INDIAN INSTITUTE OF TECHNOLOGY PALAKKAD

CE- 3090 Water Resources Engineering

TERM PAPER

Topic	:	Design of Reservoirs
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1. Introduction

The Public Works Department of Tamil Nadu is considering building a reservoir for irrigation in the Gadana River Basin, a tributary of the Tamilapalani River in Tirunelveli District (Figures 1 & 2). The proposed dam site is at the junction of two rivers (Figure 3). The proposed dam will mainly irrigate paddy fields for three growing seasons, covering a total area of about 3,774.75 ha. The crop coefficient for different stages of crop growth for paddy is given in Fig. 4 and the long-term weather data to calculate crop water requirement is given in Table 1.

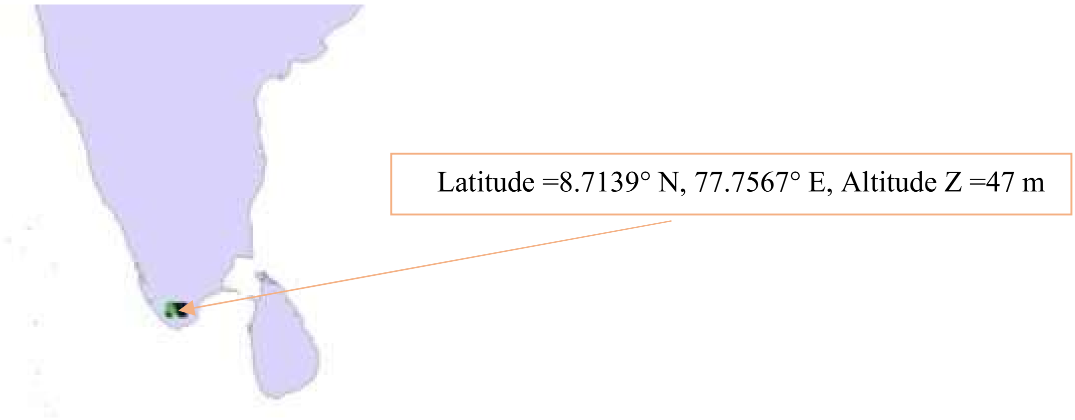


Figure 1

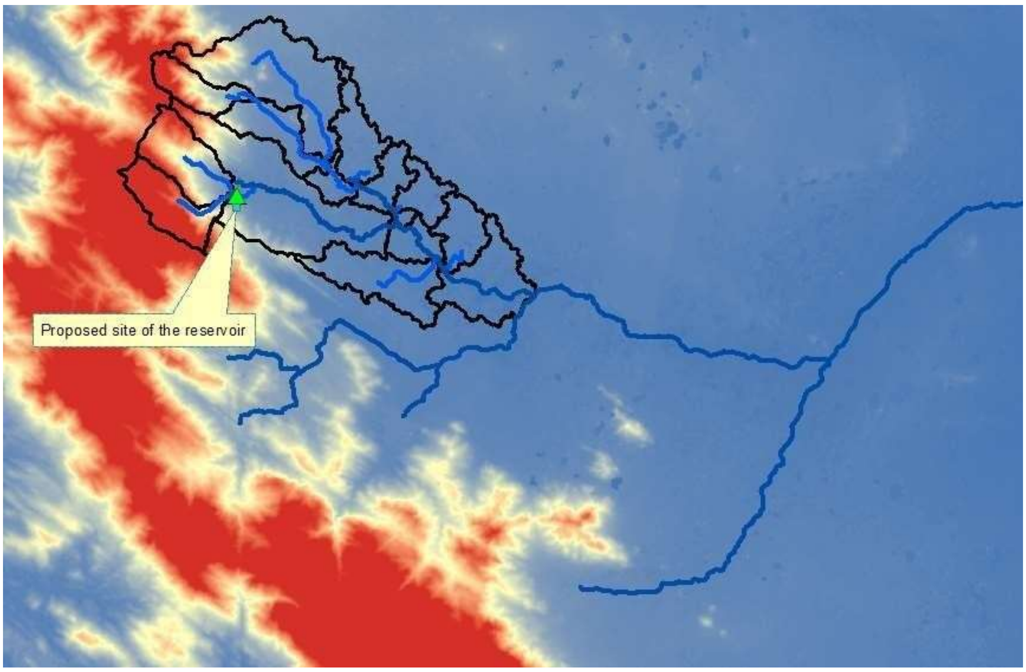


Figure 2

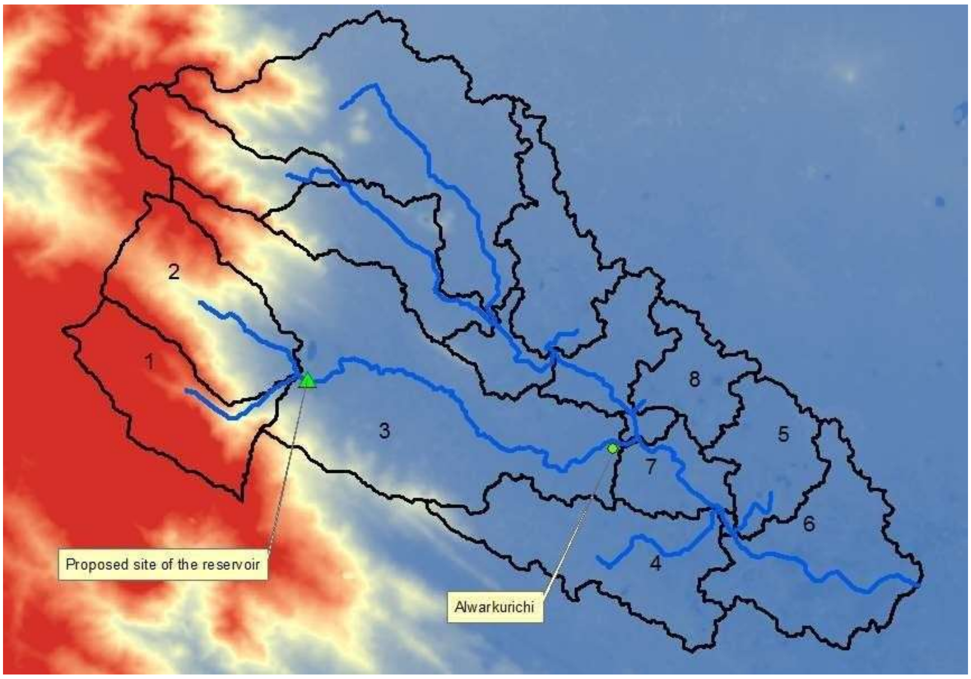


Figure 3

2. Given Data

The following data was obtained by conducting various experiments in the proposed area

Long-term monthly weather data						
Month	Rainfall (mm)	Tmax (°C)	Tmin (°C)	Wind spee d (m/s)	Shortwav esolar radiation (Rs)	Tdew (°C)
January	41.68	31.59	21.77	2	25.24	19.86
February	33.68	32.78	22.57	2	25.73	20.51
March	42.92	34.18	24.02	2	24	21.7
April	100.51	34.67	25.2	2	19.63	23.36
May	129.63	34.52	25.46	2	15.08	23.5
June	169.43	32.84	24.68	2.71	11.49	23.25
July	132.14	32.27	24.28	2.29	11.62	22.66
August	93.08	32.19	24.22	2.68	13.75	22.56
September	123.45	32.46	24.13	2	16.75	22.6
October	254.21	31.8	23.76	2	18.65	22.77
November	239.84	31.04	23.22	1.81	19.68	22.21
December	100.98	31.07	22.4	2	22.11	20.99

Table 1

Observed monthly flows (in m³) at the proposed reservoir site	
Month	**Average Inflow(m^3)**
January	7287657
February	6596958
March	3298307
April	1981358
May	1665600
June	5033226
July	8984140
August	9017700
September	5483927
October	3844478
November	13578712
December	10557592

Table 2

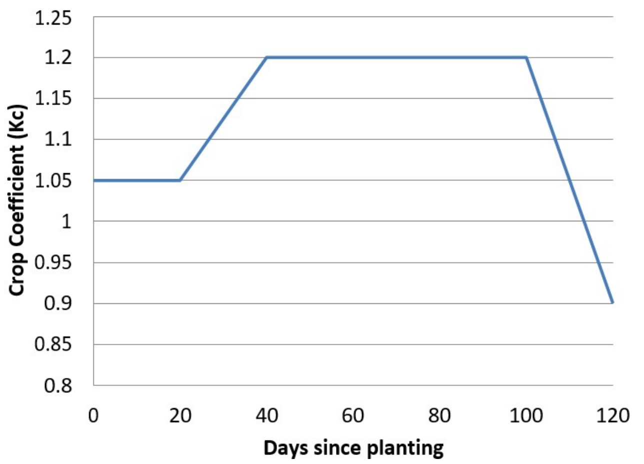


Figure 4

Topography at the proposeddam site	
Contour (in m above MSL)	**Surface Area of contours at the proposed site (sq.km)**
114.5	0.15146
115	0.16109
115.5	0.17133
116	0.18222
116.5	0.19381
117	0.20614
117.5	0.21925
118	0.23319
118.5	0.24802
119	0.26379
119.5	0.28056
120	0.2984
120.5	0.31738
121	0.33756
121.5	0.35902
122	0.38185
122.5	0.40614
123	0.43196
123.5	0.45943
124	0.48865
124.5	0.51972
125	0.55277
125.5	0.58792
126	0.62531
126.5	0.66507
127	0.70736
127.5	0.75234
128	0.80018
128.5	0.85107
129	0.90519
129.5	0.96275
130	1.02397
130.5	1.08908
131	1.15834
131.5	1.23199
132	1.31034
132.5	1.39366

Table 3

3. Estimation of Annual net irrigation water requirement

We compute reference evapotranspiration (ET_o) from meteorological data (table 1) and further using Figure 4 we find the K_c Value and hence the ET_c Value is obtained.

Penman Monteith Method

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

ET_o = reference evapotranspiration [mm day-1],
R_n = net radiation at the crop surface [MJ m-2 day-1],
G = soil heat flux density [MJ m-2 day-1],
T = mean daily air temperature at 2 m height [°C],
U_2 = wind speed at 2 m height [m s-1],
e_s = saturation vapour pressure [kPa],
e_a = actual vapour pressure [kPa],
$e_s - e_a$ = saturation vapour pressure deficit [kPa],
Δ = slope vapour pressure curve [kPa °C-1],
γ = psychrometric constant [kPa °C-1].

Using MATLAB, we generate the ET_O Values as given below,

Month	Eto (mm/day)
January	5.6015
February	5.8954
March	5.8694
April	5.1251
May	4.3350
June	3.7861
July	3.6174
August	4.1385
September	4.3812
October	4.5168
November	4.5052
December	4.9907

Table 4

We find the crop factor for each month of the year using Figure 4, using the seasons and the number of days since sowing. The area under the curve in Figure 4 for a specific number of days gives us the crop factor. By multiplying ET_o by the crop factor, ET_c is determined.

For finding ET_c

$$ET_c = ET_o \times K_c \qquad (ET_c\ in\ mm, ET_o\ in\ mm/day, K_c(area\ under\ the\ curve)\ in\ day)$$

$$\begin{aligned} K_c &= 1.05 &&, for, \quad 0 < day(D) < 20 \\ &= 0.0075D + 0.9 &&, for, \quad 20 < day(D) < 40 \\ &= 1.2 &&, for, \quad 40 < day(D) < 400 \\ &= -0.015D + 2.7 &&, for, \quad 100 < day(D) < 120 \end{aligned}$$

For kharif season, (July to October)
Considering each month has only 30days, graph have 120 days,

Therefore,

$$ET_{c_{July}} = ET_o \times K_{c_{July}}$$
$$ET_{c_{July}} = 3.6174 \times [1.05 \times 30 + \frac{1}{2} \times 10 \times (0.9 + 0.0075 \times 30 - 1.05)]$$
$$ET_{c_{Jul}} = 115.304$$

Similarly,

$$ET_{c_{August}} = 147.434$$
$$ET_{c_{September}} = 157.7232$$
$$ET_{c_{October}} = 149.054$$

Similarly, for rabi and summer season,

Month	**ETc(mm)**
January	201.65
February	194.55
March	187.09
April	182.58
May	156.06
June	124.94
July	115.30
August	147.43
September	157.23
October	149.05
November	143.60
December	177.79

Table 5

The next step is to calculate the effective rainfall using the provided precipitation data. We may determine the effective rainfall by deducting the initial abstraction from the rainfall in accordance with research conducted in and around the Tirunelveli Taluk for agricultural land, assuming soil type to be D, it is determined that the curve number is 87.

Table1: CN value for corresponding soil group for each land use category.

S.No	Landuse classification Type	Curve Number for Corresponding Soil Group			
		A	B	C	D
1	Water body	100	100	100	100
2	Built up Land	57	72	81	86
3	Forest	30	58	71	78
4	Agricultural	67	77	83	87

Source: https://www.researchgate.net/figure/Landuse-Landcover-map-of-Tirunelveli-Taluk_fig3_309803835

We know that,

$$S = \frac{25400}{CN} - 254$$
$$CN = 87 \Rightarrow S = 37.954$$
$$I_a = 0.2S = 7.59$$

Therefore,

$$P_{eff} = P - I_a$$

P effective is calculated for each case using the above equation,

Month	Rainfall (mm)	Effective Rainfall (mm)
January	41.68	34.09
February	33.68	26.09
March	42.92	35.33
April	100.51	92.92
May	129.63	122.04
June	169.43	161.84
July	132.14	124.55
August	93.08	85.49
September	123.45	115.86
October	254.21	246.62
November	239.84	232.25
December	100.98	93.39

Table 6

Irrigation water requirement is calculated using ET_c and P_{eff}, by the formula

$$IWR = ET_C - P_{eff}$$

Month	**ETo(mm/day)**	**Etc (mm)**	**Rainfall (mm)**	**Effective Rainfall (mm)**	**IWT (mm) (ET_c- P_{eff})**
January	5.6015	201.65	41.68	34.09	167.56
February	5.8954	194.55	33.68	26.09	168.46
March	5.8694	187.09	42.92	35.33	151.76
April	5.1251	182.58	100.51	92.92	89.66
May	4.335	156.06	129.63	122.04	34.02
June	3.7861	124.94	169.43	161.84	0.00
July	3.6174	115.30	132.14	124.55	0.00
August	4.1385	147.43	93.08	85.49	61.94
September	4.3812	157.23	123.45	115.86	41.37
October	4.5168	149.05	254.21	246.62	0.00
November	4.5052	143.60	239.84	232.25	0.00
December	4.9907	177.79	100.98	93.39	84.40
				Net Irrigation Water Requirement (mm)	**799.18**

Therefore, the annual irrigation water required (IWR) = 799.18 mm
Total command area of paddy crop = 3774.75 ha
Volume of water required = 30167047.05 cubic meters

4. Active storage volume of the Reservoir

The entire amount of reservoir capacity typically accessible for discharge from a reservoir below the maximum storage level. Inactive storage capacity is subtracted from the total or reservoir capacity. It is the amount of water that is present between the spillway crest and the outlet works. Using the subsequent peak approach, the reservoir's active storage volume is determined.

Month	Inflow(m^3)	Outflow demand (m^3) (IWT * Area)	I-O(m^3)	Excess(m^3)	Deficit(m^3)	Cumulative Excess(m^3)	Cumulative deficit(m^3)
January	7287657	6325122.09	962534.91	962534.9		962534.9	
February	6596958	6358875.90	238082.096	238082.1		1200617.0	
March	3298307	5728452.08	-2430145.08		-2430145.08		-2430145.08
April	1981358	3384504.55	-1403146.55		-1403146.55		-3833291.63
May	1665600	1284169.95	381430.05	381430.1		1582047.1	
June	5033226	0.00	5033226	5033226.0		6615273.1	
July	8984140	0	8984140	8984140.0		15599413.1	
August	9017700	2338233.50	6679466.5	6679466.5		22278879.6	
September	5483927	1561689.57	3922237.43	3922237.4		26201117.0	
October	3844478	0.00	3844478	3844478.0		30045595.0	
November	13578712	0	13578712	13578712.0		43624307.0	
December	10557592	3186028.19	7371563.81	7371563.8		50995870.8	
					Active Storage volume of the reservoir(m^3)		**3833291.63**

The active storage volume of the reservoir is 3833291.63 m^3

5. Storage Capacity of the reservoir based on topography

The storage capacity of the reservoir is also found out using the data given in table 2 using the contours at different heights.
We make use of the contour formula given by,

$$storage\ volume = \frac{\Delta h}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$$

Here A_1 & A_2 are the areas of the contour at a height difference of 0.5m.

Contour (in m above MSL)	Surface Area of contours at the proposed site (sq.km)	Storage Volume(m^3)	Cumulative Storage
114.5	0.15146	0	0.00
115	0.16109	78125.13412	78125.13
115.5	0.17133	83091.85367	161216.99
116	0.18222	88373.52034	249590.51
116.5	0.19381	93992.612	343583.12
117	0.20614	99971.65791	443554.78
117.5	0.21925	106330.6612	549885.44
118	0.23319	113092.0999	662977.54
118.5	0.24802	120283.4524	783260.99
119	0.26379	127932.249	911193.24
119.5	0.28056	136065.9682	1047259.21

120	0.2984	144717.0896	1191976.30
120.5	0.31738	153920.6186	1345896.92
121	0.33756	163709.0861	1509606.00
121.5	0.35902	174117.4463	1683723.45
122	0.38185	185188.1802	1868911.63
122.5	0.40614	196966.2948	2065877.92
123	0.43196	209491.8481	2275369.77
123.5	0.45943	222812.219	2498181.99
124	0.48865	236982.4675	2735164.46
124.5	0.51972	252052.6017	2987217.06
125	0.55277	268080.0535	3255297.11
125.5	0.58792	285127.3586	3540424.47
126	0.62531	303259.4758	3843683.95
126.5	0.66507	322543.9416	4166227.89
127	0.70736	343053.1903	4509281.08
127.5	0.75234	364867.2347	4874148.32
128	0.80018	388068.562	5262216.88
128.5	0.85107	412747.1352	5674964.01
129	0.90519	438995.4946	6113959.51
129.5	0.96275	466911.0785	6580870.59
130	1.02397	496601.3784	7077471.96
130.5	1.08908	528178.8863	7605650.85
131	1.15834	561766.0445	8167416.89
131.5	1.23199	597487.9243	8764904.82
132	1.31034	635481.8676	9400386.69
132.5	1.39366	675893	10076279.69
		Topography Volume(m^3)	**10076279.69**

The proposed area has sufficient topography to contain the active storage volume required.

6. Height of the Dam

The height of the dam is found using the following steps

Step 1: Take 114.5 m contour as ground level.

Step 2: the volume between two contour is calculated by using contour formula basedon the surface areas between two contours.

Step 3: Calculate the cumulative volume and subtract cumulative volume from activestorage capacity.

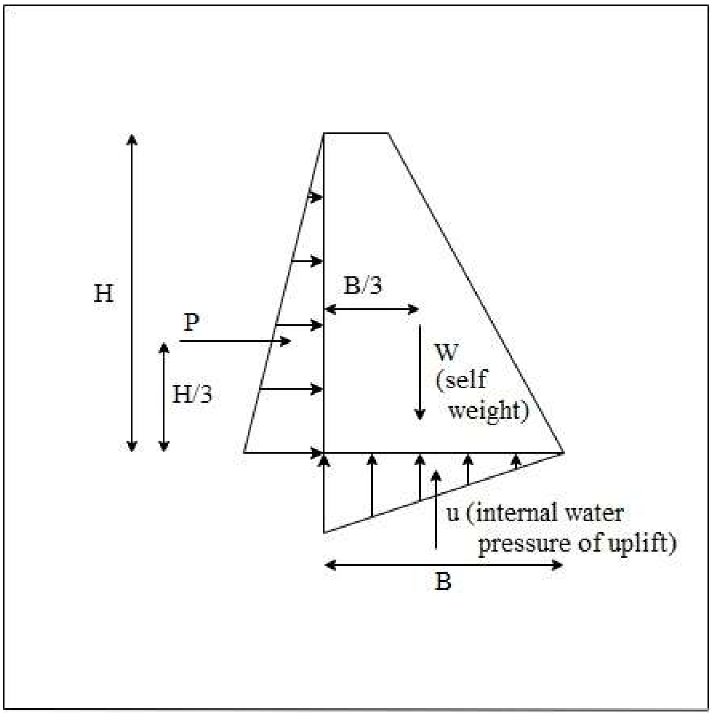
Step 4: the contour level where the difference become positive is considered. The difference in the calculated contour height and the ground level height will give youthe height of the dam.

Contour (in m above MSL)	Surface Area of contours at theproposed site (sq.km)	Storage Volume(m^3)	Cumulative Storage Volume(m^3)	Reservoir Active Volume (m^3)	Change in Volume (m^3)
114.5	0.15146	0	0.00	3833291.63	-3833291.63
115	0.16109	78125.13412	78125.13	3833291.63	-3755166.50
115.5	0.17133	83091.85367	161216.99	3833291.63	-3672074.64
116	0.18222	88373.52034	249590.51	3833291.63	-3583701.12
116.5	0.19381	93992.612	343583.12	3833291.63	-3489708.51
117	0.20614	99971.65791	443554.78	3833291.63	-3389736.85
117.5	0.21925	106330.6612	549885.44	3833291.63	-3283406.19
118	0.23319	113092.0999	662977.54	3833291.63	-3170314.09
118.5	0.24802	120283.4524	783260.99	3833291.63	-3050030.64
119	0.26379	127932.249	911193.24	3833291.63	-2922098.39
119.5	0.28056	136065.9682	1047259.21	3833291.63	-2786032.42
120	0.2984	144717.0896	1191976.30	3833291.63	-2641315.33
120.5	0.31738	153920.6186	1345896.92	3833291.63	-2487394.71
121	0.33756	163709.0861	1509606.00	3833291.63	-2323685.63
121.5	0.35902	174117.4463	1683723.45	3833291.63	-2149568.18
122	0.38185	185188.1802	1868911.63	3833291.63	-1964380.00
122.5	0.40614	196966.2948	2065877.92	3833291.63	-1767413.71
123	0.43196	209491.8481	2275369.77	3833291.63	-1557921.86
123.5	0.45943	222812.219	2498181.99	3833291.63	-1335109.64
124	0.48865	236982.4675	2735164.46	3833291.63	-1098127.17
124.5	0.51972	252052.6017	2987217.06	3833291.63	-846074.57
125	0.55277	268080.0535	3255297.11	3833291.63	-577994.52
125.5	0.58792	285127.3586	3540424.47	3833291.63	-292867.16
126	0.62531	303259.4758	3843683.95	3833291.63	10392.32
126.5	0.66507	322543.9416	4166227.89	3833291.63	332936.26
127	0.70736	343053.1903	4509281.08	3833291.63	675989.45
127.5	0.75234	364867.2347	4874148.32	3833291.63	1040856.69
128	0.80018	388068.562	5262216.88	3833291.63	1428925.25
128.5	0.85107	412747.1352	5674964.01	3833291.63	1841672.38
129	0.90519	438995.4946	6113959.51	3833291.63	2280667.88
129.5	0.96275	466911.0785	6580870.59	3833291.63	2747578.96
130	1.02397	496601.3784	7077471.96	3833291.63	3244180.33
130.5	1.08908	528178.8863	7605650.85	3833291.63	3772359.22
131	1.15834	561766.0445	8167416.89	3833291.63	4334125.26
131.5	1.23199	597487.9243	8764904.82	3833291.63	4931613.19
132	1.31034	635481.8676	9400386.69	3833291.63	5567095.06
132.5	1.39366	675893	10076279.69	3833291.63	6242988.06

positive difference at a height of 126m,
therefore, height of dam = 126 - 114.5 = 11.5 m

7. Stability of Dam

Height of the dam to be provided = 11.5 m
Let there be a freeboard of 0.5 m
Therefore, total height of the dam =12 m



Overturning should be considered while checking for stability of the dam,

$$Fos\ against\ overturning = \frac{Rresisting\ moment}{Overturning\ moment} = 2.5$$

Vertical stress distribution at the base,

$$P_{max,min} = \frac{\sum V}{B} \pm \frac{M}{I} y$$

$$P_{max,min} = \frac{\sum V}{B} [1 \pm \frac{6e}{B}]$$

where,
e = eccentricity of resultant force from the center of the base
ΣV = total vertical force
B = base width

There should be zero tension at the base, it is limited by P_{max},
Therefore, there will be no tension for the maximum value of P_{min} to be zero,

$$P_{min} = \frac{\sum V}{B}\left[1 - \frac{6e}{B}\right] = 0$$

⇒ e = B/6
self weight,

$$W = \frac{1}{2} \times B \times H \times S_c \times \gamma_W \qquad .....(1)$$

where,
S_c= specific gravity of concrete = 2.4
$\gamma_W = 9.81\ kN/m^3$

U (internal uplift) = $\frac{1}{2} \times (c \times \gamma_W \times H)B$ .....(2)

where,
c = 1 (according to USBR recommendations)

P (hydraulic thrust) = $\frac{1}{2} \times \gamma_W \times H^2$ .....(3)

Reservoir if full,
⇒ two safety criteria,

(i) Resultant of P, W and U passes through lower middle third point

$$W\left(\frac{B}{3}\right) - U\left(\frac{B}{3}\right) - P\left(\frac{H}{3}\right) = R \times 0$$

From eq (1), (2) and (3)

$$B = \frac{H}{\sqrt{S_c - c}} = \frac{12}{\sqrt{2.4 - 1}} = 10.142\, m$$

$$\Rightarrow B > 10.1422\, m\ (for\ no\ tension\ to\ develop)$$

(ii) Safety against sliding,

$$\mu(W - U) \geq P$$

$$\Sigma H = P$$

$$\Rightarrow B \geq \frac{H}{\mu(S_c - c)}$$

$$assume, \mu = 0.7$$

$$B \geq \frac{12}{0.7(2.4 - 1)}$$

$$B \geq 12.24\, m$$

Considering both cases,
B = 12.3 m

Vertical stress distribution
e = B/6 = 12.3/6 = 2.05
P_{max} at toe, $P_v = \gamma_W H(S_c - c) = 164.808 kN/m^2$
P_{min} at heel, $P_v = 0$
Principal stress near toe, $\sigma = P_v\,(\sec\alpha)^2$
where, $\alpha = \tan^{-1}(\frac{B}{H})$
for elementary profile,
, $\sigma = \gamma_W H(S_c - c + 1) = 282.528\, kN/m^2$
Shear stress, τ_o at a horizontal plane near toe,

$$\tau_o = P_v \tan\alpha = \gamma_W H(S_c - c) \times \frac{B}{H} \times H = 168.93\, kN/m^2$$

8. Conclusion

Irrigation water needs of Tirunelveli district in Tamil Nadu are found and the volume of active storage is also determined. We took the storage capacity from the terrain and checked if the terrain is suitable for building the storage tank. The height of the built dam is determined based on the estimation of the width of the foundation and the analysis of the stability of the dam.