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STABILITY ANALYSIS OF UNDERGROUND RESERVOIR FOR THE CRITICAL CONDITION: A CASE STUDY

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Abstract: Water tank can be constructed on ground, above ground or below ground depending on the requirement. It is used to store water and supply for drinking, industrial and other purposes. Major part of Delhi, water supply is being done by underground reservoirs through booster pumping stations. The ground water tanks are resting on the ground and their walls are subjected to water pressure from sides and the base is subjected to weight of water and pressure of soil from ground. This paper presents the stability analysis of underground water reservoir for critical conditions. Different cases are considered for the stability analysis. Based on the factor of safety, critical Condition is determined. Various methods are discussed and analyzed to overcome the effect of upliftment due to buoyancy for the stability of underground water reservoir.

***Index Terms* - Water tank, Uplift pressure, stability, buoyancy force, factor of safety.**

I. INTRODUCTION

Water tank is for providing storage of water for drinking, food preparation, irrigation, fire suppression and many other applications. The main emphasis in the structural analysis and design of a reinforced water tank should be to ensure it must be crack free both as a consequence of the loading and as results of temperature and shrinkage effect.

Reinforced water tanks can be constructed on ground, above ground or below ground depending on the requirement. The ground water tanks are resting on the ground and their walls are subjected to water pressure from sides and the base is subjected to weight of water and pressure of soil from ground. The water tanks may or may not be covered at the top.

All around of Delhi, the authorities permanently banned supply of water through Over Head Tank. Major part of the city water supply is being done by Under Ground Reservoirs through Booster Pumping Stations.

An Under Ground Reservoir has no foundation as it rest on the wide portion of natural, firm and different types of soil. The walls of underground tanks subjected to water pressure from inside and the soil pressure from outside. The base of underground water tank is subjected to weight of water acting downward and the soil pressure acting upward. The soil pressure depends on the soil condition whether it is wet or dry. These tanks must always be covered at the top to avoid any mishappening and to ensure the quality of water. These tanks could be constructed on fully or partially submerged soil as per the site conditions. These tanks are constructed fully underground and should not be uplifted due to ground water pressure surrounding the tank. As they are underground structure and due to presence of ground water, they are subjected to uplift and severe corrosion.

A study was conducted on underground water tank which is fully submerged. The analysis was done based on the theory of beam on elastic foundations. It was observed that the moments of wall, wall base and base slab decreases with increase in soil sub-grade modulus at constant capacity, height and breadth of the tank while they increase with increase in height of the tank at constant value of sub-grade modulus [1]. Design philosophy for the safe and economical design of tanks was used based on working stress method. The design has been made on excel sheet and concluded that in circular tanks is safe and economical, when h/d ratio is 0.45 [2]. A study was conducted on underground rectangular tank in both the cases when the tank is full or empty conditions. They studied the behaviour of tank like deflected shape, other effects on UGR for both the cases using STAAD Pro software [3]. It was observed that the shapes of water tanks play an important role in the stress distribution and economy [4]. A comparative study was conducted for the analysis of UGR using SAP and STAAD Pro and manual. It has been seen that the results remain almost same in all the three cases [5]. A finite element model was developed to study the behaviour like node displacement and stress pattern of underground tank for different L/B ratio. They also studied the base pressure, plate moments by considering the tank empty and full water level condition [6]. Underground rectangular water tank was analyzed using Staad pro. It has been observed that greater load acts at the bottom of side wall of UGR and the load linearly decreases towards the top [7].

In this study, stability analysis of underground water reservoir is carried out for selecting a site near the Yamuna River, Delhi [8]. The study is to incorporate the ground water table effect and check the stability of the underground reservoir including the weight of top slab and some overburden soil over it under different conditions. After finding the critical condition an appropriate remedial measure has to be studied with the site data of ground water, soil subgrade modulus and angle of internal friction.

II. SITE SELECTION

For the analysis, a site near the Yamuna River (not in the flood plain of river) for construction of UGR is selected. Since the lots of people are migrated and living in this area, they have no proper water supply network system rather they are depending on tanker water supply. At that site, the matter of concern is the ground water level which may vary between 2 m to 4m being in the vicinity of river. Before designing the components of UGR, it is essential to study the behavior of submerged soil and its buoyancy over the UGR structure. The water pressure of submerged soil acting upward which may uplift the structure due to buoyancy.

III. METHODOLOGY

To analyse the behaviour of structure on submerged soil, a systematic approach is adopted for computation of various forces acting upward due to amount of displaced ground water and to resist that total downward force coming from the structure. Different parameters are required for the analysis of underground water tank in submerged soil as under.

- Determination of water table
- Computation of Downward (Gravity) Forces
- Computation of Upward Buoyant Force
- Safety Factor for upliftment

3.1: Determination of Water Table

Ground water table can be determined using the following approaches as mentioned below:

- Soil Investigation Reports and Boring Data
- Regional and Seasonal Variations
- Conservative Approach

This information gives an idea to the designers to spot the potential areas of flotation where it could be an issue.

3.2: Downward Forces (Gravity Forces)

After the water level is decided, the design engineer must calculate all the downward forces which are acting on the structure. It requires to be calculated within the design of an underground structure so as to work out if the entire gravitational forces (downward, WT) are in excess of the buoyant force (upward WB). All the downward force (WT) is calculated using Eq. (1)

$$WT=W1+W2+W3+W4+W5 \qquad (1)$$

Where, W1, W2, W3, W4….. are the weights of different components of the concrete structure.

Following are the vertical downward forces (WT) which shall be considered for analysis of underground water tank.

- Weight of all components of UGR and additional concrete if applicable (W1).
- Weight of soil on top slabs (Earth fill) (W2).
- Weight of soil on extended base (W3).
- Weight of soil wedge due to internal angle of friction between soil particles (W4).
- Weight of water in tank (for tank full condition).

The various downward forces acting on the structure are shown in Fig.1. In which WB is the buoyant force and φ is angle of internal friction.

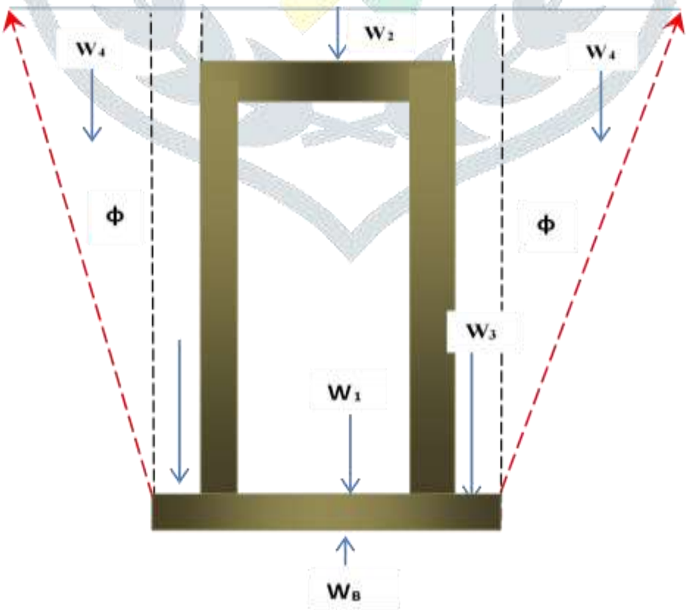

Fig 1: Downward forces on an underground structure

3.2.1 Weight of concrete (W1)

Weight of concrete is the main downward force which can be determined weight of the components of UGR like walls and slabs by getting the volume of the structure and multiplying it by the unit weight of concrete. The method for the calculation the weight of walls (Ww) and slabs (Ws)for rectangular tank is mentioned as in Eq. (2)

$$W1 = Ww + Ws \qquad (2)$$

The weight of walls and top and bottom slab can be calculated using Eq. 3 &4.

$$\text{Weight of walls } (Ww) = Lw \times Hw \times Tw \times \gamma c \qquad (3)$$

$$\text{Weight of top and bottom slab } (Ws) = Ls \times Bbt \times Tbt \times \gamma c \qquad (4)$$

Where,

Lw, Ls – Length of wall and slab

Hw – Height of wall

Bs – Width of top & bottom slab

Tw – Wall thickness

Tbt – Bottom & top slab thickness

γc- Concrete Density

3.2.2 Weight of earthfill (W2)

For Rectangular tanks weight of earthfill is taken as mentioned in Eq. (5)

$$W2 = Ls \times Bs \times Hs \times \gamma s \tag{5}$$

Where Ls, Bs, Hs – Length, width & height of earthfill soil on top slab

3.2.3 Weight of Soil on Base Extension (W3)

The weight of the soils on the extended base is calculated by multiplying the depth of the structure by the surface area of extended base of bottom slab and the unit weight of the soil. The method for getting the weight of the soil is as under in Eq. (6)

$$W3=Le\times We\times H\times \gamma s \tag{6}$$

where

Le - Length and width of extended base

We - Width and width of extended base

H - Total depth of structure including earthfill

γs - Density of soil

3.2.4 Weight of soil wedge due to Frictional Resistance on Extended Base (W4)

Due to the internal angle of soil friction a soil wedge develops which also incorporate to increase the total downward force. It can be determined by the buoyant weight of the soil wedge due to the base extension. Soil internal angle of friction vary by the type of soil, and its cohesive property. In this study, being on conservative side, value of internal friction is taken as 20^0.

3.2.5 Upward Buoyant Force

The buoyant force can be determined by the volume of displaced fluid is multiplied by the unit weight of water. It can be expressed by Eq. (7).

$$WB=\gamma w\times V \tag{7}$$

Where,

WB = buoyant force, γw = density of the water, V = displaced volume of the fluid

For the static equilibrium, the algebraic sum of all vertical forces (Σ Fv = 0) must be equal to zero to analy The buoyant force can be determined by the volume of displaced fluid is multiplied by the unit weight of water. It can be expressed by Eq.(7)

3.2.5 Factor of Safety for Upliftment

The factor of safety is expressed in Eq. (8) as a ratio of summation of resisting downward forces and a disturbing upward force due to buoyancy.

$$Factor\ of\ Safety\ (FS) = \frac{Downward\ Force(W_T)}{Upward\ Force(W_B)} \tag{8}$$

If,

$W_T > W_B$, structure will not uplift and becomes stationary

$W_T < W_B$, structure will not remain stationery and may shift upward or float.

In UGRs the factor of safety (**FS**) indicates the risk associated with hydrostatic loading conditions. In the areas, where flooding is predominant to the top of the structure and using resistance to dead weight only, generally a FS of 1.10 is adopted. Areas, where high ground water conditions persist because of high flood plains, a FS of 1.25 can be taken for the analysis. In the areas, where data of maximum ground water or high flood levels are not available or where soil friction is included in the flotation resistance, higher FS values should be considered.

In this study factor of safety for determining the stability is considered as 1.2 which as per IS 3370- Part-1-2009[9].

IV. DETERMINATION OF CRITICAL CONDITION OF UGR

. To get the critical condition for failure of the underground water tank, it is necessary to find the ground water table at the site of study. To get the input of ground water table, 5 nos. bore holes were bored and identified the water level at the site. For calculation of water demand population of the area is required. The population of the area is assumed as 7500 and water demand is calculated at the rate of 135 lpcd. Using the Microsoft excel spreadsheet for calculation of various loads, the critical conditions for both full and empty conditions for the tank, failure is obtained and probable countermeasures developed in terms of stability to achieve desired factor of safety.

Actual Ground water level data is collected from the site near Yamuna River. Bore holes data were obtained from site by drilling. The average depth of water table is obtained by averaging the depth of ground water table of individual bores as 3.58 m. The most critical depth is 2 m. Due to seasonal variation; ground water level may be on grade. For safer side, ground water level is considered on grade itself in this study.

4.1 Geometry of the Underground Reservoir

Considering the population of around 7500 and water demand as 135 lpcd, the required size of UGR is estimated as 12m × 10m × 4.50m as shown in Table 1.

Table: 1 Geometry of the UGR Based on Population

Projected population of the area	7,500 Nos.
Water Demand	135 LPCD
Water required per capita per day	1012500 Litre =1.0125 MLD
Water required per capita per day taken as	1.05 MLD=223017.6 Gallon
Required Capacity of underground reservoir	0.223018 MGD
Required Capacity of underground reservoir taken as	0.25 MGD
Volume required to accumulate required quantity of water	1052.5 m^3
Considering the rate of inflow is equal to rate of outflow, the effective storage volume required	526.25 m^3
The effective storage volume required taken as	526.00 m^3
Assuming the inside depth of the tank	4.50 m
Required area	116.89 m^2
Assuming width of tank	10 m
Required Length of tank	11.69
Length of tank taken as	12 m
Final Dimensions of UGR (in meter)	**12 m× 10 m× 4.50m**

The UGR shall be analyzed for the most critical condition in which UGR is considered to uplift due to the buoyant force exerts by submerged soil. The possible conditions of failure are:

- When Reservoir is empty and Ground Water Level is Maximum.
- When Reservoir is full and Ground Water Level is Maximum.
- When Reservoir is empty and Ground Water Level is Minimum.

For the three conditions factor of safety is checked as per the method described above. The plan & section view of the UGR is shown in Fig 2, in which grid roofing at top slab by 3 nos. of beams of size 0.23m x 0.23m on each side are taken. Depth of earthfill above the top slab is taken as 0.40 m.

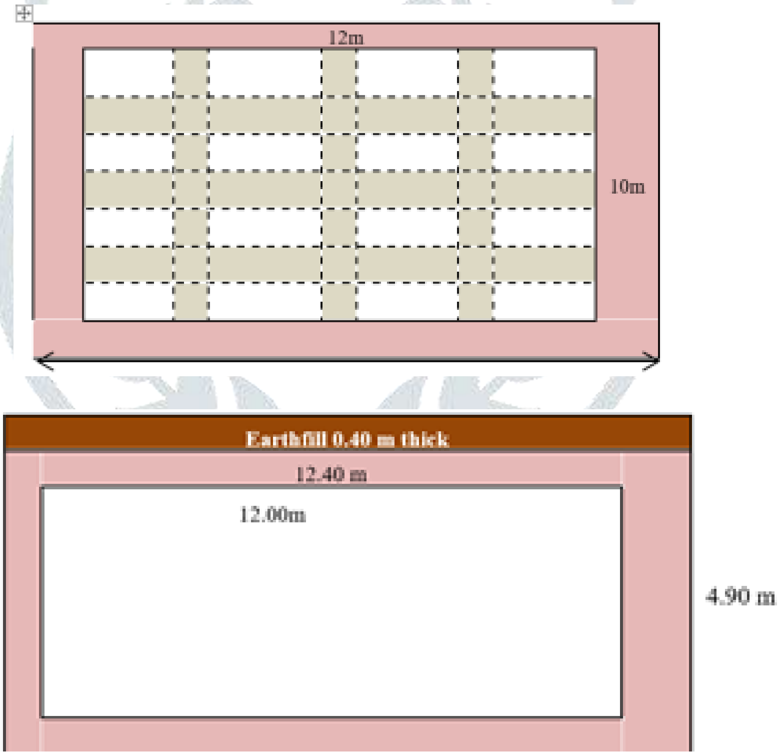

Fig 2: Plan & section view of UGR

Inner dimension of UGR is considered as 12m x10m x 4.5m. Thickness of top slab, bottom slab and wall are taken as 0.2m. Outer dimension of UGR will be 12.40m x10.40mx4.90m as shown in Fig. 6.2. Other parameters are required for the analysis are shown in Table 2.

Table 2 Parameters of UGR

Depth of Earthfill over the Top slab	0.4 m
Ground Water Table Level	At the grade
Opening in the top slab of tank	0.6 m
Unit Weiht of Concrete (γ_c)	24 kN/m^3
Unit Weight of RCC (γ_r)	25 kN/m^3
Unit weight of Soil (γ_s)	19 kN/m^3
Unit weight of Water (γ_w)	10 kN/m^3

Factor of Safety (FS)	1.2
Soil internal friction angle (ϕ)	20^0

4.2 When reservoir is empty and ground water level is maximum

First it is considered the case when reservoir is empty and ground water level is maximum. All the calculations for total downward weight and upward weight are shown in Table 3.

Table 3: When Reservoir is Empty and Ground Water Level is Maximum.

1. Total Weight of Concrete or RCC (Walls & Slabs)= $[(L \times W \times H) - (l \times w \times h] X \gamma_r$	297.60 kN
2. Total Weight of Concrete / RCC (Beams)= No. of Beams of each side × length × size × γ_r	87.29 kN
3. Weight of Overburden Soil= $L \times W \times$ Depth of earthfill × γ_s	980.10 kN
4. Weight of Opening= $(\pi/4 \times d^2 \times$ Top slab thickness × $\gamma r) + (\pi/4 \times d^2 \times$ depth of earthfill × $\gamma_s)$	3.56 kN
Total Downward Weight (W_T) = 1 + 2 + 3 – 4	3361.42 kN
Total Upward Buoyant Force (W_B) = $L \times W \times$ (H+Depth of earthfill- depth of water table) × γ_w	6834.88 kN
Factor of Safety (FS) = W_T / W_B	$0.49 < 1.2$
Result	Unstable

It is clear that when the reservoir is empty and the ground water level is maximum, the factor of safety is less than 1.2. It means that the reservoir will not stable in this condition.

4.3 When reservoir is full and ground water level is maximum.

With the same input data, it is considered the case when reservoir is full and ground water level is maximum. All the calculations for total downward weight and upward weight are shown in Table 4.

Table 4: When Reservoir is Full and Ground Water Level is Maximum

1. Total Weight of Concrete or RCC (Walls & Slabs) = $[(L \times W \times H) - (l \times w \times h] \times \gamma_r$	2297.60 kN
2. Total Weight of Concrete / RCC (Beams) No. of Beams of each side × length × size × γ_r	87.29 kN
3. Weight of overburden Soil= $L \times W \times$ Depth of earthfill × γ_s	980.10 kN
4. Weight of Water filled in UGR=$l \times w \times h \times \gamma_w$	5400.00 kN
5. Weight of opening= $(\pi/4 \times d^2 \times$ Top slab thickness × $\gamma r)+ (\pi/4 \times d^2 \times$ depth of earthfill × $\gamma_s)$	3.56 kN
Total Downward Weight (W_T) = 1 + 2 + 3 + 4 – 5=	8761.42 kN
Total Upward Buoyant Force (W_B) = $L \times W \times$ (H + Depth of earthfill - depth of water table) × γ_w	6834.88 kN
Factor of Safety (FS) = W_T / W_B	$1.28 > 1.2$
Result for above Criteria	Stable

It is clear from the above calculation, when the reservoir is full and the ground water level is maximum, the factor of safety is more than 1.2. It means that the reservoir will remain stable in this condition.

4.4 When reservoir is empty and ground water level is minimum

Now it is considered the case when reservoir is empty and ground water level is minimum. All the calculations for total downward weight and upward weight are shown in Table 5.

Table 5: When Reservoir is Empty and Ground Water Level is Minimum

1.Total Weight of Concrete or RCC (Walls & Slabs) = $[(L \times W \times H) - (l \times w \times h)] \times \gamma r$	2297.60 kN
2. Total Weight of Concrete / RCC (Beams)= No. of Beams of each side × length × size × γr	87.29 kN
3. Weight of overburden Soil = $L \times W \times$ Depth of earthfill × γ_s	980.10 kN

4. Weight of opening= $(\pi/4\times d^2 \times$ Top slab thickness $\times \gamma_r) + (\pi/4 \times d^2 \times$ depth of earthfill $\times \gamma_s)$	3.56 kN
Total Downward Weight (W_T)= 1 + 2 + 3 – 4	3361.42 kN
Total Upward Buoyant Force (W_B) = L × W × (H+Depth of earthfill- depth of water table) × γ_w	1676.48 kN
Factor of Safety (FS)= W_T / W_B	2.01 >1.2
Result of above Criteria	Stable

It is clear that when the reservoir is empty and the ground water level is minimum, the factor of safety is more than 1.2. It means that the reservoir will remain stable in this condition.

On evaluating the results of all the three conditions, the UGR will remain stable in following two conditions:

- When reservoir is full and ground water level is maximum.
- When reservoir is empty and ground water level is Minimum.

It has been observed that the critical condition or we can say that chance of failure is more when reservoir is empty and ground water level is maximum. Considering the critical condition, appropriate and favourable solution needs to be worked out in order to make the structure stable.

V. COUNTERMEASURES FOR THE STABILITY FOR THE CRTICAL CONDITION

It has been found that the UGR is unstable when the reservoir is empty and ground water level is maximum. It must be ensuring that the structure will remain safe in the critical condition. Some solutions or countermeasures needs to be worked out. The solutions are:

- Increase the thickness of components to increase the dead weight of the structure.
- Increase the depth of the structure which may be more than the required functional depth of the structure and to fill concrete in the additional depth
- Increase the size of bottom slab of the structure and the base is extended beyond the walls of the structure to incorporate the weight of soil over the extended base.
- Provision of an anti - floatation slab below the structure on which the structure rests

5.1 Add weight by increasing member thickness

In this method the geometry of the structure shall be modified to increase the dead weight of the concrete without affecting the capacity of the reservoir. Let us assume thickness of bottom slab 0.90m, thickness of top slab 0.60m and thickness of walls 0.45m. Now modified geometry of UGR will be 12.90m x 10.90m x 6m. Depth of overburden soil is increased from 0.40 m to 0.45 m. Other parameters are same as above.

Table 6: Stability Analysis – Increasing member thickness

1. Total Weight of Concrete or RCC (Walls & Slabs) = [(L × W × H) - (l × w × h)] × γr	7591.50 kN
2. Total Weight of Concrete / RCC (Beams) = No. of Beams of each side x length × size × γr	87.29 kN
3. Weight of overburden Soil= L × W × Depth of earthfill × γs	1202.22 kN
4. Weight of opening= (π/4× d2 × Top slab thickness × γr)+ (π/4 × d2 × depth of earthfill × γs)	6.66 kN
Total Downward Weight (W_T) =1 + 2 + 3 – 4	8874.35 kN
Total Upward Buoyant Force (W_B)= L × W × (H+Depth of earthfill- depth of water table) × γw	9069.35 kN
Factor of Safety (FS) = W_T / W_B	0.98 < 1.2
Result	Unstable

It is clear from the Table 6 that by increasing of member thickness even by considerable amount also is not sufficient to withstand the buoyant force although it increases the cost of the construction.

5.2 Add concrete fill to the inside of tank

To fill the concrete in the tank the geometry specially the depth is to be increased its dimensions so that the reservoir capacity could not be affected by pouring concrete. For that height of the tank, new depth is determined as:

Factor of Safety taken as=1.2

Additional weight required to resist buoyant force WT= FS × WB = 8201.86 kN

Total downward weight calculated for most critical condition, when reservoir is empty and ground water level is maximum = 3361.42 kN

Additional weight required to resist buoyant force

Wadd=8201.86-3361.42=4840.44 kN

Effective density of concrete

$\gamma_{c,eff} = \gamma c\text{-}\gamma w = 14\ \text{kN/m}^3$

Volume of additional concrete required

$V_{add} = W_{add} / \gamma_{c,eff} = 345.75\ \text{m}^3$

External area of UGR=12.40 x 10.40=128.96 m^2

Additional depth required

$h_{add} = V_{add}$ / External area of UGR=2.68 m

New Depth = H + h_{add}=7.58 m

After calculating the new depth of UGR, modified geometry of UGR will be 12mx10mx7.18m inside and 12.40m x 10.40m x7.58m outside. Thickness of bottom and top slab are 0.2m. Depth of overburden soil is also increased from 4.50 m to 0.60 m.

Now the depth of reservoir has been modified from 4.90 m to 7.58 m due to additional 2.68 m depth. In this additional depth, 321 cubic meter of concrete is required which is not an economical solution. But in this case, we assume that we have no option left out against this and we can afford so much additional concrete, now we have to check in that condition whether the structure remains stable or not because in that case overall depth is increase, so accordingly the buoyant force also increases due to increased displaced volume of ground water as explained in Table 7.

Table 7: Stability Check - Add Concrete Fill to The Inside of Tank

1. Total Weight of Concrete or RCC (Walls & Slabs) = [(L x W x H) - (l x w x h)] x γr	2898.15 kN
2. Total Weight of Concrete / RCC (Beams)=No. of Beams of each side x length x size x γr	87.29 kN
3. Weight of overburden Soil= L x W x Depth of earthfill x Ws	1470.14 kN
4. Weight of opening= (π/4x d2 x Top slab thickness x γr)+ (π/4xd2xdepth of earthfill x Ws)	4.63 kN
5. Weight of concrete infill inside= *l* x *w* x Additional Depth x Wc	7721.36 kN
Total Downward Weight (WT) = 1 + 2 + 3 - 4 + 5	12172.31 kN
Total Upward Buoyant Force W_B=L x W x (H+Depth of earthfill- depth of water table) x Ww	10550.25 kN
FACTOR OF SAFETY(FS) $FS=W_T/W_B$	1.15 < 1.20
Result	Unstable

From the above results, required FS is not achieved even after increasing the depth and filling of additional concrete, so this solution is not feasible and another solution should be worked out.

5.3 Base slab extension

The base is extended to incorporate the weight of overburden soil over the base slab to add an additional weight to counter the buoyant force. This method has two advantages

- Overburden soil over the extended base of bottom slab take part in increasing downward force.
- Wedge action of the soil adds weight due to soil internal angle of soil friction.

Figure 3 shows the effect of internal angle of friction of soil-by-soil wedge action and weight soil on extended base.

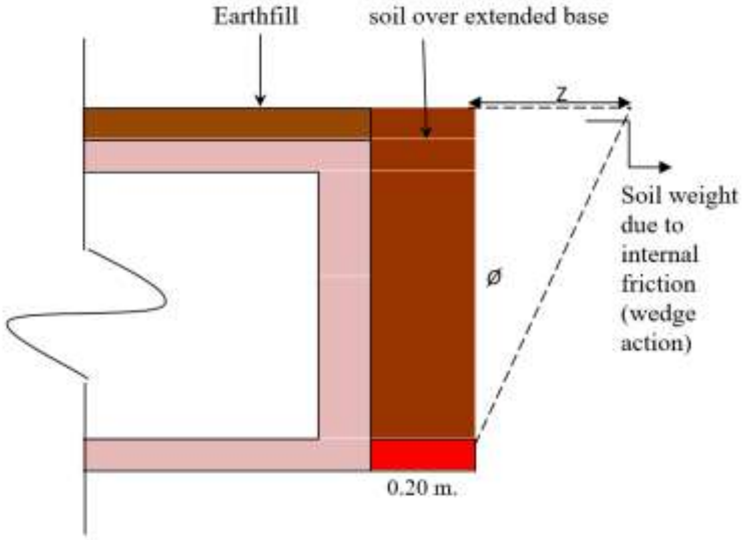

Fig 3: Effect of soil wedge action due to angle of internal friction

The analysis can be made by two ways:

- Considering the weight of overburden soil over the extended base of bottom slab only
- Weight of soil wedge due to soil internal angle of soil friction.

5.3.1 Considering the weight of overburden soil over the extended base of bottom slab only

Let us assume thickness of bottom slab 0.60m, thickness of top slab 0.40m, thickness of walls 0.45m and base extension 0.20m both sides. Now modified geometry of UGR will be 12.90m x 10.90m x 5.50m. Depth of overburden soil is taken as 0.45m. Other parameters are same as in Table 6.4. Calculation for stability analysis for this condition is shown in Table 8.

Table 8: Stability Check – Base extension without soil wedge

1. Total Weight of Concrete or RCC (Walls & Slabs) = $[(L \times W \times H) - (l \times w \times h)] \times \gamma r$	5833.88 kN
2. Total Weight of Concrete / RCC (Beams) =No. of Beams of each side × length × size × γr	87.29 kN
3. Weight of overburden Soil = $L \times W \times$ Depth of earthfill $\times \gamma s$	1202.22 kN
4. Weight of opening= ($\pi/4 \times d2 \times$ Top slab thickness $\times \gamma r$) + ($\pi/4 \times d2 \times$ depth of earthfill $\times \gamma s$)	5.24 kN
5. Buoyant Weight of soil engaged by extension Density of buoyant soil $= \gamma s - \gamma w = 9$ kN/m^3 Perimeter of Bottom slab = 13.30+10.90+13.30+10.90 = 48.40m W_5=Perimeter of Bottom slab × extended base width × (h+ top slab thickness+Earthfill) × density of buoyant soil	466.09 kN
Total Downward Weight W_T= 1 + 2 + 3 - 4 + 5	7584.23 kN
Total Upward Buoyant Force (W_B)= $L \times W \times$ (H+Depth of earthfill- depth of water table) $\times \gamma w$	8366.30 kN
Factor of Safety(Fs) $= W_T / W_B$	0.91 < 1.20
Result	Unstable

It can be seen that only weight of overburden soil over extended base does not affect the result. Since Factor of safety without considering the soil wedge is not sufficient to make the structure stable. Now we will take another case of the weight due to wedge action because of soil friction.

5.3.2 Weight of soil wedge due to soil internal angle of soil friction.

Due to soil internal angle of friction, there is wedge develop on the extended base, the effect of soil wedge helps to increase the dead weight of the structure. Stability Check for Base extension considering the soil wedge action is shown in Table 9.

Table 9: Stability Check – Base extension considering the soil wedge action

Assume angle of internal friction	20^0
$z = \tan 20^0 \times$ (h + Top slab thickness + Earthfill)	1.95 m
Outer perimeter with extension = 2 x (L+ Z + W +Z)	55.39 m
Volume of wedge = 1/2 × height × z × perimeter	288.51 m^3
Density of buoyant soil $= \gamma_s - \gamma_w = 19-10 =$	9.00 kN/m^3
Weight of soil wedge due to base extension (W_e)= =Volume × Density of buoyant soil	2596.62 kN
Add this weight to total Downward Force $W_T + W_e$	10180.85 kN
Factor of Safety due to soil wedge (FS)	1.22 >1.20
Result	Stable

It is clear from the Table 9 that the weight of soil wedge increases the downward gravity weight. This weight helps keeping the buoyant weight under control and the structure remain stable.

VI. ANTI-FLOATATION SLAB

In this method, the structure is attached to a bigger concrete slab than the bottom slab of the structure which may be precast or cast-in-situ. Let us assume thickness of bottom slab 0.60m, thickness of top slab 0.60m, thickness of walls 0.50m and base extension 0.30m both sides. Thickness of additional slab is taken as 0.60m. Now modified geometry of UGR will be 13m x 11m x 5.70m. Depth of overburden soil is increased from 0.45m to 0.60m. Other parameters are same. Calculation for stability analysis for this condition is shown in Table 10.

Table 10: Stability check – Anti- floatation slab

1.Total Weight of Concrete or RCC(walls&slab) $=[(L \times W \times H) - (l \times w \times h)] \times \gamma r$	6877.50 kN
2. Total Weight of Concrete / RCC (Beams) = No. of Beams of each side × length × size × γr	87.29 kN
3. Weight of overburden Soil = L x W x Depth of earthfill x Ws	1630.20 kN
4. Weight of opening= $(\pi/4 \times d2 \times$ Top slab thickness $\times \gamma r) + (\pi/4 \times d2 \times$ depth of earthfill $\times \gamma s)$	7.46 kN
5. Buoyant Weight of soil engaged by extension (W_5) Density of buoyant soil $= \gamma s - \gamma w = 9 kN/m^3$ Perimeter of Bottom slab = 13.30+10.90+13.30+10.90 =48.6 m W_5=Perimeter of Bottom slab × extended base width × (h+ top slab thickness +Earthfill) × density of buoyant soil	826.69 kN
Total Downward Weight $W_T = 1 + 2 + 3 - 4 + 5$	9414.21 kN
Total Upward Buoyant Force (W_B)= L × W × (H + Depth of earthfill- depth of water table) × γw	9009.00 kN
Factor of Safety (FS)= W_T / W_B	1.04 < 1.20
Result	Unstable

It is seen that mere changing of dimensions not sufficient to achieve the targeted safely factor. To overcome this problem, make an anti-floatation slab slightly larger than the bottom slab of UGR. Results can be modified as shown below. Adding an anti-floatation slab larger than the structure by 0.30 m all around

Additional Downward Force due to anti-floatation slab (We)=(L+2e) × (W+2e) ×Thickness of additional slab × buoyant density of slab material

Add this weight to total Downward Force

WT1= WT+We = 10834.05 kN

Factor of Safety due to anti-floatation slab=1.2

Therefore, stability is achieved in this case.

Once the analysis is safe then we have to design connections for connecting anti-floatation slab to the main structure. To design the tie down connections, it is require estimating that for how much force connection has to be design. Figure 4 explain the connection force and how the anti-floatation slab will be anchored to the main structure. Connection force for mechanical connection between anchored slab and the bottom slab of the structure is calculated by the relation (WB x FS) - WT and obtained equal to 1396.59 KN.

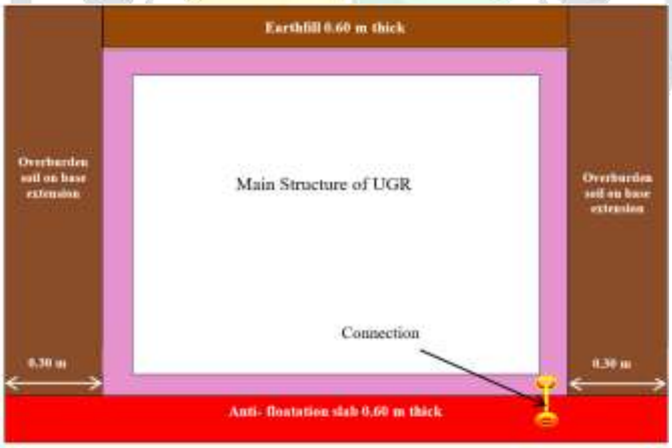

Fig 4: Connection for anchoring anti-floatation slab with main structure

VII. CONCLUSION

A study of the effect of buoyant force exerted by the submerged soil on an underground water reservoir where water table is considered on grade has been studied. The critical condition from the different possibilities of failure considering the effect of seasonal variation on ground water table has been identified. After analyzing the critical condition, various countermeasures have been adopted to make the structure safe against overturning or failure of the structure. Following conclusions are made from this study:

- The structure is unstable when the tank is empty and ground water table is maximum. This condition is considered as critical condition.
- By increasing the thickness of the components of the structure, the stability is not achieved against the critical condition.
- By increasing the depth of tank and filling of concrete in the additional depth, the structure is not stable.

- By extending the bottom slab 200mm beyond the walls and incorporate the weight of soil wedge due to angle of internal friction of soil, the desired stability is achieved.
- Provision of anti-floatation slab beneath the structure also found suitable to make the structure stable.

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