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Foundation Design Of Circular Overhead Water Tank In Seismic Zone-V

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***Abstract**:* Foundation is the structural base member which transfer the whole loads of structure to the ground with stability and longevity. The foundation is generally enlarged at the base to distribute the load over the large area such that the pressure on the soil does not exceed its permissible bearing capacity. In this project is used to define the foundation design of over head tank by manual design. The design involves load calculations manually. We use manual design for Circular over head tank IS 456-2000 consider the load as per the according to IS 1983 (part-1). Firstly it limits the stresses in steel so that concrete is not over stressed and in second aspect it limits the cracking width. This project gives in brief, The theory behind the design of liquid retaining structure (Elevated Circular Water Tank) using Working Stress Method and IS 456:2000.

Index Terms – Circular Overhead Water Tank, Natural Hazard, Working Stress Method, IS Code.

I. INTRODUCTION

It is very important to understand the loading system and the load path works in any structure. First the load is applied on the slab deck which is transferred through beam and beam transfer these load on to the column which are eventually transferred to the foundation. Load exist from the structural system and are transfer to the earth beneath it. The foundation system of any elevated water tank plays a decisive role in its overall safety and long-term performance, and this importance becomes even more pronounced when the structure is located in Seismic Zone V, where the expected ground motion is severe. Among the different foundation types available to structural engineers, footings are the most widely adopted because they offer a reliable, economical, and structurally sound means of transferring loads from the superstructure to the supporting soil.

In a circular overhead water tank, the loads coming from the container and staging are concentrated at the base of the supporting columns. The primary function of a footing, therefore, is to spread these loads over a sufficiently large soil area so that the stresses imposed on the ground remain within the safe bearing capacity. This introductory discussion highlights the purpose, behaviour, and design requirements of footings, especially for overhead tanks subjected to high seismic forces.

Reinforcement detailing is an essential part of footing design. Footings are typically designed to resist both one-way and two-way shear, and adequate bottom reinforcement must be provided to handle bending moments. In seismic regions, the detailing at the junction of the column and footing becomes particularly significant. The bars from the column must be properly anchored into the footing to prevent failure during strong ground motion. While IS 13920 focuses primarily on ductile detailing of reinforced concrete buildings, the principles of anchorage, confinement, and development length specified in the code can be adapted for footing design in tank structures as well.

II. LITERATURE REVIEW

1. In 2016, Ankush N. Asati et al. published a paper titled “Seismic Analysis and Optimization of RC Elevated Water Tank” in IJERA where circular elevated water tanks were modelled using a two-mass idealization (impulsive + convective) and analysed under response spectrum method (RSM) via SAP2000. They studied 36 combinations of staging arrangements (number of columns, staging levels) and observed that increasing the number of columns does not always improve seismic performance. This study provides a direct insight into how staging geometry and number of supports influence forces transmitted to footings — an aspect often neglected by simpler code-based practice.

2. The research by Sheetal Mohan Tarwatkar and Niraj Bias (2021) titled “Seismic Behaviour of Elevated RCC Water Tank Having Different H/D Ratio and Shape” concludes that circular tanks show better seismic resistance compared to rectangular ones. They studied variations in H/D ratio (height of water column to tank diameter) and concluded circular shape has better performance under seismic action due to symmetry and more uniform distribution of hydrodynamic pressure.
Their findings support the suitability of circular tanks in seismic zones; and indirectly suggest that foundation loads (base shear, overturning moments) may be lower or more uniformly distributed in such configurations — a point of value when designing footings.

3. A 2021 study by Tayyaba Anjum & Mohd. Zameeruddin — “Evaluation of Efficacy of the Elevated Water Tank Under the Seismic Loads” — performed non-linear time history analysis on models representing existing elevated tanks in Maharashtra, under full and empty conditions.Their results highlight the importance of choosing appropriate staging and ensuring energy dissipation capacity (ductility) of the system.

4. Another significant contribution is by C.J. Chitte (2022) in a paper “Seismic Performance of R. C. Elevated Water Storage Tanks”. This study investigates the dynamic performance of RC tanks with different water heights and staging configurations, and particularly examines the effect of including bracing in staging on reducing seismic demand. Chitte recommends a more integrated FE-based approach with nonlinear hinge properties, sloshing effects, and soil-structure interaction for realistic design — especially of foundation components and column-footing junctions.

III.GENERAL PRINCIPLE FOR SEISMIC DESIGN

Seismic design is fundamentally based on the idea that structures must be able to withstand the unpredictable and dynamic forces generated during an earthquake. Unlike static loads, earthquake forces are sudden, cyclic, and often multidirectional. Therefore, the goal of seismic design is not to make a structure completely “earthquake-proof,” but to ensure that it behaves in a controlled, ductile, and safe manner during strong shaking. The primary objective is to prevent collapse and protect human life, even if the structure undergoes repairable damage.

One of the core principles of seismic design is understanding how inertia forces act on a structure. During ground motion, the mass of the structure resists movement, creating horizontal forces proportional to its weight. This means heavier structures attract higher seismic forces. As a result, reducing unnecessary mass and adopting lighter materials can significantly improve seismic performance.

Another key principle is ensuring regularity and symmetry. Structures with uniform mass and stiffness distribution tend to respond more predictably during earthquakes. Irregular layouts or sudden changes in stiffness often lead to stress concentration and torsional effects, which can increase the risk of damage. For this reason, both the architectural layout and structural system should be planned with seismic behaviour in mind.

Ductility is another essential requirement. During strong shaking, some structural members may reach their yield point. A well-designed system should allow these members to deform without sudden failure, dissipating energy and maintaining overall stability. Proper reinforcement, confinement, and joint detailing play a crucial role in achieving this ductile behaviour.

Finally, seismic design must consider foundation performance and soil–structure interaction. A building or tank can only perform as well as the ground it rests on. The type of soil, depth of foundation, and potential issues like liquefaction influence how seismic forces are transmitted and resisted. In summary, seismic design combines principles of mass control, structural regularity, ductility, and sound foundation behaviour to ensure safety during earthquakes.

IV.FOUNDATION DESIGN IN SEISMIC ZONE-V

Designing foundations in Seismic Zone V, the highest earthquake-risk zone in India, requires a careful and thorough approach. In this zone, structures are expected to face intense ground shaking, high lateral forces, and rapid accelerations during an earthquake.

As a result, the foundation system must be capable of safely transferring not only vertical loads but also significant horizontal and overturning forces without losing stability. For elevated structures like circular overhead water tanks, the demand on the foundation becomes even greater because the staging columns act as slender load paths, making the base highly sensitive to seismic actions.

The first step in foundation design for Zone V is understanding the soil conditions through a detailed geotechnical investigation. Soil properties such as bearing capacity, density, shear strength, and liquefaction potential play a crucial role in determining how the foundation will behave during an earthquake. In regions where soil is soft or loose, additional measures such as soil improvement, deeper embedment, or larger footing dimensions may be needed to ensure adequate safety.

Footings in this zone must be designed to resist high bending moments and shear forces that arise from seismic loads. The pressure distribution beneath the footing often becomes uneven during an earthquake, with one side experiencing higher compression and the other at risk of uplift. To counter this, the foundation should be proportioned so that the resultant load remains within the middle third, preventing soil separation. Reinforcement detailing also becomes critical; proper anchorage, increased ductility, and confinement of concrete help the foundation perform better under cyclic loading.

In addition to strength, serviceability concerns such as differential settlement must be controlled, as even small tilts can disturb the staging of a water tank. By combining accurate soil data, adherence to IS 1893 and IS 456 guidelines, and robust reinforcement detailing, a well-designed foundation in Seismic Zone V can ensure long-term stability and safety, even during severe earthquakes.

V.WORKING STRESS METHOD

The Working Stress Method (WSM) is one of the earliest and most traditional approaches used in the design of reinforced concrete structures. This method is based on the fundamental assumption that both concrete and steel behave elastically under service loads, meaning that stresses remain within their permissible limits throughout the structure’s working life. Because of its straightforward nature and clear safety margins, WSM has been widely used for many decades, particularly in water-retaining structures such as overhead tanks, where crack control and serviceability are extremely important.

Under the Working Stress Method, the structure is designed so that the stresses produced by the actual working loads do not exceed the allowable stresses specified for concrete and steel.

These allowable stresses are derived by applying suitable factors of safety to the material strengths. Since water tanks must remain watertight, keeping stresses low helps minimize cracking and thereby reduces the risk of leakage. This makes WSM especially suitable for liquid-retaining structures compared to limit state methods, which focus more on ultimate strength rather than serviceability. One of the key principles of WSM is the modular ratio, which relates the elastic modulus of steel to that of concrete. This ratio allows engineers to convert steel areas into equivalent concrete areas for analysis. The method assumes a linear stress–strain relationship, simplifying calculations of bending moments, shear, and axial forces. Although this approach does not fully capture the nonlinear behaviour of concrete at higher load levels, it provides a conservative and reliable design for structures that are not expected to undergo significant overload.

Today, many modern structures are designed using the Limit State Method, but WSM still retains its relevance in the design of water tanks, reservoirs, and other structures where serviceability and crack control are critical. Its simplicity, predictability, and emphasis on safety make it a dependable method for ensuring durable and watertight construction.

VI. RESEARCH METHODOLOGY AND DESIGN

This project follows a systematic research methodology designed to understand, analyse, and develop a safe and reliable foundation design for a circular overhead water tank located in Seismic Zone V of India. Because Zone V represents the highest level of seismic hazard in the country, the methodology combines both theoretical modelling and practical engineering approaches.

Dimension of Circular Overhead WaterTank.

- Diameter of cylinder portion:

$$D=\sqrt{4b/\pi h}$$

Where D=Inner Diameter
V=Volume of Tank
H=Height of water
D=8.67
D=9m

- Radius=4.5m
- Raise of top dome=h1=0.2×D
  =1.8m
- Raise of bottom dome=h2=0.16×D
  =1.44m
- Thickness of the wall=120m
- Diameter of cylindrical part=9m
- Arc equation of the top dome
  $r1=\frac{\left(\frac{D}{2}\right)^2+h1^2}{2h1}$
  =1.461m
- Arc equation for bottom beam(r2)
  $r2=\frac{\left(\frac{D}{2}\right)^2+h2^2}{2h2}$
  =1.42m
- Height of vertical wall=h3
  $=\frac{\pi}{4}\times D^2\times h3$
  Volume of bottom dome (sphere)
  $=\pi\times h2^2\times\left(r2\times\frac{h2}{3}\right)$
  =4m
  h3=4m

1. Design of Top Dome:

- Thickness of the dome=120 mm
- Meridonal forces(T1)
- Hoops Tension(T2)

$$T1=\frac{W\times R}{1+cos\theta}$$

W=load of the dome
Live load=1.5KN/m^2
Self weight=Thickness x Density
=0.12 x 25
=3 KN/m^2

Total Load=1.5+3
=4.5 KN/m^2

- Radius of Curvature of the dome=(h)

h= rise of the dome
h=0.2 x D
=0.2 x 9
= 1.8 m
R=1.46 m

T1=$\frac{4.5\times1.46}{1+0.948}$
T1=3.372 KN/m

- Meridonal Sress=Force/Area

=$\frac{3.372\times10^3}{1000\times10}$
T1=0.3379 N/mm^2

- Direct Tension Stress=σct for M30 Concrete=15 Kg/cm^2
- Permissible Stress in the concrete=8 N/mm^2

0.337$<$ 8 N/mm^2 Hence safe.

- Area of Reinforcement:

Provide 0.24% minimum reinforcement
Ast=0.24/100 x 1000
=288 mm^2

- Hoop force(T2)

T2= W x R x cos$\theta - \frac{1}{1+cos\theta}$
= 4.5 x 1.42 x 0.948-1/1+0.948
T2= 1.774 x 10^1 N/mm^2

1.774$<$ 8 N/mm^2 hence safe.
Provide 0.24% minimum reinforcement.

2. Design of Top ring beam:

- Design for the Hoop Tension(W)

W=T1cosθ
=3.372 x cos18.39
=3.198 KN/m
Total Hoop Tension on beam=W x D/2
=3.198 x 9/2
=14.39 KN

- Ast for the Hoop Tension=T/σst

=14.39 KN/30

=479.67 mm^2

- Dimension for R.B

σct =$\frac{T}{Ag+(m-1)Ast}$
Ag=b x D

Modular Ratio m=280/3σcbc $(\sigma cbc = 10)$
m=280/3 x 10
m=9.33

- Permissible tensile stress

$$\sigma ct = \frac{T}{Ag+(m-1)Ast} < 1.5$$

T=14.39 x 1000

Ag=b x D (b=200 mm)

Ast=520 and m=9.33

=14.39 x 1000/250 x D+(9.33-1) x 520

Now, solving for the effective depth D

= 14.39 x 1000/250 x D+(9.33-1) x 520 < 1.5

= D$> 335\ mm$

=D=350 mm

=b=200 mm

Size of beam=200 x 350 mm

Provide minimum shear Reinforcement 8 mm Ø bar – 2 legged vertical stirrups.

Sv=0.87 x fy x Asv/0.4 x b

Asv=3.414/4 x d^2 x 2

=127.23 mm^2

Sv=0.87 x 415 x 127.23/0.4 x 200

=200.63 mm

- Spacing Limit

1. 0.75 x D =262 mm
2. 350 mm

   Provide 8 mm Ø bar – 2 legged vertical stirrups @265 c/c.

3. Design of Brace Beam

- Service moment in brace:

  M=2×moment in column×√2

  =2×14.677×√2

  =41.50 KN.m
- Section of brace=300×250

  b=300, d=250mm
- Limiting moment of resistance of the section is computed as =Mu lim

  Mu lim=0.138×fck×bd^2

  =68.526 KN

  m$<$ $Mu\ hence\ section\ is\ under\ reinforced.$
- Compute the parameter:

  $= \frac{Mu}{bd^2}$

  =3.428

  Ast=796 mm^2

  Provide 4 bar of 20Ø.
- Length of brace(L)

  L=2x4xsin18.43

  =2.259 m
- Maximum service load shear force in brace is computed as:

  $$V=\frac{moment\ in\ brace}{half\ length\ of\ brace}$$

  = 41.50/0.5x2.5

  =33.2 KN
- Design ultimate shear force:

  Vu=1.5x33.2=49.8 KN
- $\tau_v=\frac{Vu}{b\times d}$

  = 1.146 N/mm^2

- Shear force carried by concrete:
  $=\tau x b x d$
  =29.32 KN
  Balance shear force: 49.8-29.32
  =20.48 KN
  Using 10 mm $\emptyset$ 2 $legged\ stirrups.$

- Spacing:
  Sv=480 mm
  But Sv not greater than 0.75d or 300 mm whichever is less.
  Hence provide 10 mm $\emptyset 2\ legged\ stirrups\ at\ 300\ mm$ c/c.

4. Design of Footing:

- Total column load=782.64 KN
- Weight of the footing=126.75 KN
  Total=782.64+126.75=909.39 KN
  - Safe bearing capacity of the soil=200 KN/m^2
  - Area of the footing required=909.39/200
    =4.54 m^2
    - Let the diameter of the footing be X meter
      $\frac{\pi x^2}{4} = 4.54$
      =2.4 m
      Provide a diameter of footing equal to 2.50 m
      Radius of footing=1.25 m
    - Net upward pressure intensity on the footing:
      P=$\frac{782\times10^3}{\pi\times1.25^2}$
      = 159310 N/m^2
    - Depth of the footing:
      Bending moment, consider the shaded area of plan of the footing.
      Distance of the centroid of the shaded area from the axis of the column
      =0.695 m
    - Area shaded=$\frac{\pi}{4} \times R^2 - r^2$
      =1.20 m
    - Load on shaded area=159310×1.20=191920 N
    - Maximum Bending moment=191920×0.819=36273 N
    - Breadth of shaded part of the column face=235.61 mm
      Taking c=10 N/mm^2,t=230 N/mm^2 and equating moment of resistance to the bending moment=1.213bd^2
      d=845 mm
      Providing a clear cover of 60 mm to the lower layer of bar
      16 mm dia bar.
      Effective cover to the centre of upper layer of the bar=60+16+8=84 mm
      Overall depth=845+84=929 mm
      =950

VII. Result

1. Total Volume of concrete = 174.2 Cu.meter
2. Total quantity of steel = 87948 Kg
3. Numbers of columns = 8 Nos.
4. Type of foundation = Raft foundation
5. Diameter of tank = 9 m
6. Total pressure per m2 on the dome = 4000 N/m2
7. Load on top dome = 4.98 KN
8. Load due to ring beam=2.65 KN/m
9. Load due to Tank wall = 25000 N/m
10. Load on each column=5.248 KN
11. Total height of the structure=15.95 m

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