Underground Rectangular Water Tank Design & Analysis

1. Project Overview & Scope

The proposed Reinforced Cement Concrete Underground Water Tank was an integral part of a larger project situated in **Seismic Zone-III, India**. This project required a robust and efficient design solution for critical water storage.

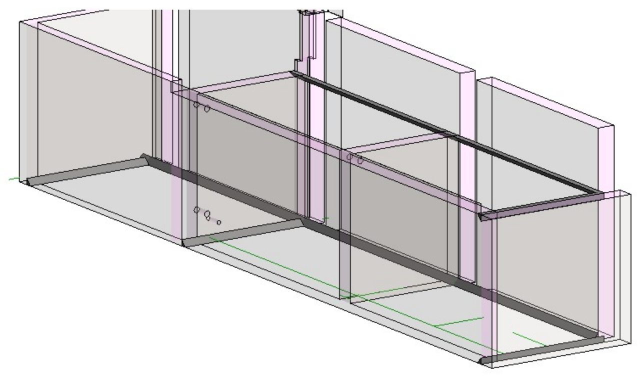
Our design was executed in strict adherence to key Indian Standards and best practices:

- **IS 456:2000** – Plain and Reinforced Concrete Code of Practice (Fourth Revision)
- **IS 13920:2016** – Code of Practice for Detailing of Reinforced Concrete Structures Subjected to Seismic Forces
- **IS 1893 (Part I)** – Criteria for Earthquake Resistant Design of Structures (Seismic Code)
- **Design Aid for Reinforced Concrete to IS 456**

Project Data & Parameters

- **Seismic Zone:** III (as per IS 1893 Part 1-2016)
- **Allowable Bearing Capacity:** Critical consideration due to low soil bearing capacity identified from the Geo-Technical investigation report (12.9 ton/m² at 3.0m depth; 16 ton/m² at 4.5m depth).
- **Material Properties:**
  - **Concrete:** M30 Grade (fcu = 30 N/mm²)
  - **Reinforcement:** Fe415 / Fe500 / Fe500D HYSD TMT bars conforming to IS 1786 were utilized for all elements.
- **Tank Dimensions (Highlighted Partition):**
  - Length (L): 4.60 m
  - Breadth (B): 2.60 m
  - Overall Depth: 4.20 m
  - Free Board: 0.30 m

The capacity and layout of the water tank were precisely finalized to meet specific project requirements. This document focuses on one key partition of the water tank for detailed illustration.



3D view of underground water tanks

2. Design Methodology & Challenges

This section details our engineering approach, showcasing the analytical rigor and problem-solving involved. You will place your Excel screenshots and detailed Civil 3D/Revit screenshots here, explaining your design decisions and workflow as the text unfolds.

Analysis & Design Approach

Our analysis began with an initial calculation of the required wall thickness, yielding a required thickness of 390 mm (calculated as Dreqd=fcbt×bM×6). We then adopted a **Proposed Wall Section Thickness of 440 mm** to ensure ample capacity and durability.

Following the provisions of **IS: 3370 (Part II)-2009** and relevant guidelines, our approach involved:

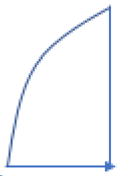
- **Approximate Analysis for Initial Load Combinations:** This included calculating Myn Cantilever moments and horizontal moments. Moment distribution or Kani's method was employed for initial wall moment calculations.
- **Advanced Seismic Analysis:** In conjunction with **IITK-GSDMA Guidelines for Seismic design of liquid storage tanks**, we utilized expressions for spring-mass models. This enabled us to accurately determine critical seismic parameters:
  - Base shear at the bottom of the wall in impulsive mode.
  - Bending moments and overturning moments.
  - Hydrodynamic Pressure and Convective Hydrodynamic Pressure.
  - Equivalent Linear Pressure Distribution and sloshing wave height.
  - This detailed analysis revealed a significant increase in design moments; for instance, vertical moments increased from 32 kN/m to **47 kN/m** due to impulsive convective modes, requiring careful adjustment of rebar quantities.
- **Reinforcement Details:**
  - For the 440 mm thick walls, **vertical reinforcement used was V_#12 @100 to V_#10 @140.**
  - **Horizontal reinforcement was H_#12 @170 to #10 @140.**
- **Foundation & Uplift Check:** The base slab was rigorously checked for bearing pressure and **uplift**, a critical challenge given the **high water table** at the site. The higher floor load path, combined with this deep water tank, necessitated fine-tuned checks for the overall foundation design.
- **Design Code & Validation:**
  - **IS India Standard code methods** provided accurate design moments, proving more reliable than approximate methods and showing strong correlation with values from the **Reynolds Handbook**.
  - Results were further validated using **Finite Element Method (FEM)** analysis, yielding very similar outcomes. This comparative approach ensured the robustness of our designs, with meticulous checks on shear forces and crack widths against permissible codal values.
  - Shear forces and crack widths were meticulously checked against permissible codal values.

COMMENTARY

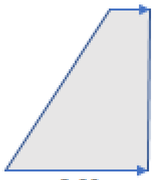
Table C 1 – Expression for parameters of spring mass model

Circular tank	Rectangular tank
$\frac{m_i}{m} = \frac{\tanh\left(0.866\frac{D}{h}\right)}{0.866\frac{D}{h}}$	$\frac{m_i}{m} = \frac{\tanh\left(0.866\frac{L}{h}\right)}{0.866\frac{L}{h}}$
$\frac{h_i}{h} = 0.375$ for $h/D \le 0.75$	$\frac{h_i}{h} = 0.375$ for $h/L \le 0.75$
$= 0.5 - \frac{0.09375}{h/D}$ for $h/D > 0.75$	$= 0.5 - \frac{0.09375}{h/L}$ for $h/L > 0.75$
$\frac{h_i^*}{h} = \frac{0.866\frac{D}{h}}{2\tanh\left(0.866\frac{D}{h}\right)} \quad 0.125$ for $h/D \le 1.33$	$\frac{h_i^*}{h} = \frac{0.866\frac{L}{h}}{2\tanh\left(0.866\frac{L}{h}\right)} - 0.125$ for $h/L \le 1.33$
$= 0.45$ for $h/D > 1.33$	$= 0.45$ for $h/L > 1.33$
$\frac{m_c}{m} = 0.23\frac{\tanh\left(3.68\frac{h}{D}\right)}{\frac{h}{D}}$	$\frac{m_c}{m} = 0.264\frac{\tanh\left(3.16\frac{h}{L}\right)}{\frac{h}{L}}$
$\frac{h_c}{h} = 1 - \frac{\cosh\left(3.68\frac{h}{D}\right) - 1.0}{3.68\frac{h}{D}\sinh\left(3.68\frac{h}{D}\right)}$	$\frac{h_c}{h} = 1 - \frac{\cosh\left(3.16\frac{h}{L}\right) - 1.0}{3.16\frac{h}{L}\sinh\left(3.16\frac{h}{L}\right)}$
$\frac{h_c^*}{h} = 1 - \frac{\cosh\left(3.68\frac{h}{D}\right) - 2.01}{3.68\frac{h}{D}\sinh\left(3.68\frac{h}{D}\right)}$	$\frac{h_c^*}{h} = 1 - \frac{\cosh\left(3.16\frac{h}{L}\right) - 2.01}{3.16\frac{h}{L}\sinh\left(3.16\frac{h}{L}\right)}$
$K_c = 0.836\frac{mg}{h}\tanh^2\left(3.68\frac{h}{D}\right)$	$K_c = 0.833\frac{mg}{h}\tanh^2\left(3.16\frac{h}{L}\right)$

Equivalent linear impulsive pressure distribution is shown below:



0.57

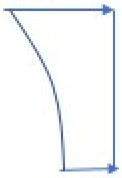


3.72
Actual
Distribution

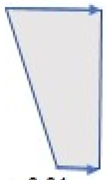
2.83
Linearised
distribution

Equivalent linear convective pressure distribution is shown below:

0.61



0.41



0.08
Actual
Distribution

-0.01
Linearised
distribution

Sloshing Wave Height

Maximum sloshing wave height,

$d_{max} = (A_h)_c$ R L / 2	0.029*2.00*4.60/2	0.132	m

Net -ve horizontal bending moment at the corners of walls:				
Long wall, $M_{nx,max}$ - (T_L * e) =		20.46-30.85*0.154	15.70	kN.m/m
	add hydrodynamic to stati	1.13	17.72	kN.m/m
Short wall, $M_{ny,max}$ - (T_B * e) =		20.46-51.99*0.154	12.45	kN.m/m
	add hydrodynamic to stati	1.1286	14.05	kN.m/m
Net +ve horizontal bending moment at the mid spans of vertical walls:				
Long wall, $M_{nx,max}$ - (T_L * e) =		16.88-30.85*0.154	12.13	kN.m/m
	add hydrodynamic to stati	1.13	13.68	
Short wall, $M_{ny,max}$ - (T_B * e) =		0.78-51.99*0.154	-7.23	kN.m/m
	add hydrodynamic to stati	1.13	-8.15	

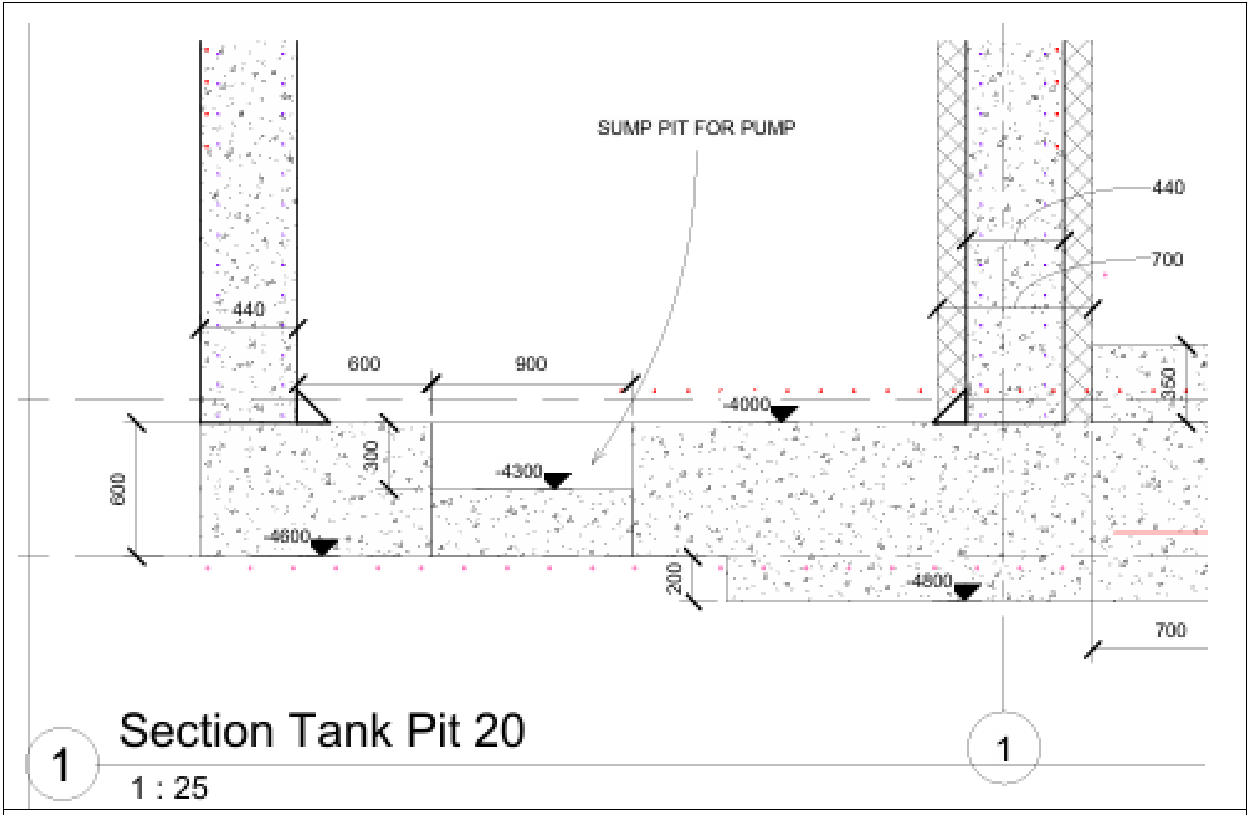
<u>REF: IITK-GSDMA GUIDELINES FOR SEISMIC DESIGN OF LIQUID STORAGE TANKS: oct 2007</u>

Check for bearing Pressure

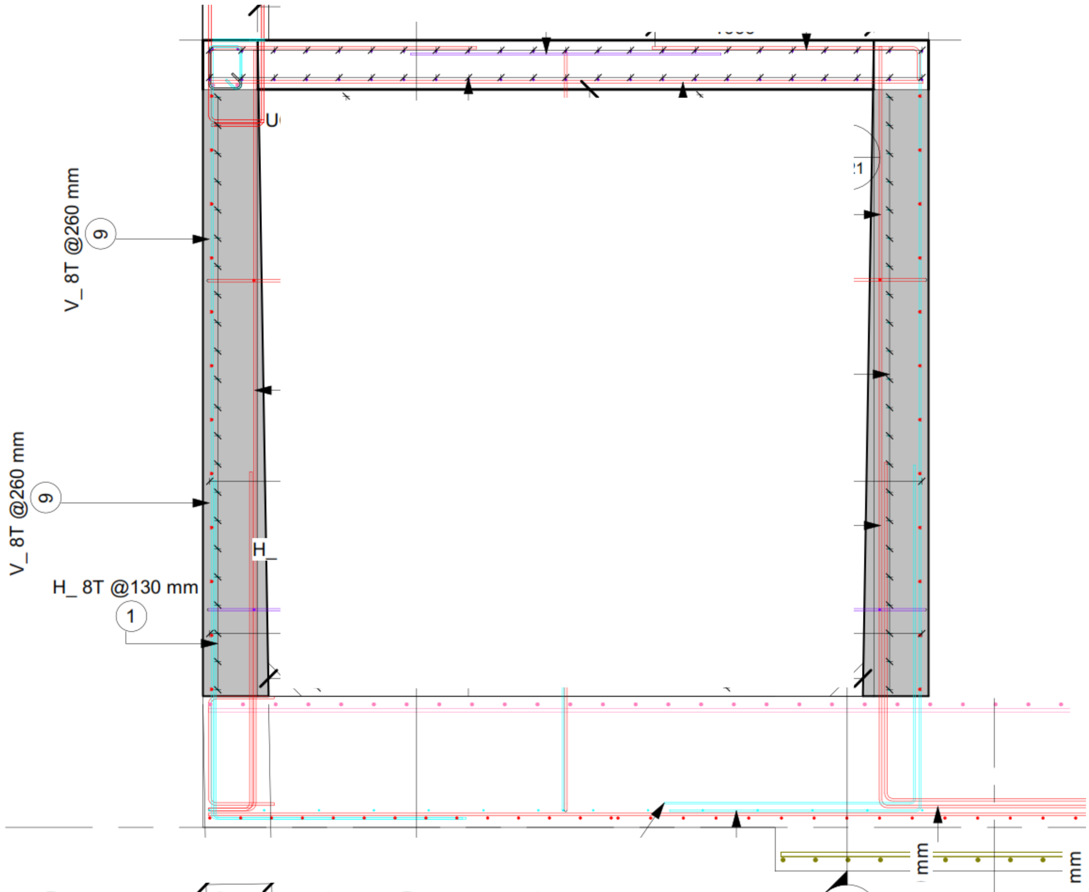
First the bearing presuure on the soil is computed.

Load from roof (if an Live load		Roof thicknes	D.L	D.L+L.L			
	3.0	0.20	5.00	8.00	8.00*5.00*3.00	120.0	kN
Load from vertical walls, columns (if any)			2*(5.00+3.00)*0.40*4.20*25.0			672	kN
Load of the liquid/water			4,600*2,600*4,200*11.0/10^9			552.552	kN
Load of the bottom/base slab			5.60*3.60*400/1000*25.0			201.6	kN
Total Load						1546.2	kN
Then Soil pressure			1,546.15/(5.60*3.60)			76.69	KN/m^2
Check SBC			IF(76.69<=160.00Pass,Fail			Pass	

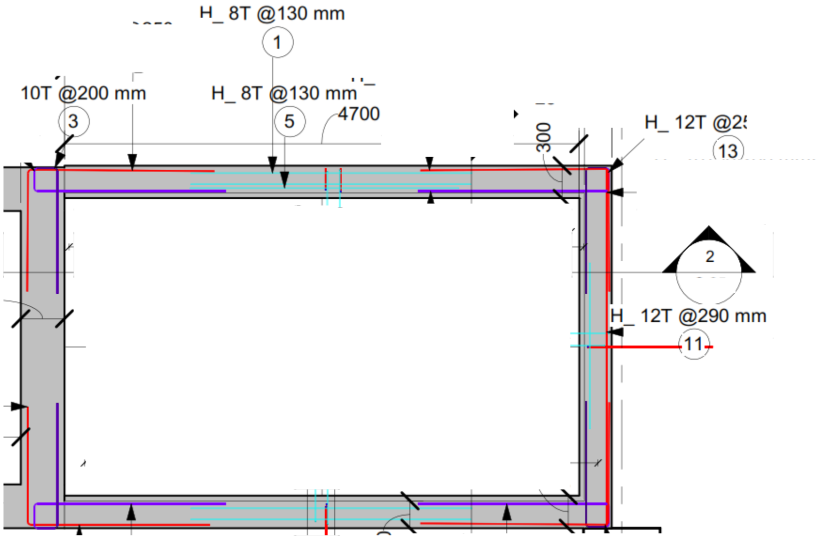
Detailed Drawings/Rebar Layout: Detailed Revit screenshots showing the tank's sections, rebar detailing views.



Enlarged Section of junction of Tanks wall to base slab



Section-A Under Ground Tank
1 : 25



3 PLAN UG Tank Mid level
1 : 50

Plan- Section of Tanks Wall and base slab and cover slab.

Workflow Efficiency & Value-Added Deliverables

- **Optimized Workflow:** While FEM and proprietary software can derive moments and forces, we found that defining precise boundary conditions for water tanks can be time-consuming. Our **formula-based approach** proved to be more efficient for this project, allowing for rapid iterations and precise control.
- **Clear & Constructible Detailing:** Reinforcement drawings were meticulously detailed for **easy readability and site implementation**, minimizing potential on-site confusion.
- **3D Model & Site Communication:** A complete **3D Revit model** with full rebar detailing, complemented by a supplementary video, was provided to site workers. This innovative approach significantly **enhanced their understanding of complex rebar placement**, drastically reducing common installation errors and ensuring accurate construction.
- **Proactive Cost Management:** We provided **early rebar quantity and cost estimates** based on prevailing rates. This crucial step empowered the client to understand and manage project costs in advance, contributing to overall budget adherence.

Project Challenges & Adaptive Solutions

This project involved several dynamic challenges and revisions:

- **Client Revisions:** We managed multiple revisions due to changes in tank sizing, slight adjustments to building column positions, and modifications to staircase placement and large pump installations.
- **Integrated Solutions:** The design had to seamlessly integrate with existing building columns and layouts.
- **Load Optimization:** Despite these challenges, all design iterations focused on **optimizing forces** as per all applicable codes, including critical seismic load combinations, to consistently deliver the most **economical and robust solution**.

Our Design Insight (Tip or Trick)

Strategic Validation for Complex Structures: While advanced software excels, we've found that for water tank designs, **cross-validating results from IS Code methods and even the Reynolds Handbook against Finite Element Analysis (FEM)** is invaluable. This layered approach not only boosts confidence in your design but can often reveal that robust, formula-based calculations are more efficient for establishing complex boundary conditions than solely relying on time-consuming FEM setups. Always compare and validate your results from multiple trusted sources for optimal accuracy and project efficiency.

This specific underground rectangular water tank project showcases our detailed approach to structural design and analysis. Our expertise, however, extends to a variety of water retention structures, including **circular, overhead, and other on-ground tank designs**, with over eight additional projects completed.

Conclusion & Next Steps

This in-depth showcase of our Underground Rectangular Water Tank project demonstrates our meticulous approach to complex structural challenges, from advanced seismic analysis and precise rebar detailing to efficient workflow optimization and proactive risk mitigation. We pride ourselves on delivering not just designs, but **cost-effective, highly constructible, and code-compliant solutions** that truly add value to our clients' projects. Our unique insights, such as the strategic validation of design results, ensure exceptional accuracy and reliability.

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Beyond Water Tanks

While this project highlights our expertise in water retention structures, our capabilities extend across a comprehensive range of structural engineering services. We are adept at designing diverse **building structures, industrial facilities, and specialized foundations**, always with an eye towards innovation, efficiency, and adherence to global standards.

Partner with Us:

Ready to discuss your next Civil or Structural Engineering challenge? We're equipped to provide tailored, high-quality design solutions for projects of any scale.

Contact us today to explore how our expertise can benefit your upcoming endeavors.
