Finite Element Analysis of Underground Water Tank with different Safe Bearing Values of Soil

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Abstract—Underground liquid storage tank as part of environmental engineering facilities and primarily used for water and sewage treatment plants and other industrial wastes. Normally, they are constructed of reinforced concrete in the form of rectangular or circular configurations. The behavior of liquid storage underground tank during earthquakes is more important than the economic values of the tanks and their contents. A good understanding of the seismic behavior of these structures is necessary in order to meet safety objectives while containing construction and maintenance costs. In this paper Underground water tank with different safe bearing values of soil is used to analyze the typical behavior caused by seismic load. The finite element method (FEM) is selected as the examination method for the underground water tank. The most challenging part of this dissertation is seismic calibration stage which is executed by SAP2000 FEM package.

Keywords—underground water tank, Finite element modeling, earthquake loads, SAP 2000.

I. INTRODUCTION

Storage reservoirs and underground water tank are used to store water, liquid petroleum, petroleum products and similar liquids. The force analysis of the reservoirs and tanks is about the same irrespective of the chemical nature of the product. All tanks are designed as crack free structures to eliminate any leakage. Water or raw petroleum retaining slab and walls can be of reinforced concrete with adequate cover to the reinforcement. Industrial waste can also be collected and processed in concrete tanks with few exceptions. The petroleum product such as petrol, diesel oil, etc. are likely to leak through the concrete walls, therefore such tanks need special membrane to prevent leakage. Reservoir is a common term applied to liquid storage structure and it can be below or above the ground level. Reservoirs below the ground level are normally built to store large quantities of water whereas those of overhead type are built for direct distribution by gravity flow and are usually of smaller capacity.

II. OBJECTIVES

- To understand governing loads and carry out literature review related to underground water tank.
- To study the behavior of underground water tank under different safe bearing values of soil using analytical methods.
- To know about the design philosophy for the safe and economical design of water tank.
- To study the displacement and deformation pattern of underground water tank and are compared for different safe bearing values of soil.
- To study the base moments, side wall moments and settlement of underground water tank structure by considering dynamic type of loading when the tank is empty and full water level conditions.

III. DESIGN REQUIREMENTS

In water retaining structure a dense impermeable concrete is required therefore, proportion of fine course aggregates to
cement should be such as to give high quality concrete. Concrete mix weaker than m20 is not used. The minimum quantity of cement in the concrete mix shall not be less than 30KN/m3. The design of the concrete mix shall be such that the resultant concrete is sufficiently impervious. Efficient compaction preferably by vibration is essential. The permeability of the thoroughly compacted concrete is dependent on water cement ratio. Increase in water-cement ratio increases permeability, while concrete with lower water cement ratio is difficult to compact. Other causes of leakage in concrete are defects such as segregation and honey combing. All joints should be water tight as these are potential sources of water leakage. Design of liquid retaining structure is different from ordinary R.C.C structures as it requires that concrete should not crack and hence the tensile stresses in concrete should be within permissible limits. A reinforced concrete member of liquid retaining structure is designed on the usual principles ignoring tensile resistance of concrete in bending. Additionally it should be ensured that tensile stress on the liquid retaining face of the equivalent concrete section does not exceed the permissible tensile strength of concrete. The co-efficient of expansion due to temperature change is 11 x 10^-6 /°C and co-efficient of shrinkage may be taken as 450 x 10^-6 for initial shrinkage and 200 x 10^-6 for drying shrinkage.

A) Finite element analysis of underground water tank.

B) Bearing capacities of different rocks

<table>
<thead>
<tr>
<th>Sl no</th>
<th>description</th>
<th>Sbc(kpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rocks (hard) without laminations and defects. For e.g. granite trap &amp; diorite</td>
<td>3240</td>
</tr>
<tr>
<td>2</td>
<td>Laminated Rocks. For e.g. Sand stone and Lime stone in sound condition</td>
<td>1620</td>
</tr>
<tr>
<td>3</td>
<td>Residual deposits of shattered and broken bed rocks and hard shale cemented material</td>
<td>880</td>
</tr>
<tr>
<td>4</td>
<td>Soft rock</td>
<td>440</td>
</tr>
</tbody>
</table>

C) Presumptive safe bearing values for different types of Sandy soil

<table>
<thead>
<tr>
<th>Sl no</th>
<th>description</th>
<th>SBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gravel, sand and gravel, compact and offering resistance to penetration when excavated by tools</td>
<td>440</td>
</tr>
<tr>
<td>2</td>
<td>Coarse sand, compact and dry</td>
<td>440</td>
</tr>
<tr>
<td>3</td>
<td>Medium sand, compact and dry</td>
<td>245</td>
</tr>
<tr>
<td>4</td>
<td>Fine sand, silt (dry lumps easily pulverized by fingers)</td>
<td>150</td>
</tr>
<tr>
<td>5</td>
<td>Loose gravel or sand gravel mixture, Loose coarse to medium sand, dry</td>
<td>245</td>
</tr>
<tr>
<td>6</td>
<td>Fine sand, loose and dry</td>
<td>100</td>
</tr>
</tbody>
</table>
D) Presumptive safe bearing values for different types of Cohesive soil

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Description</th>
<th>SBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soft shale, hard or stiff clay in deep bed, dry</td>
<td>440</td>
</tr>
<tr>
<td>2</td>
<td>Medium clay readily indented with a thumb nail</td>
<td>245</td>
</tr>
<tr>
<td>3</td>
<td>Moist clay and sand clay mixture which can be indented with strong thumb pressure</td>
<td>150</td>
</tr>
<tr>
<td>4</td>
<td>Soft clay indented with moderate thumb pressure</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Very soft clay which can be penetrated several centimeters with the thumb</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>Black cotton soil or other shrinkable or expansive clay in dry condition (50 % saturation)</td>
<td>130-160</td>
</tr>
</tbody>
</table>

IV. ANALYSIS AND DESIGN

DESIGN CASES:
Case 1: Tank is full and
Case 2: Tank is empty.

The above cases are extreme cases and hence the underground tank design has been carried out considering these two cases.

DESIGN CALCULATIONS:

Case 1: Tank is full.
a. Maximum soil pressure = 18000 x 4.875 x (1-sin30/(1+sin30))
   Ps = 32951.5 N/m²
   Ps = 32.95 KN/m²
b. Maximum water pressure = 9810 x 4.875
   Pw = 47823.8 N/m²
   Net pressure at the bottom of wall = Pw - Ps
   Pnet = 14872.25 N/m²

These pressure values have been incorporated in the finite element software. Simultaneously these values are utilized for the further computation of forces.

Fig 6 moment co-efficients

Moment Co-efficient and individual wall panels, top and bottom hinged.
Vertical walls fixed.

Hence appendix 01 is created which is based on IS 456-2000 and the design of top slab has been carried out. Assumptions for design of top slab:

Loads:
- **Dead load** = 2KPa
- **Live load** = 5KPa

Following input details are considered in the FEM model:
1) **K spring constant** = 250 / 0.005 = 50,000
2) **Unit weight of soil** = 18 KN/m³
3) **Ka** = 0.33
4) **Unit weight of water** = 10 KN/m³
5) **Surcharge pressure** = 10 KN/m²
6) **Depth of overburden** = 3.15M

By considering the above loads and the geometry, the following mathematical model
Case 1: Tank is full
1.5 x (Self weight + internal water pressure + lateral dry soil pressure
+ Surcharge + live load + floor finish)

Case 2: Tank is full
1.5 x (Self weight + lateral submerged soil pressure + surcharge + live load + floor finish)

Note: Since it is envelop minimum and maximum forces are produced.
V. CONCLUSIONS

TIME PERIOD AND FREQUENCY
1) It is well known that natural time period goes on decreasing with increasing in frequency.
2) Time period is high when the underground water tank is full water level compared to empty. If the underground water tank is full of water obviously it takes more time to complete one cycle of free vibration than the empty tank.
3) Frequency is less when the tank is full compared to empty. If the tank is full obviously it takes less rotation per second.

DEFORMED SHAPE DUE TO DIFFERENT LOADINGS
The deformed shape are extracted for safe bearing value 500KN/m2
1) The deformation is negligible in all loading conditions.
2) The maximum deformation due to full water load is only 364*E-3m.
3) Due to uniform distribution of water, and external loading at top, the deformation is more at the center of the side walls of tank.
4) Since the vehicular load (live load) at the top portion, hence the maximum deformation is at top portion of tank.

SIDE WALL MOMENTS
1) The side wall moment in all considered safe bearing values and in all conditions is almost linear . But if we compare among those water level, side wall moment is little bit varying in full water condition compared to empty condition.
2) During earthquake, due to water hammering action the displacement is little bit high in safe bearing value 150KN/m2 compared to safe bearing value 500KN/m2.
3) The side wall moment is decreasing with increasing safe bearing values.

With this, finally we concluded that, for every load case the soil with safe bearing value 150KN/m2 has higher value. Hence the underground water tank in soil with safe bearing value 150KN/m2 will get affect more than the underground water tank in soil with safe bearing value 500KN/m2 during earthquake.

Therefore for heavy and important structures such as underground liquid storage tanks, dams, bridges etc., the soil with higher safe bearing values are preferred. Since joints are the weakest positions in the underground water tank, hence providing the rubber dampers at the joint segment is one of the methods in earthquake resistant design. This method can be use practically by conducting some more investigations and experiments to make underground water tank earthquake resistant.

VI. SCOPE OF FUTURE WORK
1. The analyses can be extended by considering when tank is half water level condition. In this way, the behavior of different safe bearing values of soil are observed more sensitively.
2. Furthermore, the analysis can be carried out by considering circular shape of underground water tank.

REFERENCES


TEXT BOOKS

CODES/STANDERDS