MANTECH Publications

Journal of Water Resource Engineering & Pollution Studies

Volume 7, Issue 2, May- August, 2022

Hydrodynamic Forces on High Head Gate

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Abstract

The project is envisaged as a storage scheme. The Hydro Electric Project (1000 MW) consists of 167m High Concrete Face Rock fill Dam. Two head race tunnels to the power house are of horse shoe/circular shape with diameter of 7.2 m and length of about 9.6 km each. The underground power house consists of 4 units of 250 MW each. The turbine is of Vertical Francis type. The 4 numbers of tail race channels are of horse shoe shape of diameter 5.5 m and 125 m in length. When vertical lift gates are used for controlling flow in closed conduits a hydrodynamic force is imposed on it by the flow. When high velocity flow occurs at the bottom of a gate it causes considerable reduction in pressure at the bottom partly due to change of potential energy in to kinetic energy and partly due to change in the direction of the flow. With the pressure acting on the top of the gate remaining near about constant, the gate resulting in resultant force acting in the downward direction, which is termed as "hydrodynamic down pull force". If the resultant factors influencing the design of the gate and its hoist equipment. Lesser the down pull, smaller, would be the hoist capacity, resulting in reduced cost. In this thesis an attempt is made to calculated hydrodynamic forces analytically further this calculation are checked with the models studies.

These are the objective which is achieved in this thesis:

Estimate the hydraulic down pull and uplift forces on gates.

Analytical calculation was calculated for the following gates:

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Case.1

1. *Radial gate assembly=-11098tonnes*
2. *Tunnel spillway bulkhead gate=128tonnes*

Case.2

1. *Power tunnel bulkhead gate=410tonnes*
2. *Power intake service gate = 4464tonnes*

These are the result of analytical calculation of high head gate.

Model studies of these gates will be done in the hydraulic laboratory.

Keywords: *Hydrodynamic forces, down pull forces, uplift forces*

INTRODUCTION

Water resources projects are constructed for supply of water for irrigation, power and drinking purpose etc. or for flood disposal. The main storage of water is created by constructing a suitable type of dam and water is conveyed to the downstream region by means of a suitable control system or through an opening kept in the body of the dam, with suitable control devices. It is of utmost importance that adequate and timely supply of water for the above purpose is released through the dam to meet the end requirement. Therefore, success of any water resources project would largely depend on how efficient the various gate are. The construction of hydrodynamic gates was closely related with the development of irrigation, water supply and river navigation system. In the early days of hydrodynamic engineering, water was backed up by small dams and conveyed to side irrigation canals. The excess water discharged over the dam. As a natural evolution, movable dam were built. These movable dams could be removed from their normal position to provide passage for excess water, thus permitting greater safety and flexibility in the operation of hydraulic work.

BODY OF THE PAPER

Hydrodynamic forces on gate

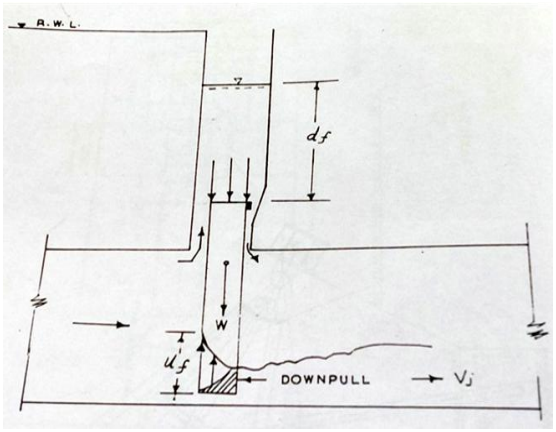


Fig 1: Hydrodynamic forces on gates

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Basic equation

P = W+A (df – uf) γ + F Where,

P = Hydraulic and gravity / tones

W= self weight of gate, tones

A = Cross sectional area of gate, sqm

df = Avg. down thrust per unit area on top of gate , m of water

uf= Avg. up thrust per unit area on bottom of gate, m of water

γ= specific weight of water= 1 tonne/m3

F = Frictional forces, tone

Submerged Gate

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

Upstream water trust

W =½γ B (H2-h1 2) And

$$e = \left(\frac{H-h1}{3}\right)\left(\frac{H+2h1}{H+h1}\right)$$

Downstream water thrust

WJ=½γB hJ 2

Where hJis the minimum depth of the tail water.

The centroid of WJ is calculated by

eJ=1/3hJ

Since the pressure diagram has a triangular shape.

The result water trust is:

W = WM WJ=½γ B (H^2-h1 ^{2}) - ½γ B hJ ^{2}

=½ γ B (H^2- h1 ^{2} – hJ^2)

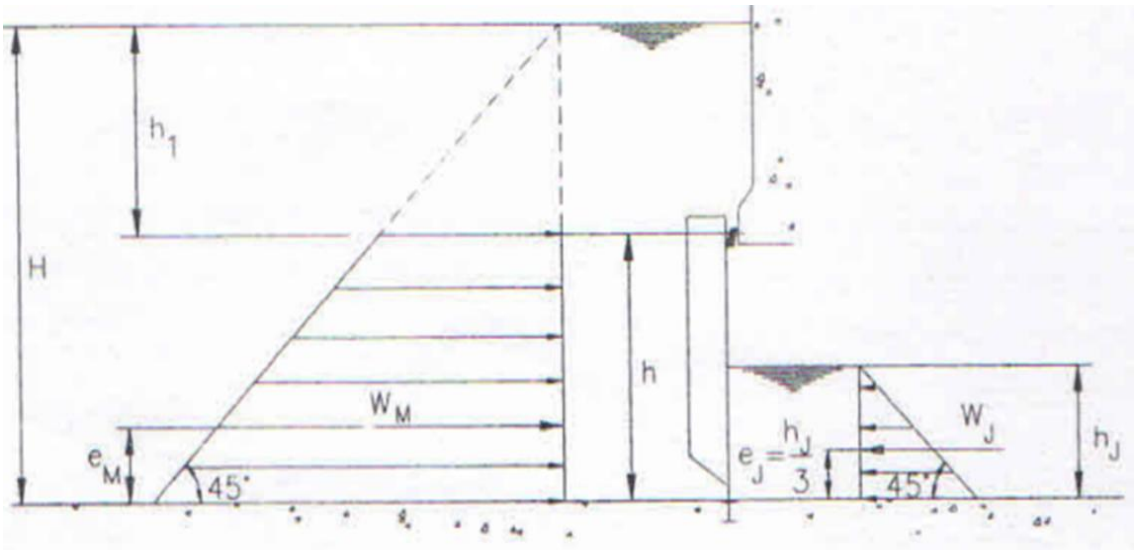


Fig 2: For submerged gates, with both sides of the skin plate in contact with water

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Radial Gates

The line of action of the water thrust on radial gates passes through the center of curvature of the skin plate. For ease of calculation the resultant water thrust is determined from its horizontal and vertical components. The formulae presented below are generic and can be indistinctly used for weir and submerged segment gates, sector gates and flap gates with radial skin plate.

The horizontal component of the water thrust is: W=γBh (H-h/2)

The vertical component is:

Wv=γBR(Dm(cosαs-cosαi)+

$$\frac{R(\alpha i-\alpha s)}{2}+\frac{R(\sin \alpha s*\cos\alpha s-\sin\alpha i*\cos\alpha i)}{2}$$

Where

γ-specific weight of water - 9.81 kNm

B-side seal span

R=skin plate radius (measured on the wet surface)

H=maximum headwater on sill

h=gate ceiling height

Dm- difference between the elevations of the water level and the center of curvature of the skin plate

αs=arc sin Ds/R

αi=arc sin Di/R

D = difference between the elevations of the center of curvature of the skin plate and the top seal (for submerged gates) or the water level (in case of weir gates) D. - difference between the elevations of the center of curvature of the skin plate and the sill.

NOTES

a) Dm, Ds, and Di refer to difference of elevations and may assume positive or negative sign,
b) depending on the gate arrangement;
c) The angles αs and αi are taken in radians and can also assume a positive or negative The direction of the vertical component is given by its sign:

- Positive: upward
- Negative: downward.

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

$$W=\sqrt{Wh^2-Wv^2}$$

$$B = \arctan W_v / W_h$$

Formulae for the Prediction of Down pull Gate down pull is normally determined using an equation such as:

Dp=γKAH (in kN)

Where

y =specific weight of water, in kNm

K-down pulls coeffient

A-cross-sectional area of gate, in m2

H=operating head on the gate bottom, in meters.

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The gate bottom shape is shown in the figure, next to the corresponding chart. The main Features of these antes are in Table 8.1.

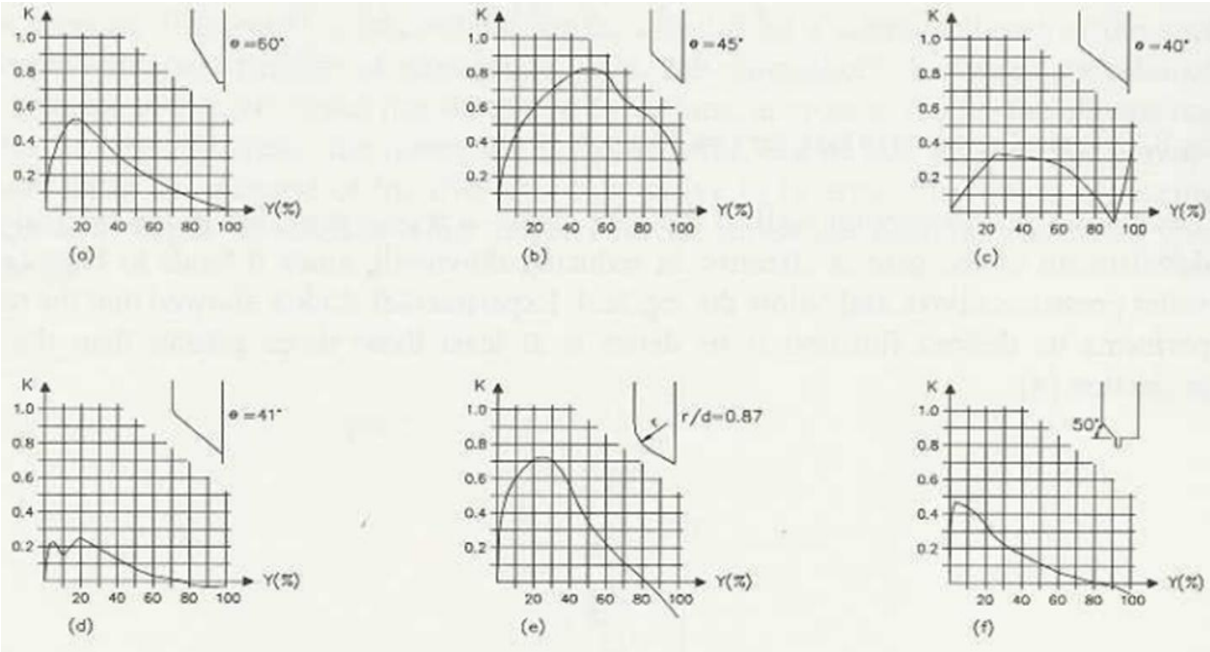


Fig.3: Typal variation of the dewell efficient k with o pening Y for various projects (a Fumas; (bFisti (c) lumbar diversione di lumbara Intake gatele) So Simon Marimbondo

MODEL 1: TUNNEL SPILLWAY RADIAL GATE

Radial Gate Assembly

1. Sill elevation = 1580m
2. FRL = 1700m
3. MWL =1703m
4. Trunnion level = 1589.9m
5. Width =6.2m
6. Height = 7m
7. Radius =15m
8. Total height of FRL = 120m
9. Total height of MWL =123m
10. Total height of trunnion=9.8m

- Calculation
- Hydrostatics load on gate- Horizontal components of water thrust

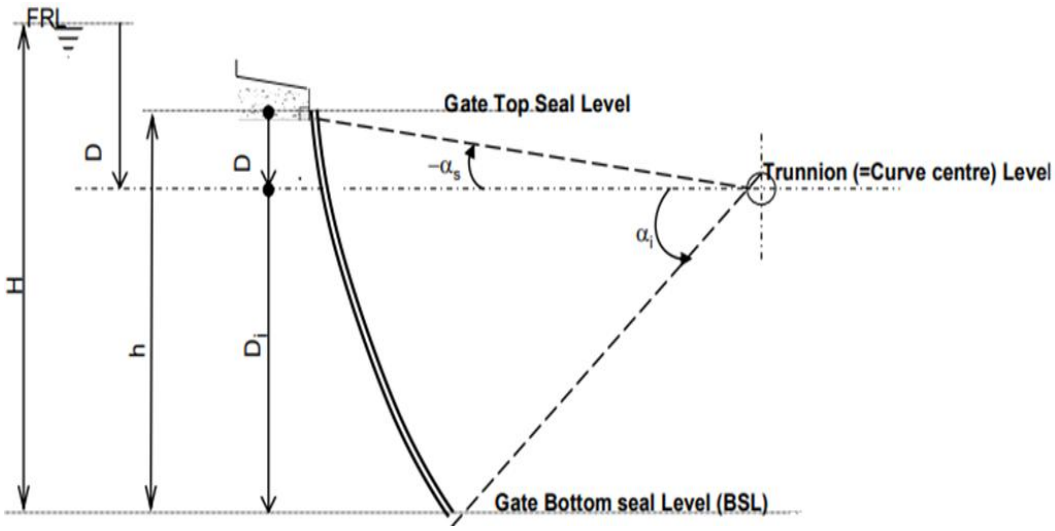
It is given by

$Wh = \gamma.B.h.(H-h/2)$

$= 1*6.5*7.96*(123.06-7.96/2)$

$= 6006$ tonne

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γ= specific weight of water= 1 tonne/m^3

B=side seal span

R=skin plate radius

H= maximum headwater on seal

h = gate ceiling height

Dm = difference between the elevation of the water level and the centre of curvature of the skin plate.

αm = arc sin Ds/R

αi= arc sin Di/R

Ds=difference between the elevation of the centre of curvature of the skin plate and the top seal or the water level.

Di= difference between the elevation of the centre of curvature of the skin plate and the sill.

Di , $EL_{trunnion}$ - $EL_{gatebot}$ = 1589.88-1579.94= 9.940 m

Dm , $EL_{water\ level}$ - $EL_{trunnion}$ = 123.06-9.94= 113.120 m

Ds , $EL_{trunnion}$ - $EL_{gatetop}$ = 9.94-7.96= 1.980 m

(Negative value=>trunnion is below)

αs = arc sinDs/R

= arc sin1.98/15

= 0.13rad

Sinαs =0.132

Cosαs =0.99125

αi=arc sinDi/R

= arc sin 9.94/15

= 0.7244rad

Sinαi=0.66

Cosαi=0.75

- Vertical component is:

Wv=γBR(Dm(cosαs-cosαi)+

$$\frac{R(\alpha i-\alpha s)}{2}+\frac{R(\sin \alpha s*\cos\alpha s-\sin\alpha i*\cos\alpha i)}{2})$$

=1x6.5x15(110.12x(cos0.13)-cos(0.7244)+

$$\frac{12(0.7244-0.13)}{2}+\frac{15(\sin\ \ 0.13*\cos0.13-\sin 0.7244*\cos 0.7244)}{2}$$

= 2767.5 tonne

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Magnitude of W $=\sqrt{Wh^2 - Wv^2}$

$=\sqrt{6006^2 - 2767.5^2}$

= 6612.9 tonne

- Direction of W(β) = arc tan (Wv/Wh)
  = arc tan (2767.5/6006)
  = 24.74 degree
- Down pull coefficient (k) = -0.05
- Weight of gate(Wg) =208.897 tonne

Down pull force =γ*k*A*H

= 1x-0.05x43.4x120.06

=-260.53

Hydrodynamic forces (P)

=Wg+A(df-uF)*γ+F

= 208.897+43.4*-260.53

=-11098 tonne

Table 1 Calculation of service gate :Radial

FRL elevation		M		1700	1620	1587.9	1587.6	1586.6	1585.6	1584.6	1583.6	1582.6	1581.6	1579.94
sill elevation		M		1579.94	1579.94	1579.94	1579.94	1579.94	1579.94	1579.94	1579.94	1579.94	1579.94	1579.94
MWL elevation		M		1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703
width between side seal	B	M		6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
gate loaded height	H	M		7.96	7.96	7.96	7.66	6.66	5.66	4.66	3.66	2.66	1.66	0
Maximun water level	H	M		120.06	40.06	7.96	7.66	6.66	5.66	4.66	3.66	2.66	1.66	0
head at top load				1121	32.1	0	0	0	0	0	0	0	0	0
specific density		Tone		1	1	1	1	1	1	1	1	1	1	1
Horizontal component	Wh	Tone	γBh(H-h/2)	6006.0	1866.8	205.9	190.7	144.2	104.1	70.6	43.5	23.0	9.0	0.0
radius	R	M		15	15	15	15	15	15	15	15	15	15	15
area of gate		Sqm	b*h	43.4	43.4	43.4	43.4	43.4	43.4	43.4	43.4	43.4	43.4	43.4
Top seal or WL(elevation)		M		1587	1587	1587	1587	1587	1587	1587	1587	1587	1587	1587
elevation of trunnion		M		1589.88	1589.88	1589.88	1589.88	1589.88	1589.88	1589.88	1589.88	1589.88	1589.88	1589.88
Difference of elevation of WL and trunnion elevation	Dm	M		110.12	30.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Difference between trunnion and elevation of gatebot	Ds	M		1.98	1.98	1.98	2.28	3.28	4.28	5.28	6.28	7.28	8.28	9.94
Difference between trunnion and elevation of gatebot	Di	M		9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94
αs		Rad	αs=arc sinDs/R	0.13	0.13	0.13	0.15	0.22	0.29	0.36	0.43	0.51	0.58	0.72
α			sinα s	0.132	0.132	0.132	0.152	0.219	0.285	0.352	0.419	0.485	0.552	0.663
α			cosαs	0.99	0.99	0.99	0.98	0.97	0.95	0.93	0.90	0.87	0.83	0.74
αi		Rad	αi=arc sinDi/R	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
			Sinai	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
			Cosai	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
vertical component	Wv	Tone	γBR(Dm(cosas-cosai)+R(ai-as)/2+(sin as*cosas-sinaicosai)/2)	2767.5	877.3	165.7	165.1	161.6	155.2	144.7	128.9	106.5	75.8	0.0
magnitude of W			root(Wh^2-Wv^2)	6612.9	2062.7	264.3	252.2	216.6	186.9	161.0	136.1	109.0	76.3	0.0
direction of W		Degree	arc tan (Wv/Wh)	24.740	25.172	38.817	40.880	48.269	56.141	63.997	71.343	77.820	83.259	#DIV/0!
specific weight of water		tonne/cum		1	1	1	1	1	1	1	1	1	1	1
weight of gate		Tone		208.8	208.8	208.8	208.8	208.8	208.8	208.8	208.8	208.8	208.8	208.8
Down pull coefficient	K			-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Down pull force			γ*k*a*H	-260.53	-86.93	-17.2	-16.6	-14.45	-12.28	-10.11	-7.9	-5.7	-3.6	0
Hydrodyanamic forces	P	Tone	Wg+A(df-uf)γ*+F	-11098	-3564	-541	-513	-418	-324	-230	-136	-42	53	209

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Tunnel spillway bulkhead gate

FRL(H) =120m

MWL =123m

Size of gate =6.2x7m

c/c of side seal (B) =6.47m

sill to top seal(h) =7.1m

- water thrust is given by

=γBh(H-h/2)

= 1 x6.47x7.1 (120-7.1/2)

= 5349.36 tonne

Gate weight (Wg) =88tonne

Total frictional forces (F) =5.35tonne

Total net up thrust on gate = 0.79tonne

Specific gravity of water (γ) =1 tonne/m3

Intake Blukhead Gate				
Width of the Gate		M		6.2
c/c of side seal	B	M		6.47
Gate height		M		7
sill to top seal	H	M		7.1
Full reservoir level	H	M		120
Maximun head water	H	M		123
specific density	W	Tone		1
h1		M	H-h	116
Minimun depth of tail water	Hj	M		10.5
water thrust at FRL		tonne/sqm	WBh(H-h/2)	123.2572
MWL at water thrust	Wm	tonne/sqm	WBh(H-h/2)	126.43
Em		M	((H-h1)/3)*((H+2*h1/(H+h1)	3.47
Downstream water thrust Wj(KN)	Wj	tonne/sqm	0.5*γ*B*hj²	8.22
Ej		M	hj/3	3.5
Resultant water thrust	W	tonne/sqm	Wm-Wj	118.21
Total net up thrust on gate	df-uf	Tone		0.79
Weight of gate	Wg	Tone		88
Total frictional forces	F	Tone		5.35
Area	A	Sqm	B*h	43.4
Hydrodyanamic forces	P	Tone	Wg+A(df-uf)γ*+F	128

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CALCULATION

Area of gate (A)= Bxh =43.4m^2

Hydrodynamic force= Wg+A*(Df-Uf)*1+F

=88+43.4*0.79*1+5.35

=128tonne

Power Intake Bulkhead Gate

Sill elevation =1605m

FRL =1700m

MWL =1703m

Gantry crane floor level =1707m

Width = 5.6m

c/c of side seal (B) =5.8m

Height =7.7m

Seal to top seal c/s (h) =7.8m

Total height to FRL (H) =95m

Total height to MWL =98m

Total height of gantry =102m

Gate size = 5.6x7.7m

Water thrust on gates at FRL

=γBh(H-h/2) = 1x5.8x7.8(98-7.8/2)

=4121.4tonne

Water thrust on gates at MWL

= γBh(H-h/2)

=1x5.8x7.8 (98-7.8/2)

=4257.08tonne

Gate weight = 71.24 tonne

Total frictional force =4.8tonne

Total net up thrust on gate= 7.74tonne

Area of gate (A) = 43.12sqm

Hydrodynamic force

= Wg+Ax(df-uf)xγ+F

=71.24+43.12x7.74x1+4.8

=410tonne

Intake bulkhead gate				
Width of the Gate		M		5.6
c/c of side seal	B	M		5.8
Gate height		M		7.7
seal to top seal c/s	H	M		7.8
Full Reservoir levl	H	M		95
Maximun head water	H	M		98
specific density	W	Tone		1
h1		M	H-h	90.3
Minimun depth of tail water	Hj	M		7.2

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Water thrust at FRL	Wm	tonne/sqm	WLh(H-h/2)	4121.36
water thrust at MWL			WLh(H-h/2)	4257.08
		M	((H-h1)/3)*((H+2*h1/(H+h1)	3.80
Weight of gate	Wg	Tone		71.24
Area	A	Sqm	B*h	43.12
total frictional forces	F	Tone		4.8
specific weight of water		tonne/cum		1
net uptrust on gate	df-uf	Tone		7.74
Hydrodyanamic forces	P	Tone	Wg+A(df-uf)γ*+F	410

Power Intake service gate

Gate weight (W) =78.5tonne

Total frictional force (F)= 73.65tonne

Up thrust =100tonne (assume)

Down pull =100tonne (assume)

Area (A) = 45.24sqm

Hydrodynamic force=W+A(uf-df)xγ+F =78.5+45.24x1+73.65=4464tonne

SERVICE GATE				
Width of the Gate		M		5.6
c/c of side seal	L	M		5.8
Gate height		M		7.7
seal to top seal c/s	H	M		7.8
full reservoir level	H	M		95
maximum water level	H	M		98
specific density	W	Tone		1
h1		M	H-h	87.3
Minimum depth of tail	Hj	M		7.2

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water				
water thrust at FRL	Wm	tonne/sqm	WLh(H-h/2)	4121.36
water thrust at MWL		tonne/sqm	WLh(H-h/2)	98.73
eM		M	((H-h1)/3)*((H+2*h1/(H+h1)	3.80
Downstream water thrust Wj(KN)	Wj	tonne/sqm	$0.5*\gamma*B*hj^2$	3.49
Ej		M	hj/3	2.4
Resultant water thrust	W	tonne/sqm	Wm-Wj	95.24
Weight of gate	Wg	Tone		78.5
Area	A	Sqm	B*h	43.12
total frictional force	F	Tone		73.65
upthrust (assume)		Tone		100
down thrust(assume)		Tone		100
Hydrodyanamic forces	P	Tone	Wg+A(df-uf)γ*+F	4464

RESULT

1: Tunnel Spillway Radial Gate

Radial Gate Assembly

Resultant water thrust (W)= 6612.9 tonne

Down pull Force (K) = -260.5 tonne

Hydrodynamic forces (P) =Wg+A(df-uF)xγ+F

= 208.897+43.4*-260.53

=-11098 tonne

Hoist capacity= hydraulic down pull+gate weight+ frictional forces

= -260.53+208.8

= -51.73tonne

Tunnel spillway bulkhead gate

Resultant water thrust (W)= 118.21 tonne

No down pull forces because of balanced condition

Hydrodynamic force =Wg+Ax(df-uf)xγ+F

=88+43.4x0.79x1+5.35

=128tonne

Hoist capacity= hydraulic downpull+gate weight+ frictional forces

= 0+88+5.35

=93.35tonne

2: Power intake bulkhead gate

Resultant water thrust (W)= 6612.9 tonne

No down pull forces because of balanced condition

Hydrodynamic force= Wg+Ax(df-uf)xγ+F

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=71.24+43.12x7.74x1+4.8

=410tonne

Hoist capacity= hydraulic downpull+gate weight+ frictional forces

= 0+71.24+4.8

=76.04tonne

Power Intake service gate

Resultant water thrust (W) = 95.24 tonne

Down pull Force (K) = 100 tonne (Assume)

Down pull forces will be checked on the bases of hydraulic model studies.

Hydrodynamic force=W+A(uf-df)xγ+F

=78.5+45.24x1+73.65

=4464tonne

Hoist capacity= hydraulic downpull+gate weight+ frictional forces

=100+78.5+73.65

=252.15tonne

CONCLUSION

The radial or Tainter gate offers advantages of relatively small hydrodynamic hoisting forces, as does the cylinder gate, as long as the supporting pin is located in the geometric center of the cylindrical skin plate. The most widely used high-head gates for flow regulation or emergency closure of large outlets or conduits are leaf gates because of the many advantages they offer in construction and maintenance. In this project provided hoisting capacity of 450 tonnes which is sufficient to counterbalances all the forces acting on the gates. Analytically this method proves to gives satisfactory results. Hydraulic model studies are also carried out for the above gates and found to gives approximately similar results.

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