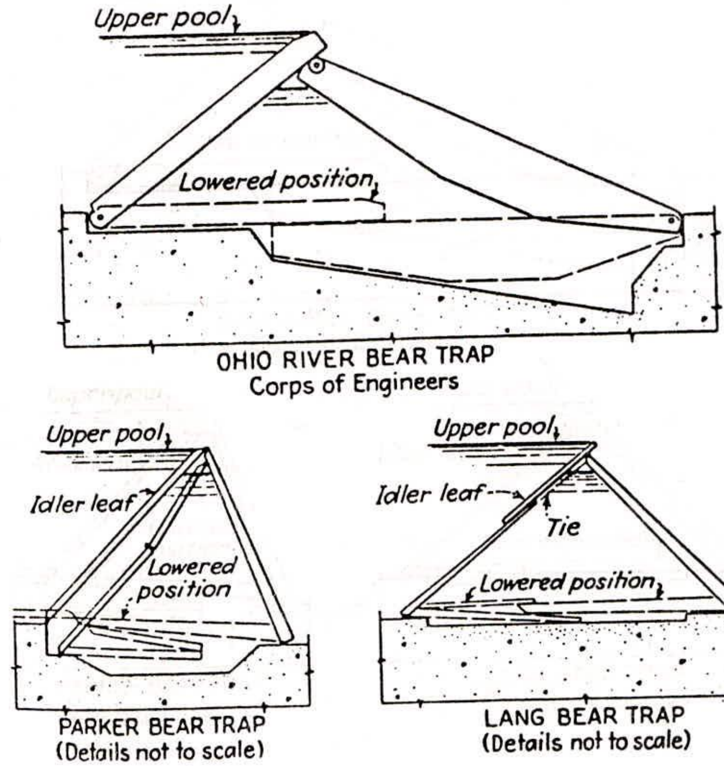


Fig. 16 Bear trap gates

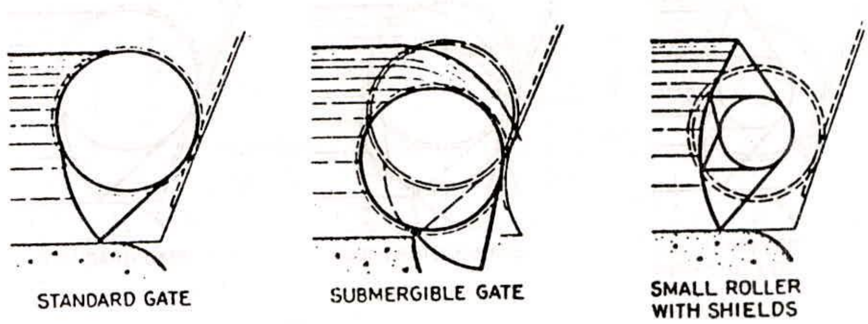


Fig. 17 Types of rolling gates

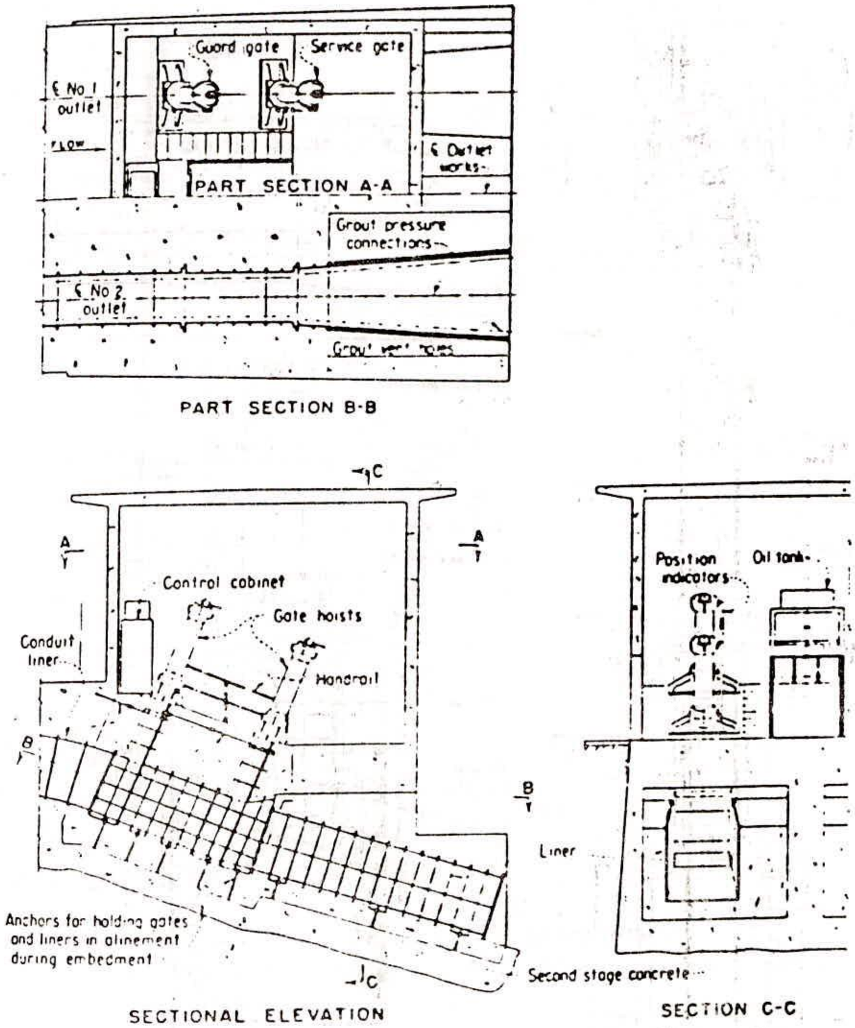


Fig. 18 Typical tandem slide gate installation

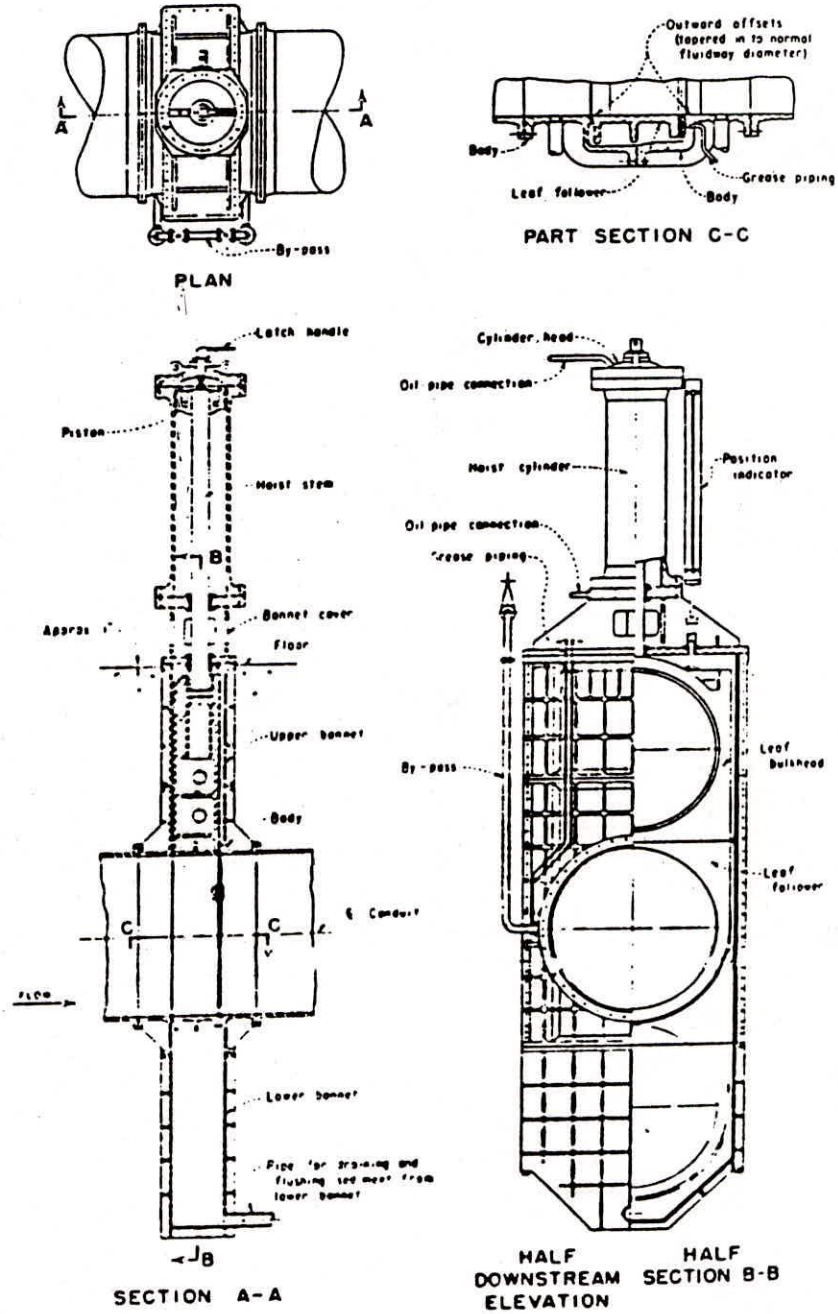


Fig. 19 General assembly and details of ring follower gate

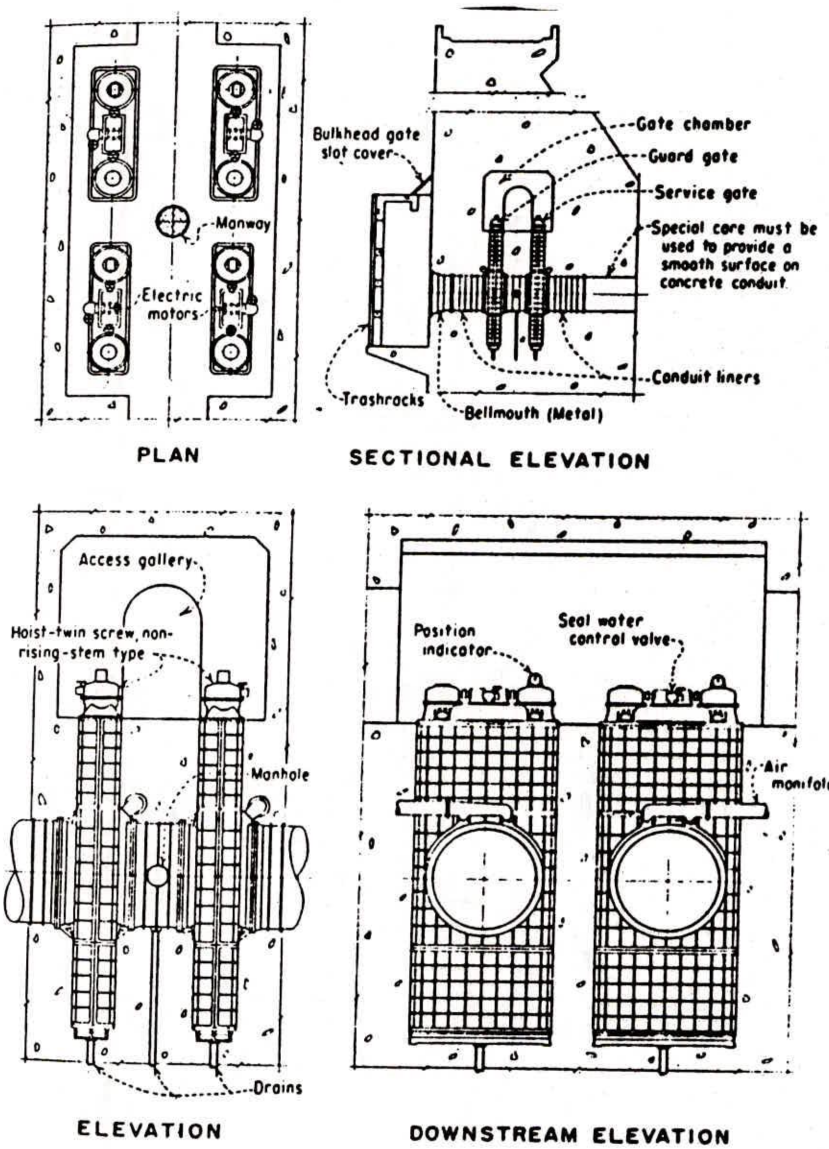


Fig. 20 Ring seal gate

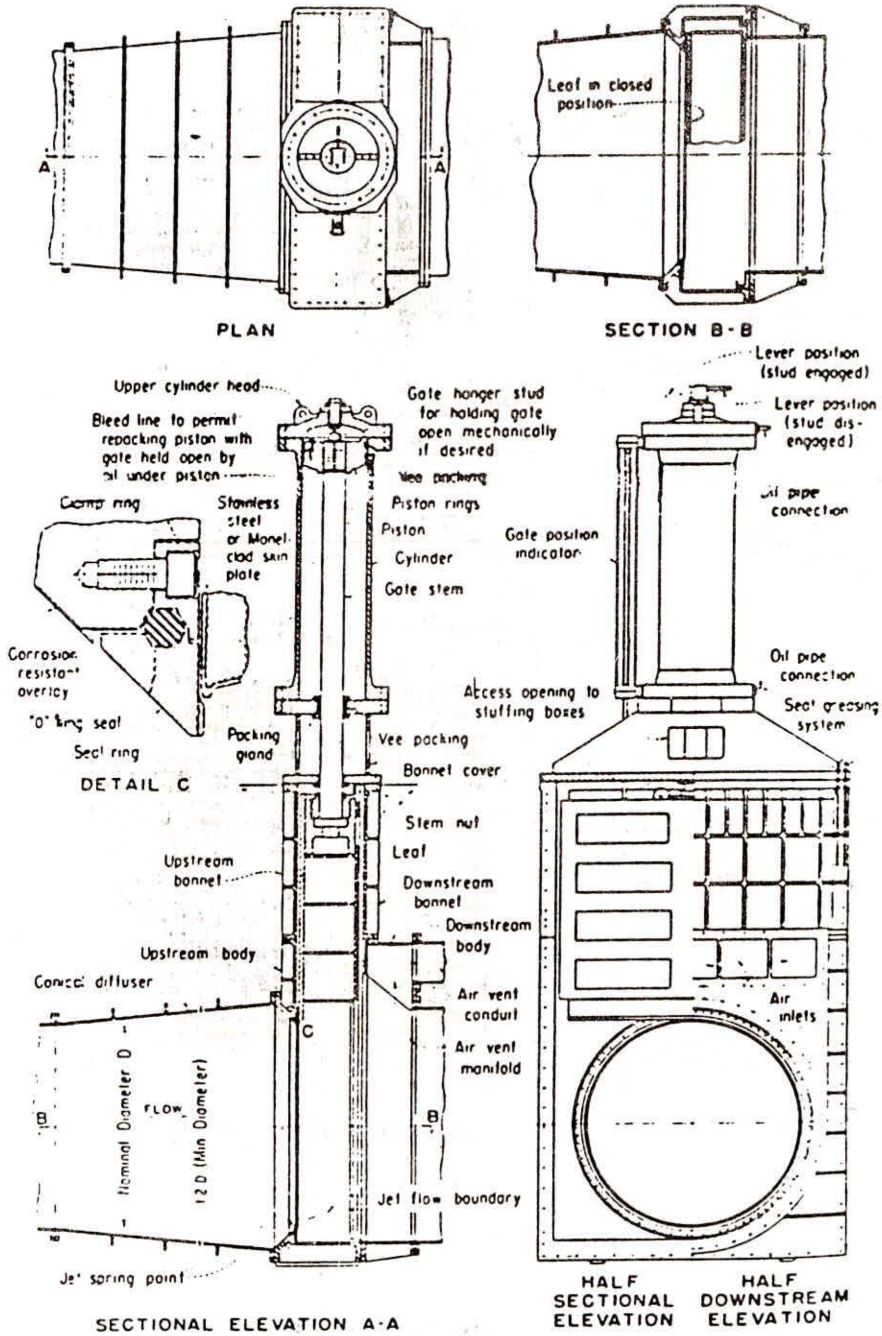


Fig. 21 Jet flow gate

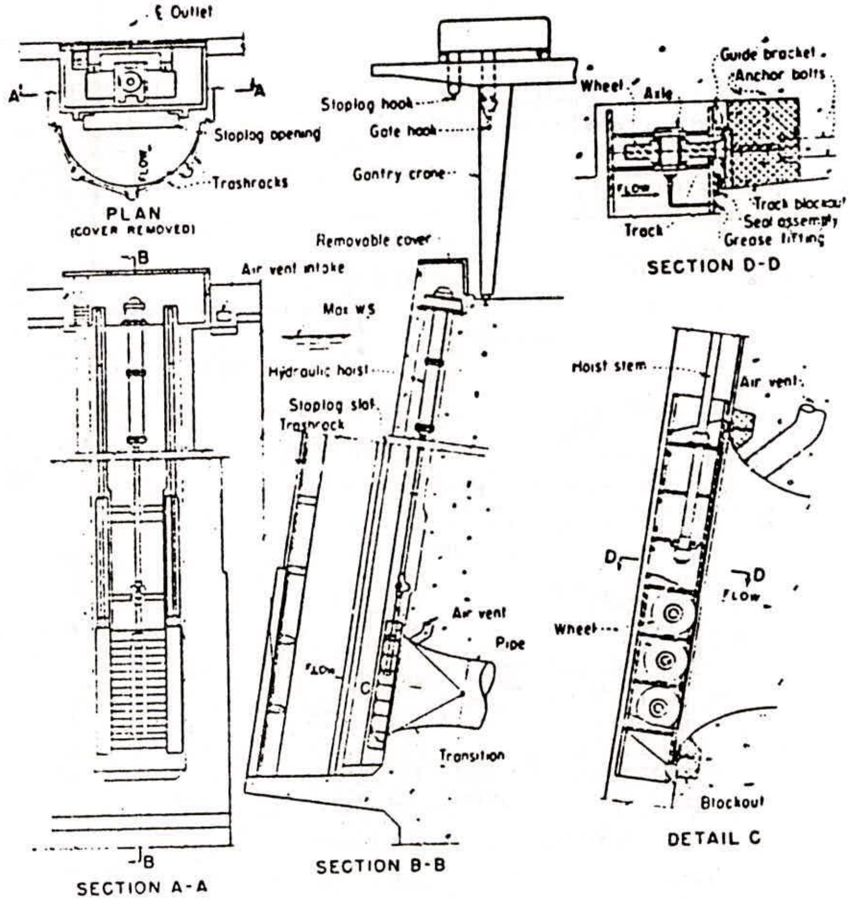


Fig. 22 Wheel mounted gate

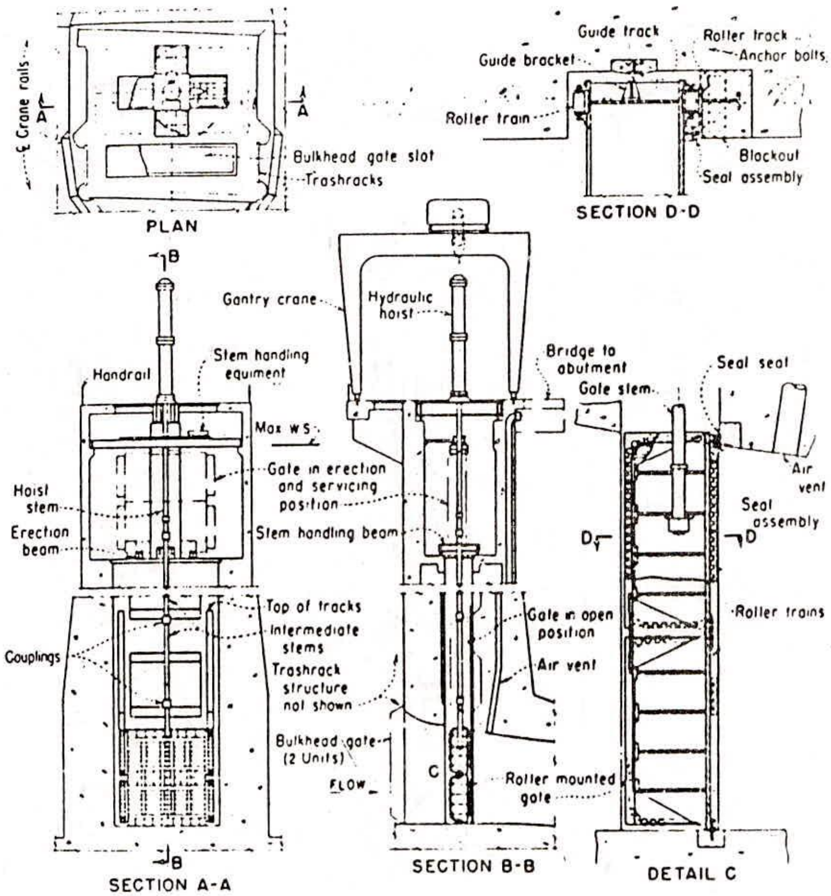


Fig. 23 Roller mounted gate

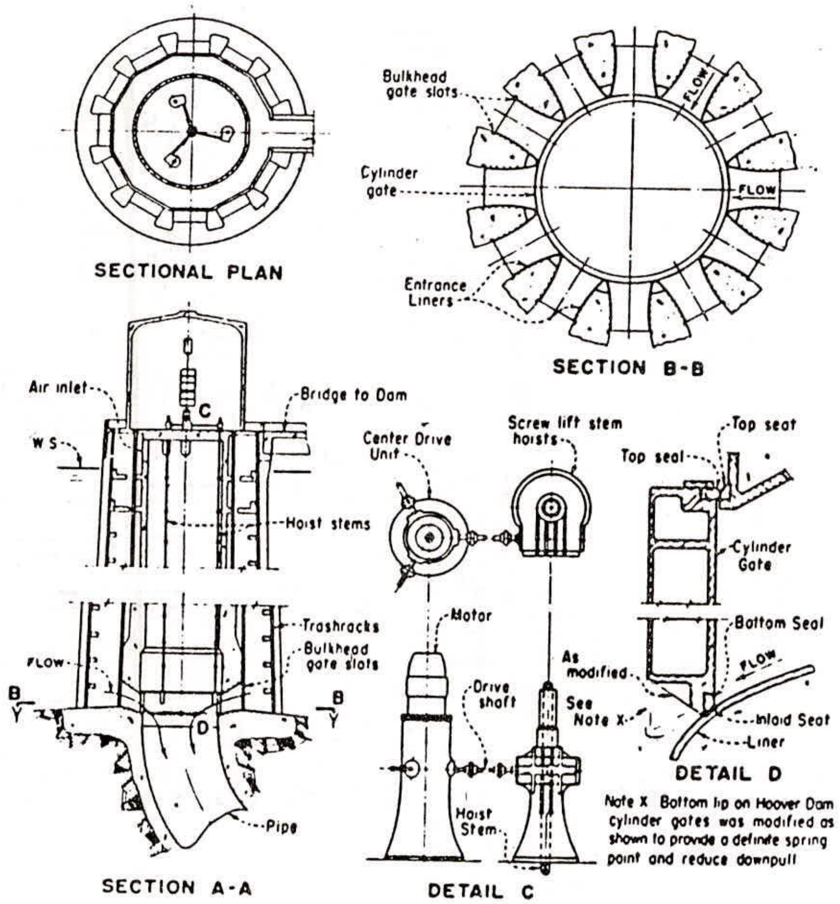


Fig. 24 Cylinder gate

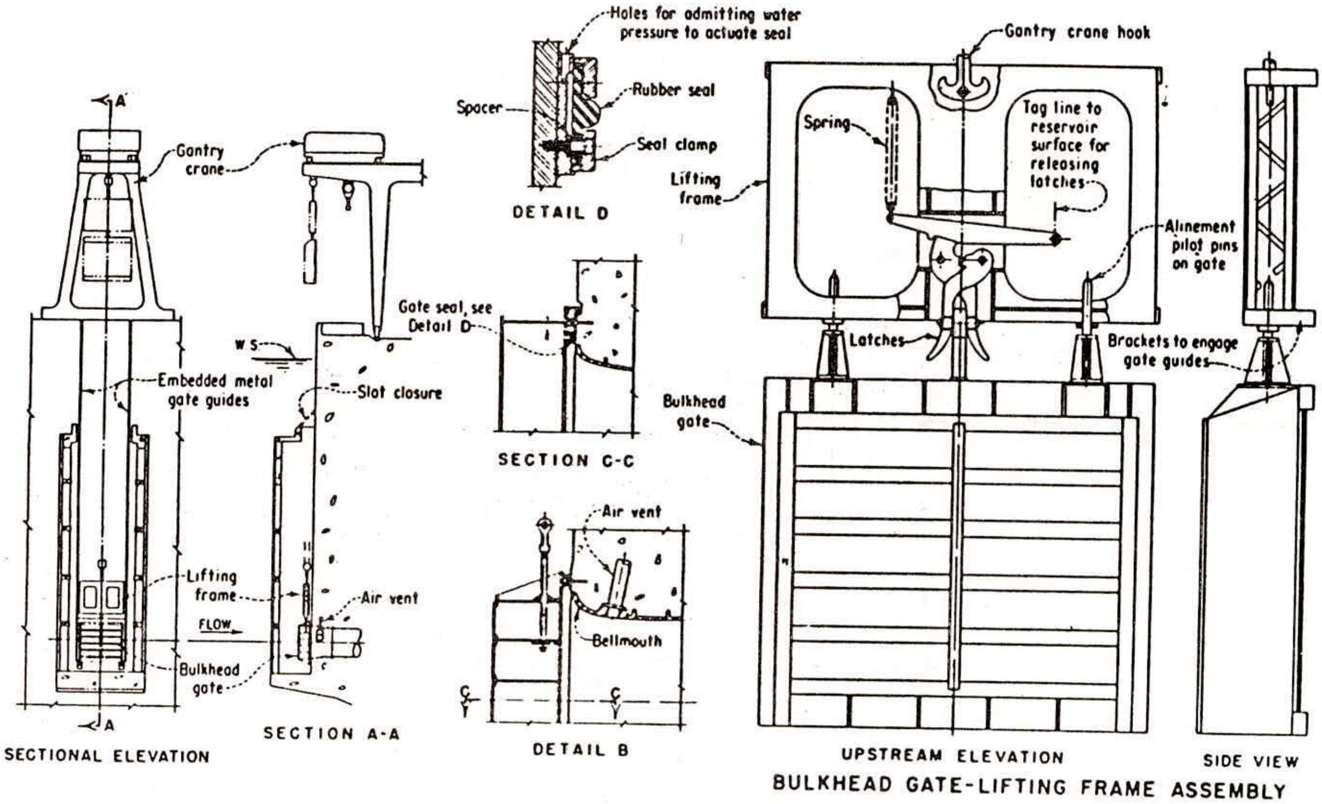


Fig. 25 Bulk head gate

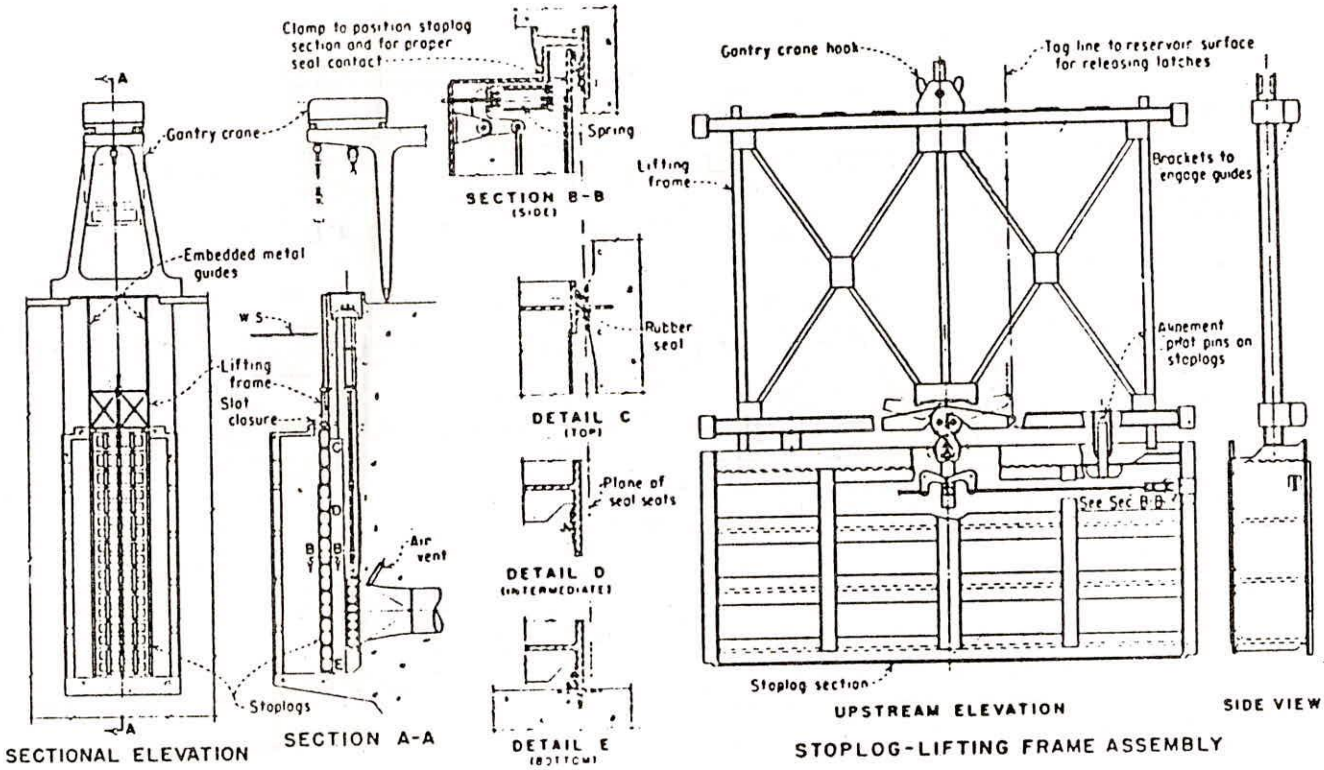
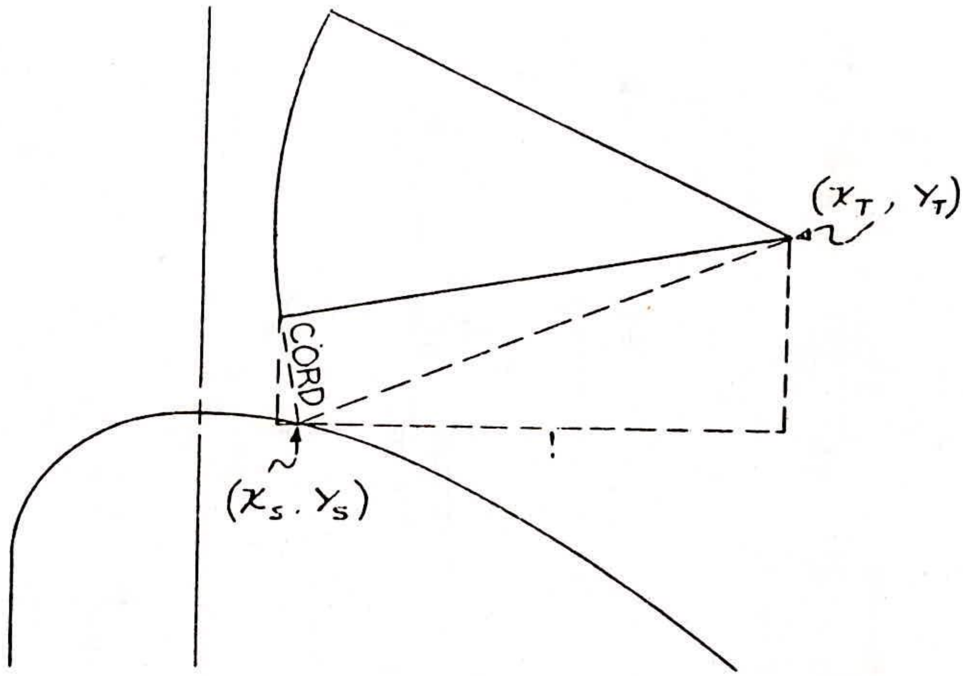


Fig. 26 Stop log gate



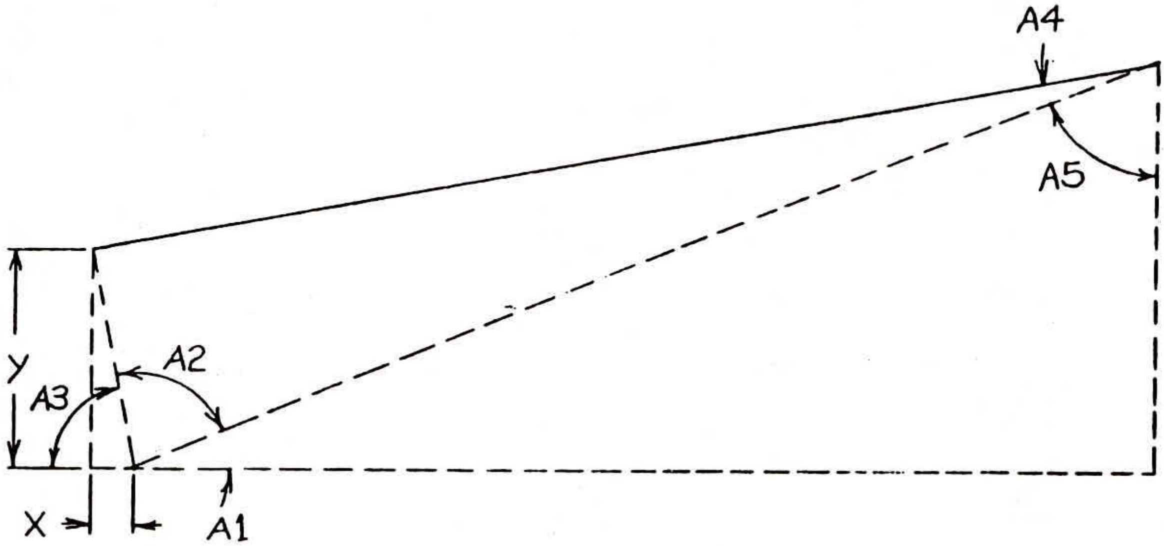


Fig. 27 . Variables used in computer program

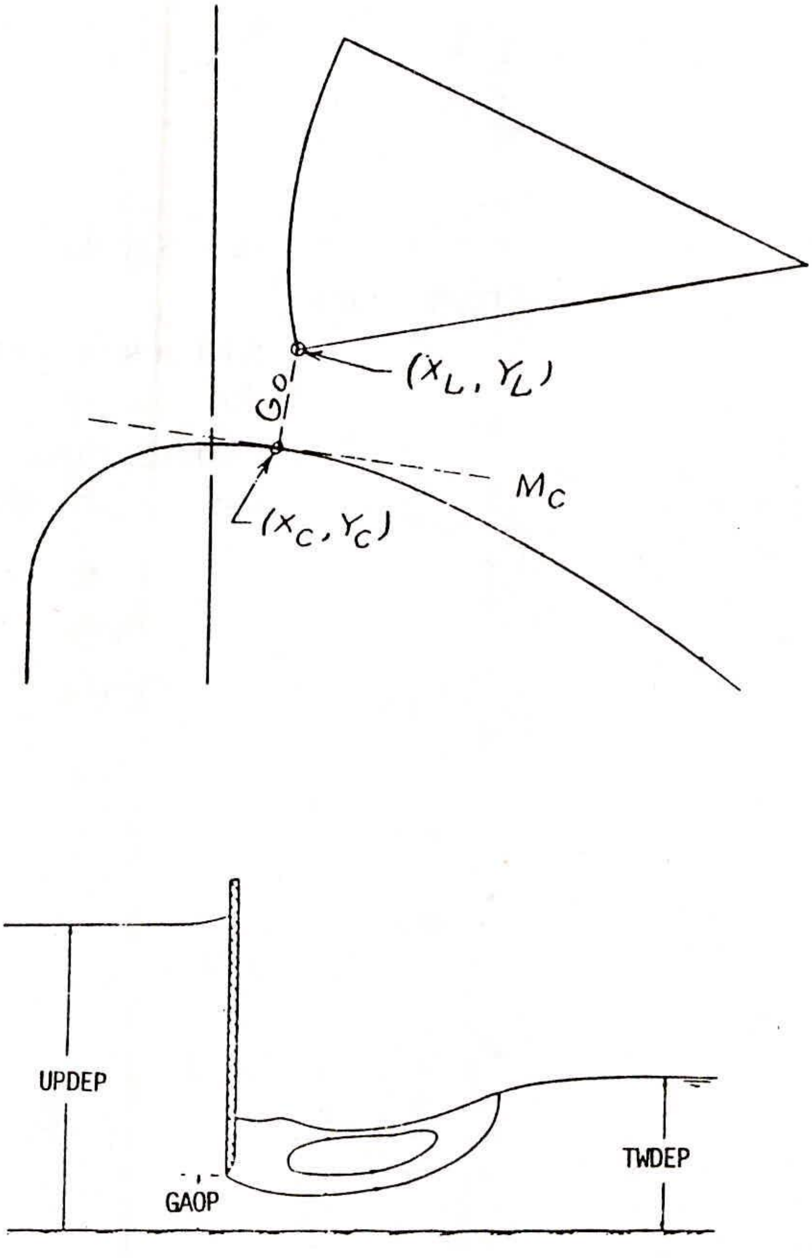


Fig. 28 Variables used in computer program

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