SPILLWAY DESIGN FOR A COMPOSITE DAM

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Abstract - *Spillways are provided for storage and detention dams to release surplus floodwater, which cannot be contained in the allotted storage space. In this paper we have designed a spillway for a composite dam proposed at Kanthalloor as a part of Pattiserry irrigation project. Pattiserry irrigation project envisages construction of 140 m long and 23m high composite dam, earthen bund with concrete overflow section, across the river chengalar a tributary of Pambar river, located in Kanthalloor village. The project aims at irrigating 240 Ha of land in Marayoor area, through 8 km long unlined canal. The proposed dam is located 5m downstream of the existing weir which is 20m long and 5m high, constructed during 1937. The proposed dam comprises, 15m long concrete overflow section at the centre and 25m long non-overflow section on the right and 15m long on the left. The concrete section is flanked by earthen dam, 50 m long in the left and 35m in the right. In the proposed dam spillway is at the concrete overflow section. We chose an ogee type spillway for the dam proposed.*

***Key Words*: Composite dam, Ogee Spillway, Spillway profile, Safety against sliding, Trajectory bucket.**

1.INTRODUCTION

Pambar river basin is faced with severe drought situation during summer season when the crops grown in Kanthalloor village need water for irrigation. The soil is highly fertile for paddy, sugarcane, vegetables and varieties of fruits. In order to cater to the irrigation needs, the possible solution in this catchment is to store water during the monsoon months and also to facilitate for storage of water from rainfall received during summer. This concept lead to the proposal of construction of dam at Kanthalloor.

Spillway is one of the most important component of a dam. Many failures of dams have been reported due to inadequate capacity or improper design of spillway, especially for earthen and rockfill type dams which are likely to be destroyed ,if overtopped ,unlike concrete dams which may not fail with slight overtopping for a small period of time.

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2. FACTORS AFFECTING SPILLWAY DESIGN

a. Safety considerations consistent with economy:

Many failures of dams have resulted from improperly designed spillway or spillways of inadequate capacity. Properly designed structure of adequate capacity may be found to be only moderately higher in cost than a structure of inadequate capacity.

b. Hydrological and site conditions:

The spillway design and its capacity depend on

- Inflow discharge, its frequency, and shape of hydrograph
- Height of dam
- Geological and other site conditions Important topographical features, which affect spillways design, are
- Steepness of terrain
- Amount of excavation and possibility of its use as embankment material.
- The possibility of scour
- Stability of slopes, safe bearing capacity of soils.
- Permeability of soils.

c. Type of Dam

The type of dam influences the design flood and spillway. For earth and rockfill dam ogee or chute spillway is preferred.

3. DESIGN OF SPILLWAY

Full Reservoir Level (FRL) =1581.00 M

Maximum Water Level (MWL)=1582.00 M

Height of Dam=23 m

Top Level=1584.00 M

Crest Level=1578.00 M

Deepest rock level= 1561.82M

Therefore, Head = MWL – Crest level

=1582 – 1578

= 4.00 m

Maximum flood discharge = 26.03 m^3/sec

H_d (design head) = 0.9×4 (IS: 6934- 1998)

= 3.6 m

P/ H_d = (spillway crest level – deepest level)/ H_d

= (1578 – 1561.82)

= 4.494 m > 2

3.1 Upstream profile

u/s quadrant of the crest may confirm to ellipse

$X_1^2/A_1^2 + Y_1^2/B_1^2 = 1$ (IS: 6934, cl 4.1.3.1)

For P/H_d > 2,

A_1/H_d = 0 .28 (from fig 2, IS 6934)

B_1/H_d = 0.164

Where, P= height of spillway crest from river bed

H_d = Design head

$A_1 = 0.28 \times H_d$

$= 0.28\times 3.6$

$=1.008$ m

$B_1 = 0.164 \times 3.6$

$= 0.5904$ m

Therefore, $X_1^2/A_1^2 + Y_1^2/B_1^2 = 1$

$X_1^2/ (1.008)^2 + Y_1^2/(0.5904)^2 = 1$

$X_1^2= \{1- Y_1/(0.5904)^2 \}\times 1.008^2$

$X_1^2 = 1.016 – 2.9149Y_1^2$

Table -1: Upstream profile co-ordinates

Y_1	X_1
0	1.0097
0.15	0.9748
0.25	0.9131
0.3	0.8681
0.35	0.8117
0.4	0.7413
0.45	0.6524
0.5	0.5359
0.55	0.3663
0.59	0

3.2 Downstream profile

d/s profile of the crest may confirm to the equation

IS: 6934 , cl 4.1.3.2

$X_2^{1.85} = K_2 \times H_d^{0.85} \times Y_2$

$K_2 = 2$ (IS 6934, FIG 2)

$P/H_d = 4.494 > 2$

Therefore, $X_2^{1.85} = 2 \times 3.6^{0.85} \times Y_2$

$X_2 = 2.62\ Y_2^{0.5405}$

Table -2: Downstream profile co-ordinates

Y_2	X_2
0	0
0.25	1.2383
0.5	1.8013
1	2.6200
1.5	3.2619
2	3.8107
2.5	4.2992
3	4.7444
3.5	5.1566
3.6	5.2357

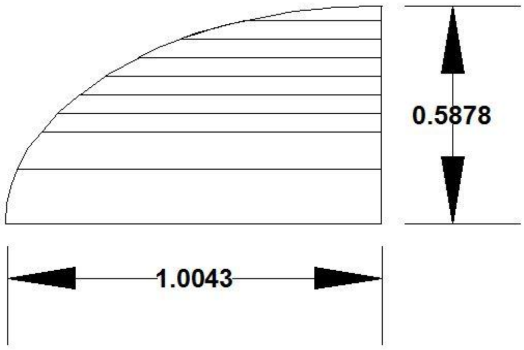

Figure 1: Upstream profile

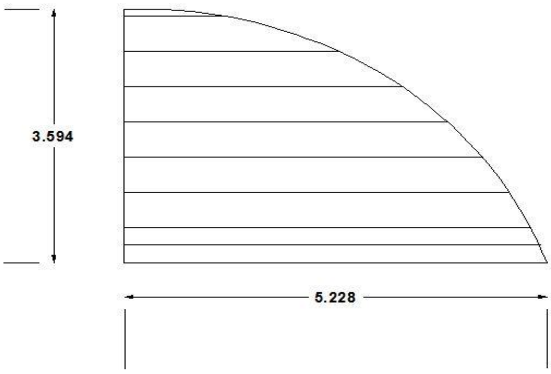

Figure 2: Downstream profile

3.3 Tangent point

$X = 2.62Y^{0.5405}$

$dx/dy = 2.62 \times 0.5405\ Y^{-0.4595}$

$= 1.4161\ Y^{-.4595}$

Adopt a slope of 0.75 (slope varies from 0.7:1 to 0.8:1)

$0.75 = dx/dy = 1.4161\ Y^{-0.4595}$

$Y^{0.4595} = 1.4161/0.75$

$Y = 3.9877$

At tangent point,

$Y_2 = 3.9877$ m

$X_2 = 2.62 \times 3.9877^{0.5405}$

$= 5.5333$ m

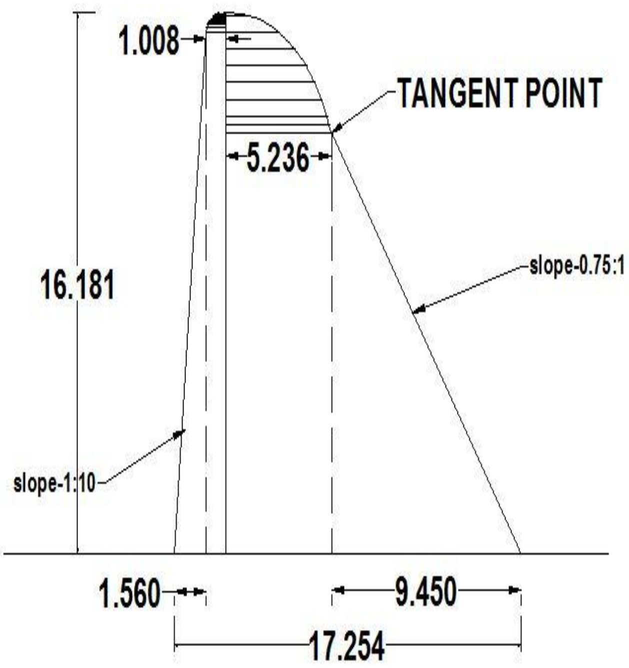

Figure 3: Spillway Profile

3.4 Computation of forces and moments

The entire area of spillway profile was divide into rectangles and triangles numbered from 1 to 38.

Vertical force = Area x Unit weight of concrete

Moment = Force x Lever arm

Table-3: Forces and Moments

No.	Vertical Force	Lever Arm	Moment
1.	0.372	16.014	5.957
2.	0.744	15.806	11.76
3.	2.16	15.431	33.33
4.	3.144	14.931	46.943
5.	3.114	14.431	44.938
6.	4.573	13.931	63.706
7.	5.16	13.431	69.304
8.	5.693	12.931	73.616
9.	6.188	12.631	78.161
10.	0.065	16.081	1.045
11.	0.087	15.981	1.31
12.	0.064	15.906	1.018
13.	0.078	15.856	1.237
14.	0.095	15.806	1.502
15.	0.097	15.756	1.528
16.	0.104	15.706	1.633
17.	0.109	15.656	1.707
18.	0.094	15.611	1.467
19.	29.203	5.2	151.856
20.	37.74	7.8	294.372
21.	158.34	6.3	997.542
22.	142.884	4.2	600.113
23.	0.168	15.764	2.648
24.	0.246	15.348	3.776
25.	0.385	14.848	5.716
26.	0.33	14.348	4.735
27.	0.2931	13.848	4.059
28.	0.2671	13.348	3.564
29.	0.2473	12.848	3.177
30.	0.0953	12.281	1.17
31.	0.0204	15.964	0.326
32.	0.007	15.898	0.111
33.	0.0053	15.848	0.084
34.	0.0042	15.798	0.066
35.	0.0034	15.748	0.054
36.	0.0027	15.698	0.042
37.	0.0037	15.648	0.058
38.	0.0016	15.604	0.025

3.5 Water Pressure

At MWL all shutters will be open. Hence the water above crest i.e, at +1578 to MWL(1582) will flow over the crest.

Hence, the pressure developed above the crest will be 'wh' i.e, wh= 1×(1582-1578)= 4

Pressure diagram will be rectangle from base to crest level and triangle from base of dam up to MWL.

a) **Water at MWL**

Table- 4: Forces and Moments

Description	Force, KN	Lever Arm	Moment, KNm
Rectangle	64.724	8.09	523.62
Triangle	130.91	5.39	706.08
Total	195.634		1229.7

b) **Water at FRL** Shutter closed

Table- 5: Forces and Moments

Description	Force, KN	Lever Arm	Moment, KNm
Triangle	203.64	6.73	1369.89

3.6 Uplift Pressure

a) **Water at MWL**

Table- 6: Forces and Moments

Force	Lever arm	Moment, tonne
174.1	11.5	2002.61

b) **Water at FRL**

Table- 7: Forces and Moments

Force	Lever arm	Moment, tonne
165.47	11.5	1902.91

3.7 Silt pressure(IS 6512-1984)

Bed level= 1561.82

Silt height is taken as 2m

As per IS vertical pressure, r_s' =1925-100 =0.925 t/m^3

Horizontal pressure, r_s'' = 1360-1000 =0 .36 t/m^3

Vertical force = 1/2×2×1.56×0.925= 1.443 t

Horizontal force =2×2×0.36/2 = 0.72 t

Table-8: Loads/moments at base of toe

Description	Force, t	Lever Arm	Moment, tm
Vertical	1.443	16.214	23.397
Horizontal	0.72	0.67	0.482

3.8 Weight of water

Loads/moments of base of toe due to water

a) **Water at MWL**

Table- 9: Forces and Moments

Description	Force, t	Lever Arm	Moment, tm
Rectangle	7.16	16.474	117.95
Triangle	12.16	16.734	203.48

b) **Water at FRL**

Table- 10: Forces and Moments

Description	Force, t	Lever Arm	Moment, tm
Rectangle	5.6	16.474	92.25
Triangle	12.16	16.734	203.48

3.9 Load combination

LOAD	DESCRIPTION	H	V	M_0	M_x
A	Weight of structure		402.18		2513.66
B	Weight of structure		402.18		2513.66
	Water pressure	203.64		1369.89	
	Uplift pressure		165.47	1902.91	
	Silt pressure	2.163		23.88	
	Water load		17.76		295.73
C	Weight of structure		402.18		2513.66
	Water pressure	195.63		1229.7	
	Uplift pressure		174.1	2002.61	
	Silt pressure	2.163		23.88	
	Water load		19.32		321.43

H- Horizontal Force M_o – overturning moment

V- Vertical Force M_x – resisting moment

3.10 Check for sliding

Factor of safety against sliding

$F = ((w-u) \tan \phi / F_\phi + CA/F_c)/P$

w→ total mass of dam

u→ total uplift pressure

tan ϕ → coefficient of internal friction

$\phi = 25^\circ$

A→ area under consideration

F_ϕ→ partial safety factor of reaction

F_c→ partial safety factor of cohesion

P→ total horizontal force

COMBINATION B

$F = ((w - u) \tan \phi / F_\phi + C \times A / F_c) / P$

$F = (((402.19 - 165.47) \tan 25^\circ) / 1.5 + 100 \times 16.181 / 4.5) / 205.8$

= 2.1 kN>1 Hence safe

COMBINATION C

$F = ((w - u) \tan \phi / F_\phi + C \times A / F_c) / P$

$= (((402.19 - 174.1) \tan 25^\circ) / 1.5 + 100 \times 16.181 / 4.5) / 197.8$

= 2.17 kN>1 Hence safe

4. HYDRAULIC DESIGN OF TRAJECTORY BUCKET TYPE ENERGY DISSIPATOR (IS 7365:2010)

a) Bucket shape

For practical consideration, a circular shape of trajectory bucket is proposed for the design.

b)Bucket invert elevation

Available data

Total discharge = 88 m^3/s

Width of bucket = 10 m

Max. reservoir pool elevation = 1582 m

Crest level of spillway = 1578 m

Max. tail water level = 1562 m

So assume bucket invert elevation = 1562.50 m

c) Radius of bucket

H_1 = reservoir pool elevation – bucket invert elevation

= 1582 – 1562.50

= 19.50 m

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H = reservoir pool elevation – crest level

= 1582 – 1578

= 4 m

H_5 = reservoir pool elevation – jet surface elevation

= 1582 – 1563.50 = 18.44

As per IS 7365: 2010 cl: 5.2.3

Radius of bucket = 0.6 to $0.8(H.H_5)^{0.5}$

= 0.6 to $0.8(4 \times 18.44)^{0.5}$

= 5.15 to 6.87

Provide radius of bucket as R = 6.00 m

d) Lip elevation and exit angle

In order to minimize the sub-atmospheric pressure on lip provide a lip angle of 30°

$R - R\cos\phi = 6 - 6\cos(30)$

= 0.803

So lip level = 1562.5 + 0.803 = 1563.304 m

Therefore tail water level is lower than lip level. Lip shall be made flat. (As per IS 7385:2010, cl:5.2.4)

e) Trajectory length

Actual velocity of jet at lip of bucket

V_a = 16.91 m/s

γ= Lip level – Tail water level

= 1563.304-1562= 1.304 m

$H_\gamma = V_a^2/2g = 16.91^2/2\times9.81$

= 14.574 m

$X/H_\gamma = \sin 2\phi + 2\cos\phi\sqrt{\sin^2\phi + \gamma/H_\gamma}$

$X/14.574 = \sin60 + 2\cos30\sqrt{\sin^2 30 + (1.304/14.574)}$

X = 27.32 m

Vertical distance of throw as per IS 7365 cl 5.2.5.2

$a = V_a^2 \sin^2\phi/(2g)$

$= 16.91^2 \times \sin^2 30/(2\times9.81) = 3.64$ m

f) Estimation of scour downstream of spillway (IS 7365:2010)

Depth of scour, $d_s = m(q\times H_a)^{0.5}$

m = 0.36 (minimum expected scour)

q = 17.9 m^3/s

H_4 = reservoir pool elevation – bucket lip level

= 1582 -1562.304 = 18.696 m

Therefore $d_s = 0.36 \times (17.90 \times 18.696)^{0.5}$

= 6.58 m

g) The shape and width of lip

As per IS 7365:2010,cl 4.2.2.3,width of lip is provided 1/10 of radius of bucket.

6/10 = 0.6 m

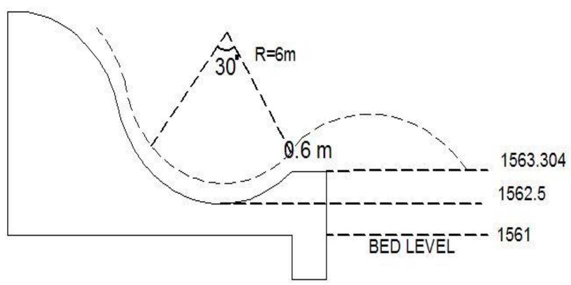

Figure 4: Trajectory Bucket

5. CONCLUSIONS

The overflow section of the dam is of concrete where spillway is located. So the design of the spillway of composite dam was based on the spillway design criteria of a gravity dam. Ogee type spillway was adopted because of high discharging efficiency. For energy dissipation and the prevention of downstream scour, trajectory bucket is also included in the design.

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