DESIGN OF FOUNDATIONS FOR STORAGE TANKS IN PETROLEUM REFINERIES

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Abstract

Storage tanks are critical infrastructure in petroleum refineries, used for storing crude oil, intermediate products, and finished fuels. The design of their foundations plays a vital role in ensuring structural stability, safety, and long-term performance. Improper foundation design can lead to settlement, tilting, leakage, or catastrophic failure. This paper presents a comprehensive study on the design principles, soil–structure interaction, loading considerations, and modern analytical approaches used in designing foundations for storage tanks. Emphasis is placed on ring wall foundations, mat foundations, and pile-supported systems under static and dynamic loading conditions, including seismic effects.

Keywords

Storage tanks, foundation design, petroleum refinery, soil–structure interaction, ring wall foundation, settlement analysis, API 650.

1. Introduction

Petroleum refineries rely heavily on large cylindrical storage tanks for operational continuity. These tanks impose substantial loads on the supporting soil, making foundation design a crucial aspect of structural engineering.

The design must ensure:

- Uniform settlement
- Adequate bearing capacity
- Resistance to seismic and wind loads
- Prevention of differential settlement

Standards such as **API 650** and EEMUA guidelines provide recommendations for tank and foundation design in oil storage facilities.

2. Types of Storage Tank Foundations

2.1 Ring Wall Foundation

- Most commonly used for large tanks
- Supports shell load while the central area is filled with compacted soil

- Economical and suitable for medium to good soil conditions

2.2 Mat (Raft) Foundation

- Used where soil bearing capacity is low
- Distributes load uniformly over a large area
- Reduces differential settlement

2.3 Pile Foundation

- Used in weak or compressible soils
- Transfers load to deeper, stronger strata
- Suitable for coastal or marshy refinery locations

3. Soil Investigation and Site Characterization

Before foundation design, detailed geotechnical investigations are essential:

- Standard Penetration Test (SPT)
- Cone Penetration Test (CPT)
- Soil classification and stratification
- Groundwater table analysis

Soil behavior significantly influences foundation response, especially under cyclic and dynamic loads. Advanced models such as macroelement modeling help simulate soil–foundation interaction.

4. Design Considerations

4.1 Load Analysis

The following loads must be considered:

- Dead load (tank + stored liquid)
- Live load
- Wind load
- Seismic load
- Hydrostatic pressure

4.2 Settlement Analysis

Settlement must be within permissible limits:

- Total settlement
- Differential settlement
- Angular distortion

Excessive settlement can lead to tank bottom failure and leakage.

4.3 Bearing Capacity

Safe bearing capacity is calculated using:

- Terzaghi's bearing capacity theory
- Meyerhof and Hansen methods

4.4 Seismic Considerations

Storage tanks behave differently from buildings due to fluid–structure interaction. Hydrodynamic pressures significantly influence design.

5. Soil–Structure Interaction (SSI)

SSI plays a crucial role in foundation performance:

- Interaction between tank base and soil
- Redistribution of stresses
- Influence on vibration and seismic response

Modern approaches use **finite element methods (FEM)** for accurate modeling.

6. Design Methodology

Step 1: Site Investigation

Step 2: Selection of Foundation Type

Step 3: Load Calculation

Step 4: Bearing Capacity Check

Step 5: Settlement Analysis

Step 6: Stability Check (sliding, overturning)

Step 7: Structural Design of Foundation

7. Failure Modes of Tank Foundations

- Differential settlement
- Edge settlement
- Shell buckling
- Bottom plate corrosion and leakage
- Uplift due to seismic forces

8. Case Study (Conceptual)

A refinery tank of 40 m diameter was analyzed:

- Soil: Clayey sand
- Foundation: Ring wall
- Result: Settlement within permissible limits

Use of FEM improved prediction accuracy compared to conventional methods.

9. Modern Trends in Foundation Design

- Use of geosynthetics for soil improvement
- Smart monitoring systems
- AI-based predictive maintenance
- Advanced numerical modeling

Fixing Details of Base Plate with Shell Plate (Storage Tanks)

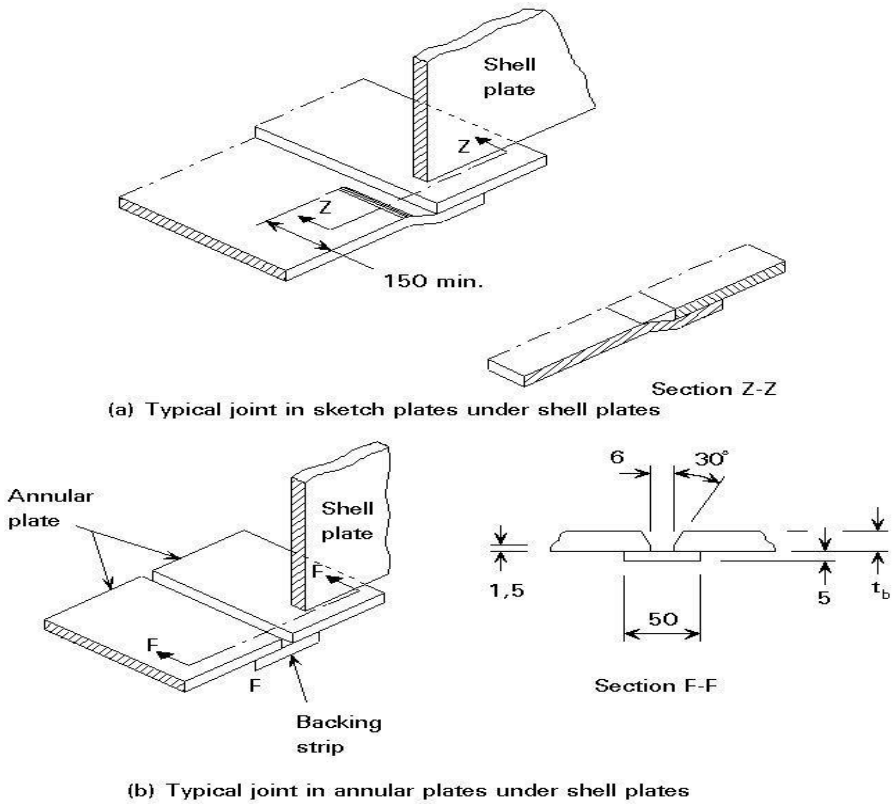


Fig 1: Joints in Bottom Plates Below Shell Plates

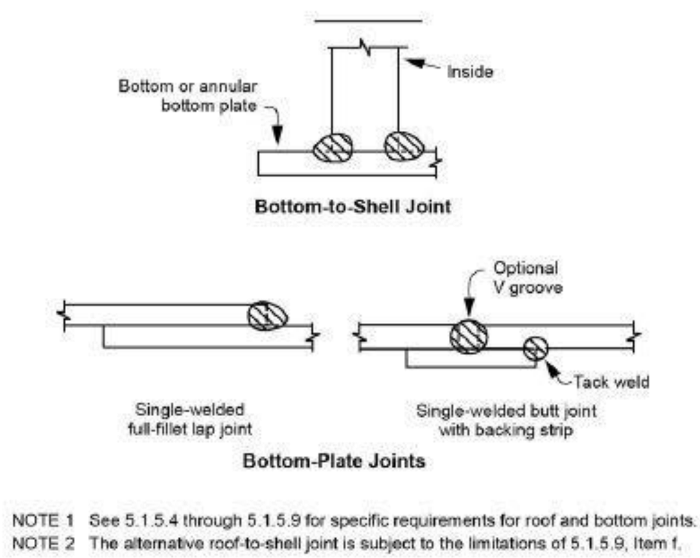
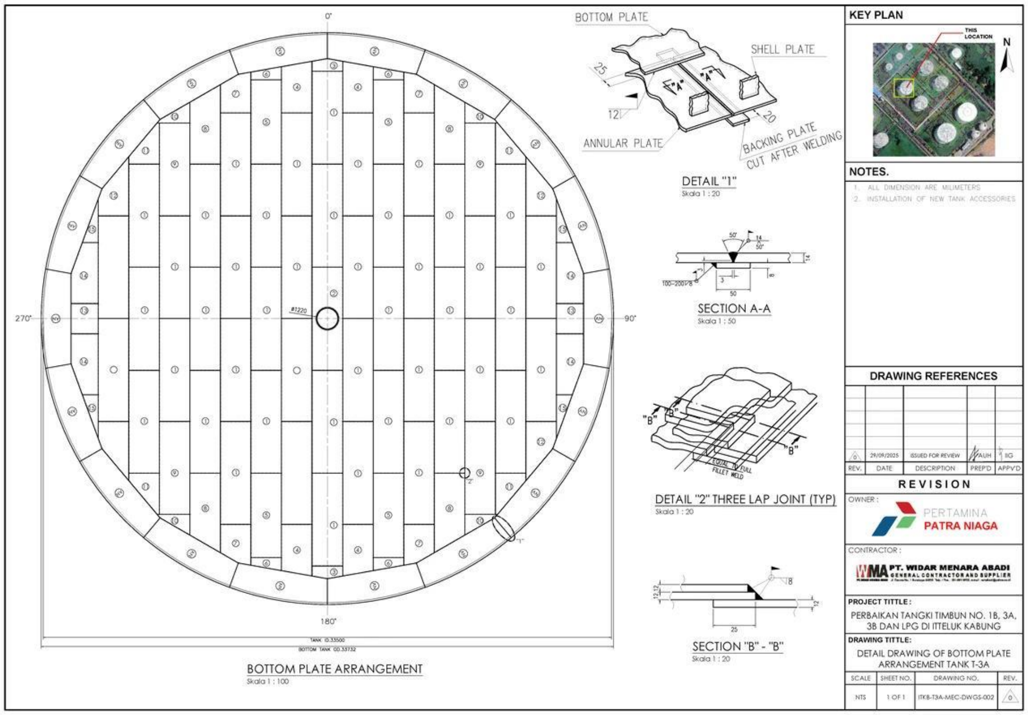


Fig 2: Typical Roof and Bottom Joints



1. Overview

In petroleum storage tanks, the **shell plate** (vertical wall) is connected to the **base plate** (bottom plate) through a critical junction that must ensure:

- Liquid tightness
- Structural stability
- Resistance to settlement and corrosion

This connection is typically designed according to American Petroleum Institute **API 650** guidelines.

2. Components of the Joint

2.1 Bottom (Base) Plate

- Flat steel plates resting on compacted soil or foundation
- Thickness varies depending on tank size and corrosion allowance

2.2 Annular Plate (Important)

- Thicker ring of plates placed at the periphery
- Supports the shell and distributes high edge stresses
- Mandatory for large-diameter tanks

2.3 Shell Plate

- Vertical cylindrical plates forming the tank wall
- Transfers load to annular plate and foundation

3. Types of Shell-to-Bottom Joints

3.1 Fillet Weld Joint (Most Common)

- Double fillet weld connecting shell to annular plate
- Used in small to medium tanks

Features:

- Simple and economical
- Adequate for moderate loads

3.2 Butt Weld with Backing Strip

- Groove weld used for higher strength
- Backing strip ensures full penetration

Features:

- Better stress distribution
- Used in critical or large tanks

3.3 Lap Weld Joint

- Bottom plate overlaps annular plate
- Fillet weld applied along overlap

Features:

- Easy fabrication
- Less preferred for large tanks

4. Load Transfer Mechanism

Load Path:

1. Hydrostatic pressure → shell plate
2. Shell load → annular plate
3. Annular plate → foundation

Key Stresses:

- Hoop stress in shell
- Compressive stress at base
- Shear stress at weld

5. Design Considerations (API 650 Based)

5.1 Weld Design

- Minimum fillet weld size based on shell thickness
- Continuous weld required for leak prevention

5.2 Annular Plate Thickness

- Designed for:
  - Shell load
  - Bending stresses
  - Settlement effects

5.3 Settlement Allowance

- Joint must tolerate slight rotation
- Flexible detailing preferred

5.4 Corrosion Protection

- Corrosion allowance added (typically 1.5–3 mm)
- Use of coatings and cathodic protection

6. Common Failures at This Joint

- Weld cracking due to differential settlement
- Corrosion at shell-bottom interface
- Leakage due to poor welding
- Edge settlement causing uplift

7. Recommended Detailing (Best Practice)

- Use **annular plates for tanks > 12 m diameter**
- Provide **double fillet welds (inside + outside)**
- Ensure **smooth transition (no sharp stress concentration)**
- Maintain **proper weld inspection (NDT methods)**
- Use **bituminous layer under bottom plate** for corrosion protection

10. Literature Review

Research on storage tank foundation design has evolved from classical bearing capacity approaches to advanced soil–structure interaction modeling.

Early foundational work by Karl Terzaghi (1943) established the theoretical basis for bearing capacity and settlement analysis. Later, J. E. Bowles (1996) expanded these concepts to practical foundation design, emphasizing allowable settlement criteria for large structures such as tanks. Similarly, Braja M. Das (2010) provided detailed formulations for shallow and deep foundations, widely adopted in tank design.

Studies specifically focusing on storage tanks highlight the importance of **non-uniform settlement control**. Research by FabrizioPaolacci and Hoang Nam Phan (2018) demonstrated that fluid–structure interaction significantly alters stress distribution in tank shells during seismic events. Their work shows that ignoring hydrodynamic effects may lead to unsafe designs.

Further advancements were made by Alain Pecker et al. (2008), who introduced macroelement modeling to simulate shallow foundation behavior under cyclic loading. This approach enables better prediction of settlement and rotation in tank foundations subjected to earthquakes.

In addition, guidelines such as American Petroleum Institute (API 650, API 653) and Engineering Equipment and Materials Users Association (EEMUA 183) provide industry-accepted practices for tank foundation design, inspection, and leakage prevention.

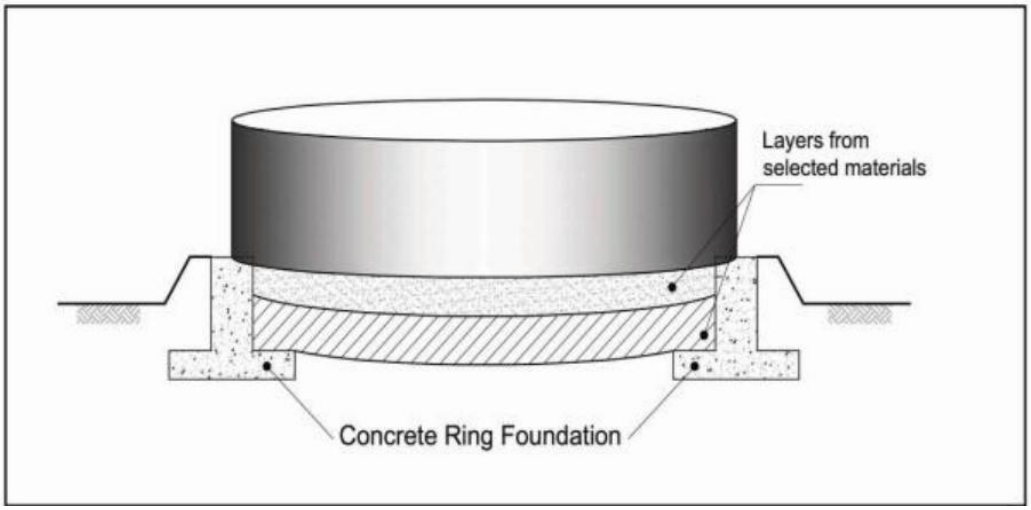
Recent research trends emphasize:

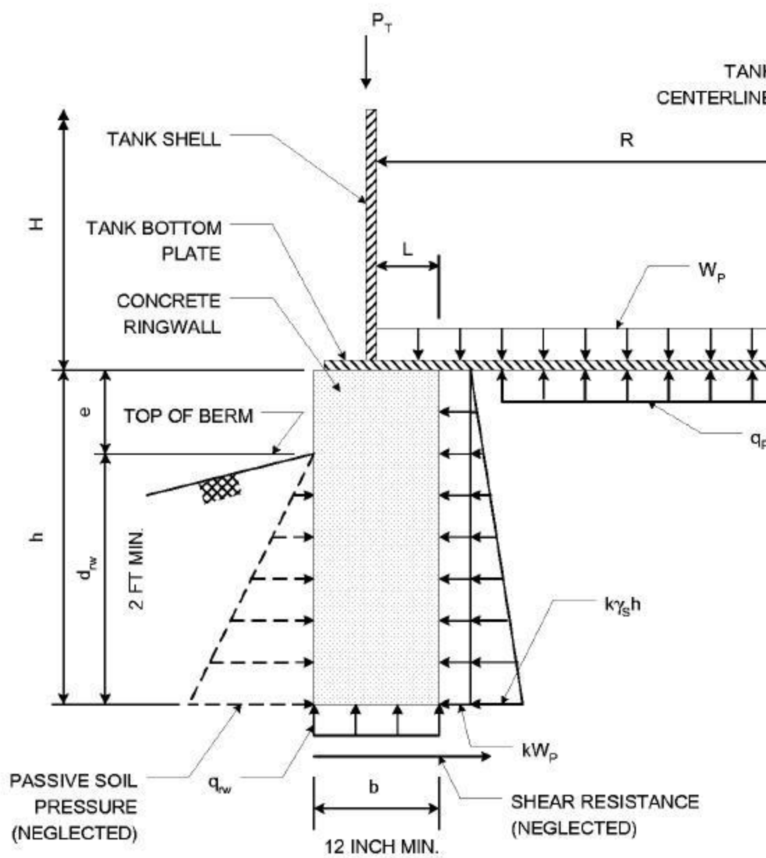
- Use of **finite element modeling (FEM)** for accurate SSI analysis
- Application of **ground improvement techniques** (stone columns, geogrids)
- Integration of **monitoring systems** for real-time settlement tracking

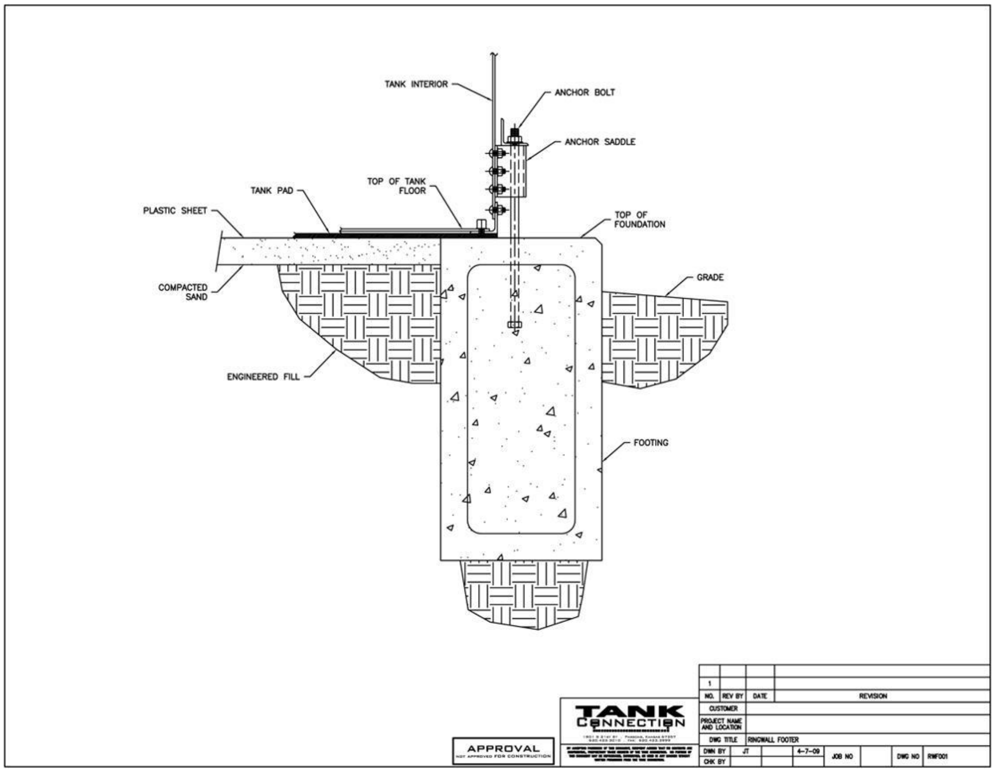
Overall, literature indicates that modern tank foundation design requires combining classical geotechnical theory with advanced numerical and experimental approaches to ensure safety and durability.

11. Diagrams (Foundation Types & Load Distribution)

11.1 Ring Wall Foundation


Layers from
selected materials
Concrete Ring Foundation


P_T
TANK
CENTERLINE
TANK SHELL
R
H
TANK BOTTOM
PLATE
L
W_P
CONCRETE
RINGWALL
e
TOP OF BERM
q_P
h
d_rw
2 FT MIN.
kγ_S h
kW_P
PASSIVE SOIL
PRESSURE
(NEGLECTED)
q_rw
b
12 INCH MIN.
SHEAR RESISTANCE
(NEGLECTED)



Explanation:

- Load is transferred mainly through the tank shell to the ring wall
- Central area is filled with compacted soil or sand
- Minimizes material usage while maintaining stability

11.2 Mat (Raft) Foundation

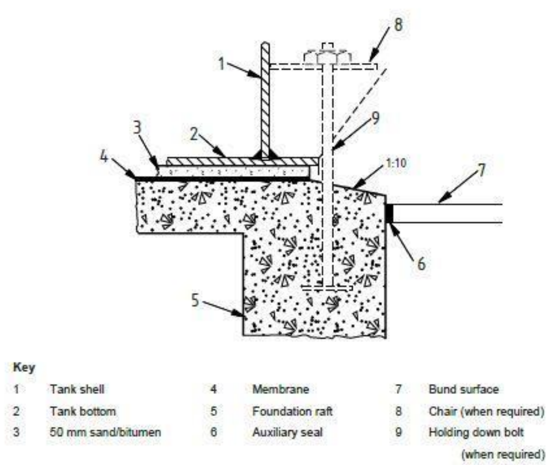


Fig 4- Typical Concrete Raft Foundations

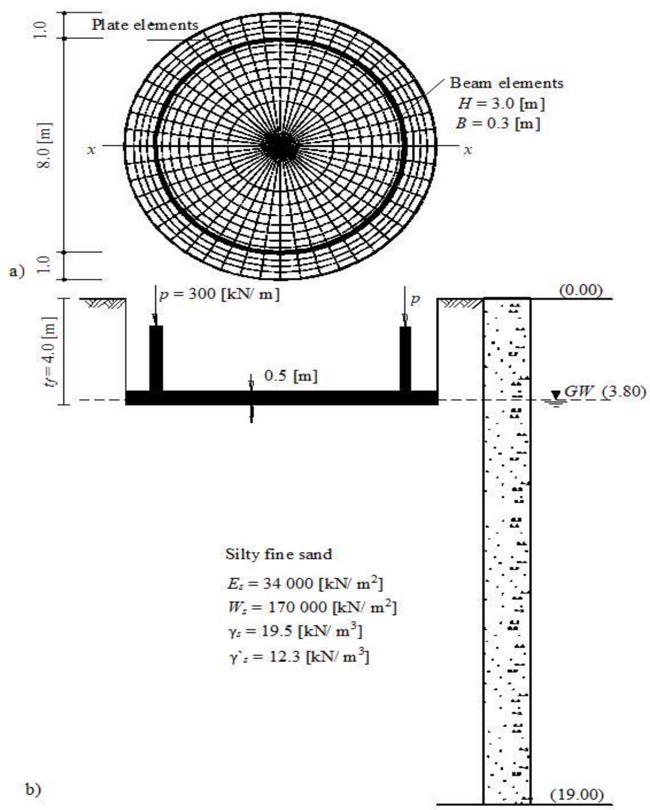


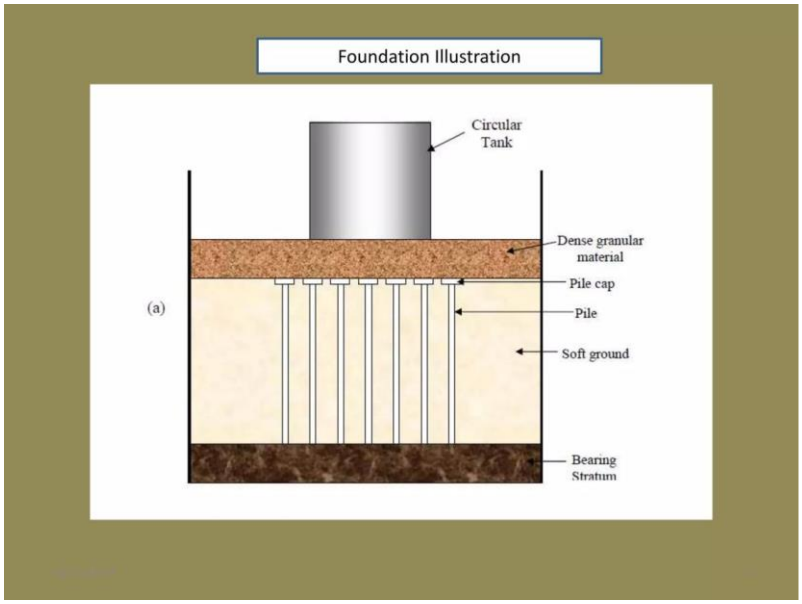
Fig- a) Plan of the Raft with wall load, dimensions and mesh

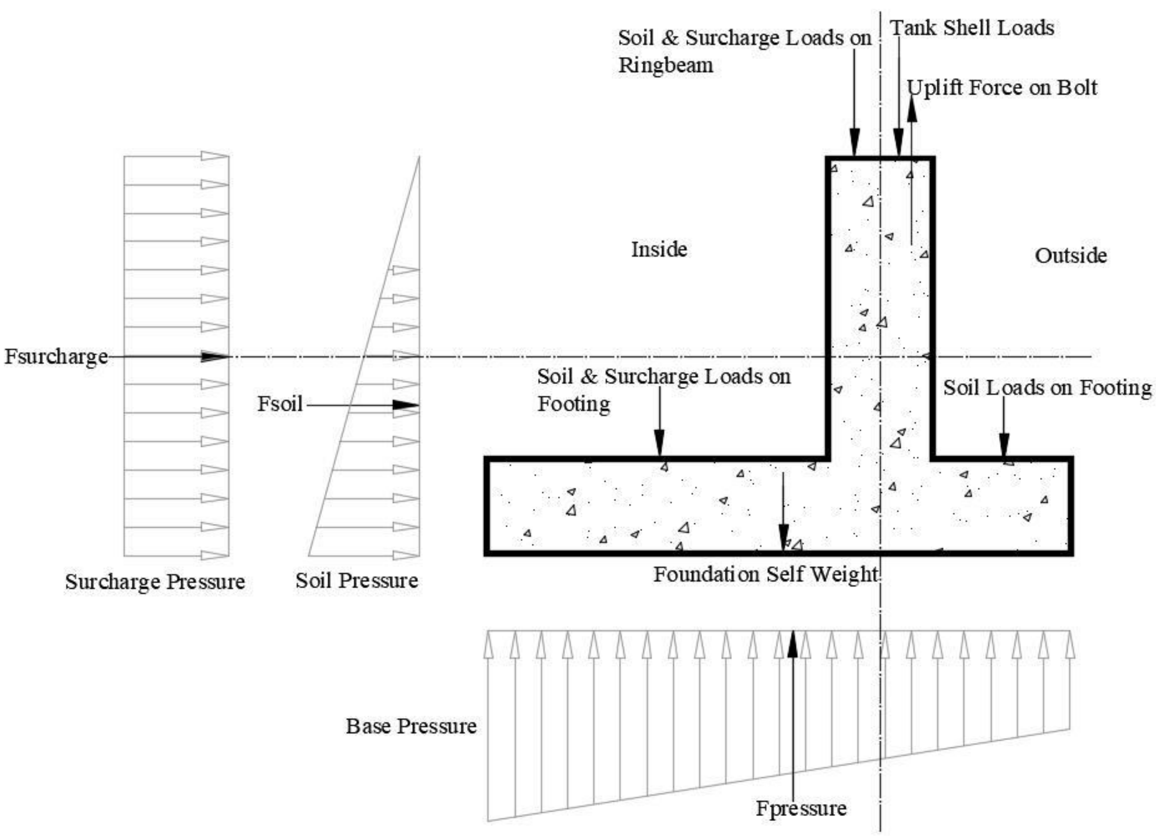
b) Section through the raft and subsoil

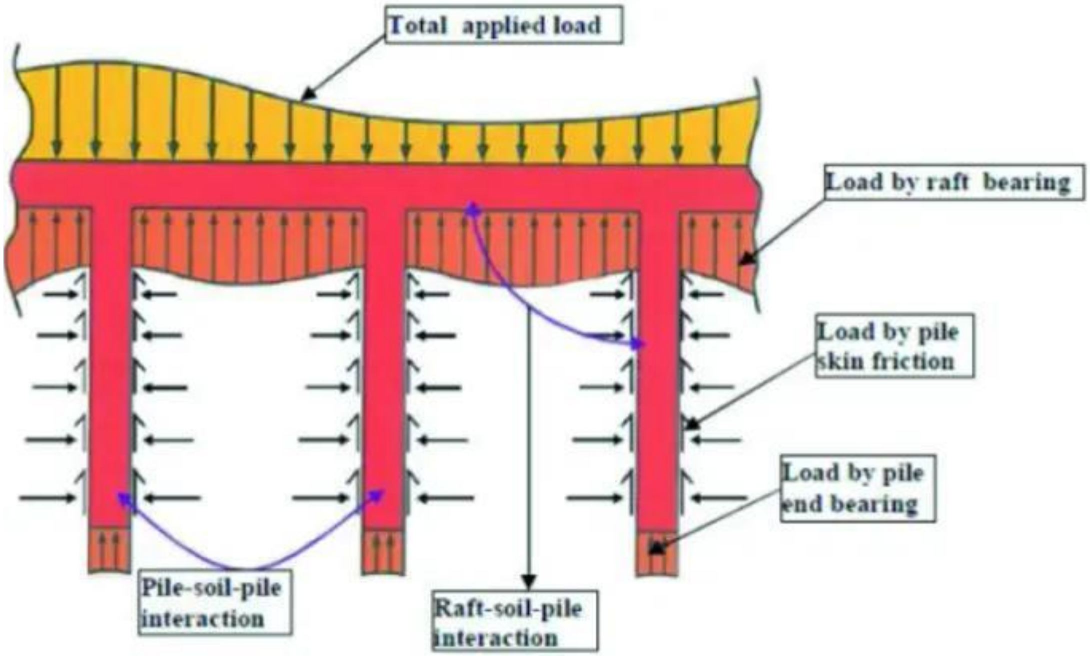
Explanation:

- Entire tank load is distributed over a large concrete slab
- Suitable for weak soils
- Reduces differential settlement significantly

11.3 Pile Foundation


Foundation Illustration
Circular Tank
Dense granular material
Pile cap
Pile
(a)
Soft ground
Bearing Stratum

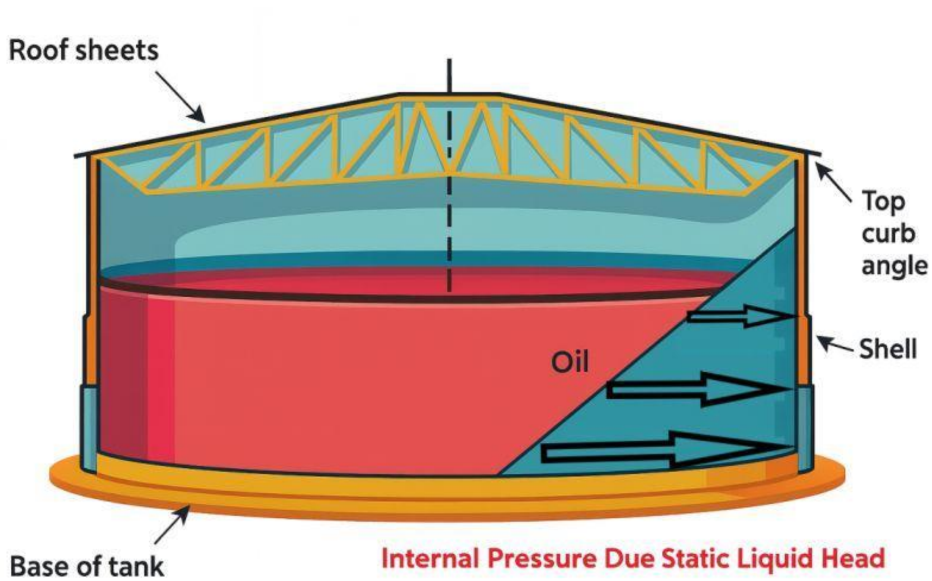

Soil & Surcharge Loads on Ringbeam
Tank Shell Loads
Uplift Force on Bolt
Inside
Outside
Fsurcharge
Fsoil
Soil & Surcharge Loads on Footing
Soil Loads on Footing
Surcharge Pressure
Soil Pressure
Foundation Self Weight
Base Pressure
Fpressure

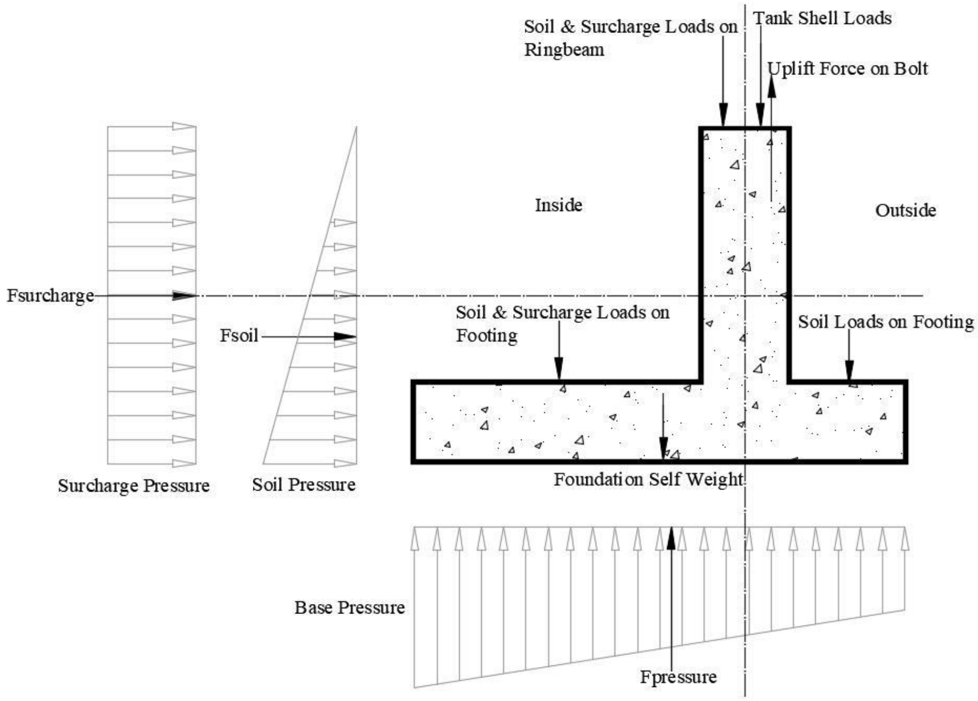


Explanation:

- Loads are transferred to deeper, stronger soil layers
- Used in soft or compressible soils
- Often combined with pile caps or raft systems

11.4 Load Distribution in Storage Tank

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Inside
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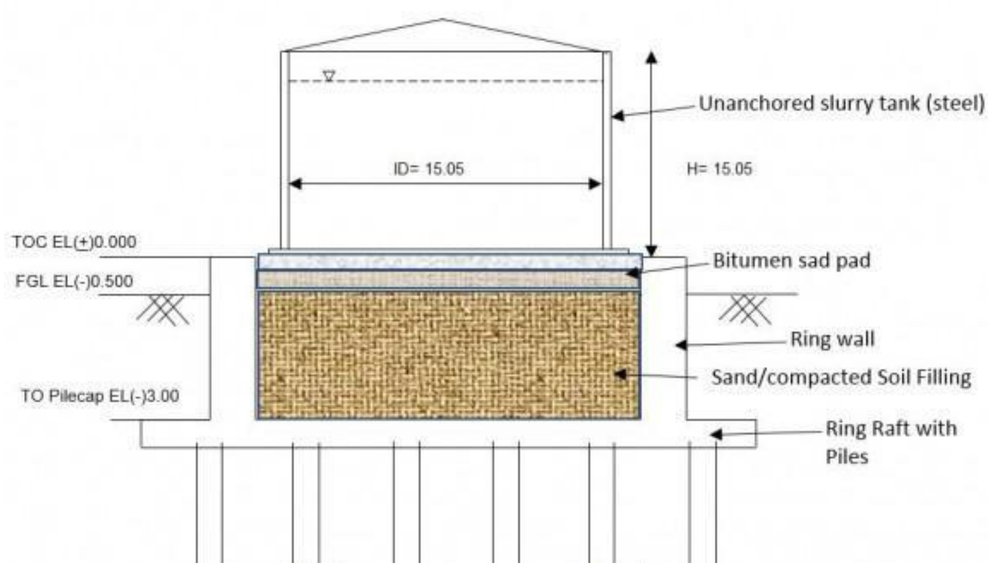
Unanchored slurry tank (steel)
ID= 15.05
H= 15.05
TOC EL(+)0.000
FGL EL(-)0.500
Bitumen sad pad
Ring wall
Sand/compacted Soil Filling
TO Pilecap EL(-)3.00
Ring Raft with Piles

Explanation:

- Hydrostatic pressure increases with depth
- Maximum stress occurs at the tank base edges
- Uneven soil conditions can cause differential settlement

12. Conclusion

Foundation design for storage tanks in petroleum refineries is a complex engineering task involving geotechnical, structural, and environmental considerations. Proper design ensures safety, durability, and economic efficiency. Advanced modeling techniques and adherence to international standards significantly improve performance and reliability.