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UNDERPINNING, TYPES; METHODS; TECHNIQUES AND MITIGATION; A CASE STUDY OF A (G+3) RESIDENTIAL BUILDING ANALYSIS AND DESIGN

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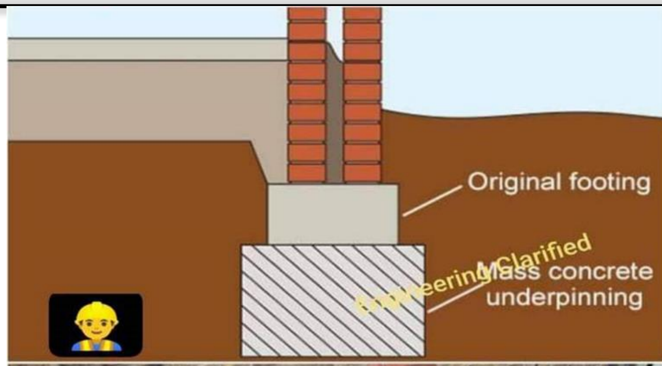
INTRODUCTION

Underpinning is a construction technique employed to strengthen and stabilize the foundations of existing structures. This method becomes essential when the original foundation is no longer capable of supporting the building due to factors such as soil subsidence, changes in usage, or nearby excavations. The primary goal of underpinning is to transfer the building's load to a more stable stratum, ensuring structural integrity. A process of placing a new foundation under an existing one or strengthening an existing foundation is known as underpinning of foundation. Underpinning may be required for many purposes. To strengthen the shallow foundation of an existing building when a building with the deep foundation is to be constructed adjoining it. To strengthen the existing foundation which has settled and caused cracks in the wall. To deepen the existing foundation (resting on poor strata) to rest it on deeper soil strata of a higher bearing power.

This term is employed in construction industry for buildings and it related to geotechnical engineering field.



What is Underpinning ??

Method of Underpinning :

Pit method: On this method, the entire length of a foundation to be underpinned is divided into a section of 1.2 m to 1.5 m lengths. One section is taken up at a time. For each section, a hole is made in the wall, above the plinth level, and the needle is inserted

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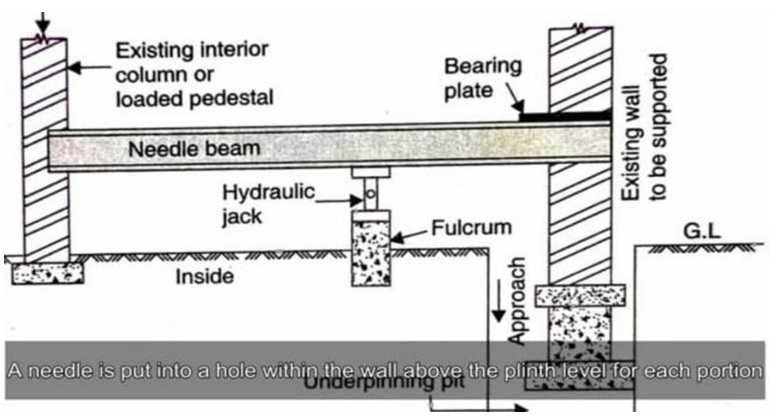
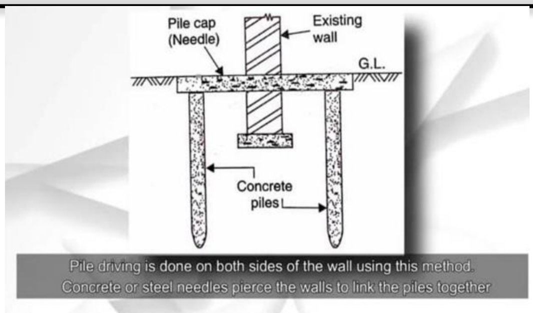
in the hole. The needle may be either of a stout timber or steel section. Bearing plates are placed above the needle to support the masonry above it. The needle is supported on either side of the wall on crib supports(wooden blocks) and screw jack's. A foundation pit is then excavated up to the desired level and a new foundation is laid. When the work of the one section is over ,work on the next section is taken up, i.e ,alternate section are underpinned in the first round, and then the remaining sections are taken up. If the wall is to be underpinned is weak, taking shores may be provided. Similarly, the floor may also be supposed, if required. If an strong interior column exists, or if the foundation is to be extended only to one side, cantilever needle beams may be used in the place of the central needle beam. Jack is placed between the column and the wall. The alternate section is taken up in the first round. The remaining intermediate sections are taken then taken up. Only one section is to be taken at a time. If the wall is long, the work is started from the middle and is extended in both directions. If the new foundation is deeper, proper timbering of the foundation trench may be done. Needle beams etc should be removed only when the new foundation has gained strength. This is desirable to do the new foundation working concrete. A needle holes etc should be closed in masonry using cement mortar.

Pile method: On this method ,piles are driven at regular intervals along both sides of the wall. Generally, boreholes piles or underreamed piles may be used. In these piles are connected by concrete or steel needles, penetrating through the wall. These beams incidentally act as pile caps also. This method is very much useful in clayey soils, and also in water logged areas. The existing foundation is very much relieved of the load.

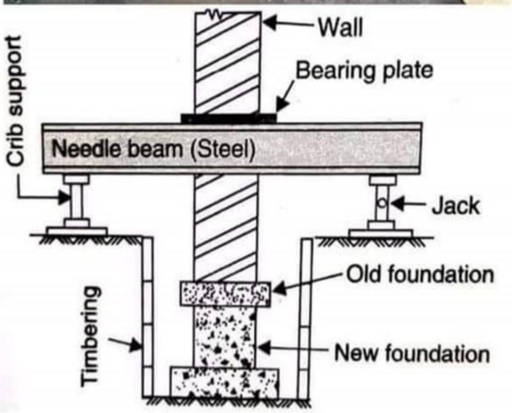
What Is Underpinning?





Common Underpinning Techniques:

1. **Mass Concrete Underpinning (Pit Method):** This traditional approach involves excavating sections beneath the existing foundation in a sequential manner and filling them with concrete. Over time, this creates a new, deeper foundation beneath the original one.
2. **Beam and Base Method:** In this technique, a reinforced concrete beam is constructed below or alongside the existing foundation. The beam distributes the structural load to concrete bases or piers, which are positioned at strategic points to provide enhanced support.
3. **Mini-Piled Underpinning:** Suitable for sites with limited access or where soil conditions are challenging, this method uses small-diameter piles (typically ranging from 150mm to 300mm) to transfer loads to deeper, more stable soil layers or bedrock.
4. **Jet Grouting:** This process involves injecting a cementitious grout into the ground at high pressure, which mixes with the existing soil to form a solid, stable mass. It's particularly useful for underpinning in areas with loose or granular soils.



Experimental Studies and Applications in Punjab, Pakistan:

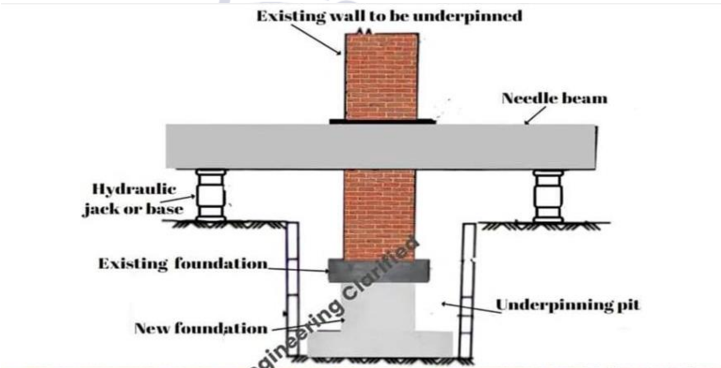
In Punjab, Pakistan, the need for effective retrofitting and foundation stabilization techniques has been underscored by various research initiatives as Underpinning. One notable study focused on developing low-cost and efficient retrofitting methods for unreinforced masonry buildings, which are prevalent in the region. The research investigated three primary techniques:

- **Ferrocement Overlay**: This method involves applying a steel welded wire mesh to the surface of masonry walls, followed by plastering with a rich mortar. The efficacy of this technique depends on the bond between the masonry and the plaster coating, established through connectors such as screws or bolts.
- **Bed Joint Reinforcement:** This approach entails inserting reinforcement materials into the horizontal mortar joints of masonry walls to enhance their tensile strength and overall stability.
- **Grout Injection:** This technique involves injecting a cement-based grout into the masonry to fill voids and cracks, thereby improving the structural integrity of the walls.

The study concluded that the proposed cement-based grout could restore or even improve the pre-damaged state of unreinforced brick masonry buildings. When combined with bed joint reinforcement, it effectively strengthened cracked regions. Ferrocement overlay, in particular, was found to significantly enhance the seismic performance of unreinforced masonry buildings, increasing lateral strength and stiffness by more than 100% without substantially affecting deformation and energy dissipation capacities. This technique was deemed simple, efficient, and economical, with the total cost of retrofitting being less than 20% of the cost of replacing the building.

While specific empirical formulas for underpinning applications can vary based on soil conditions, structural requirements, and the chosen underpinning method, general engineering principles apply. For instance, when designing underpinning solutions, engineers often calculate the bearing capacity of the soil and the load from the structure to determine the dimensions and reinforcement details of the underpinning elements. These calculations ensure that the new foundation can safely support the imposed loads.

In the context of Punjab, Pakistan, where soil conditions can vary significantly, it's crucial to conduct thorough geotechnical investigations before selecting an underpinning method. Techniques such as electrical resistivity surveys have been employed to assess subsurface conditions, aiding in the effective planning and execution of underpinning projects.



A case study of a (G+3) residential building analysis and design based on Underpinning technique

To develop underpinning technique a 5-10 year-old, four-story residential government married accommodation (G+3) and ensure its suitability for another 25 years, we need to follow a structured approach based on geotechnical and structural engineering principles.

Structural Load Assessment & Soil Bearing Capacity Calculation

The underpinning method must consider:

- Existing load on foundation (Q)
- Safe bearing capacity of soil (SBC, denoted as q_n)
- Factor of Safety (FoS)
- Settlement limits (Δs)

Empirical Formula for Load Distribution & Bearing Capacity

For an existing foundation:

$Q_{actual} = P / A$

where:

P = total load from the building (kN)

A = existing foundation area (m^2)

For a newly underpinned foundation:

$Q_{new} = P / A_{new}$

To prevent failure:

$Q_{new} \leq q_n \div FoS$

(typically FoS = 3 for safety)

Required Depth of Underpinning

To determine the necessary underpinning depth, we use Terzaghi's Ultimate Bearing Capacity equation:

$Q_u = c\,N_c + \gamma\,D_f\,N_q + 0.5\,\gamma\,B\,N_\gamma$

where:

Q_u = ultimate bearing capacity (kPa)

c= soil cohesion (kPa)

γ \ gamma = soil unit weight (kN/m^3)

Df = foundation depth (m)

B = footing width (m)

Nc,Nq,NγN_c, N_q, N_{\gamma}Nc,Nq,Nγ = bearing capacity factors

For underpinning depth, we ensure:

$D_f \geq q_u / \gamma$

(to ensure stable soil-bearing conditions)

Underpinning Strengthening Approach

(a) Beam and Base Method

For load distribution through a reinforced concrete (RC) beam:

$M = w\,L^2/8$

where:

M = bending moment (kN·m)

w = uniformly distributed load (kN/m)

L = span length of the beam (m)

The reinforcement area:

$A_s = M / 0.87 f_y\,d$

where:

Fy = yield strength of steel (MPa)

d= effective depth of the beam (m)

Settlement Control

To limit settlement to acceptable limits (<25 mm for 4-story buildings), the empirical equation for expected settlement:

$\Delta s = q_{new}\,B\,(1-\nu^2) / E$

where:

V = Poisson's ratio of soil

E = soil modulus of elasticity (MPa)

Ensure $\Delta s < 25$ mm for habitability.

Case Study:

A case study of a (G+3) residential building analysis and design based on Underpinning technique

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16 x Airmen Quarters (G+3) married residential building/accommodation in Bilal camp residential area colony in Pakistan Aeronautical Complex Kamra Cantt Tehsil Hattian Distt Attock.

Bearing capacity is 0.5 Ton per SQ ft. based on soil investigation report of the area of subject building with settlement allowed is 25 mm. FOS is 2 and having dead load of brick masonry; frame structure; raft footing; two-way roof slab monolithic continuous/simply supported beam detailed design. Soil is sandy silt/clay cohesive soil.

Given your inputs, let's design the underpinning system for a 5-10year-old, four-story residential building analysis and design are discussed below:

Given Data

- Bearing Capacity (SBC, q n) = 0.5 ton/ft² = 48 kN/m²
- Allowed Settlement (Δs) = 25 mm (0.025 m)
- Factor of Safety (FoS) = 2
- Dead Load from Structure: Brick masonry + RCC frame + two-way slab + beams
- Foundation Type = Raft Foundation

Load Calculation

(a) Structural Load Estimation

For a 4-story brick masonry + RCC frame structure:

- Self-weight of Brick Walls = 6 kN/m² per floor
- Self-weight of RCC Slabs (two-way) = 4 kN/m² per floor
- Beams & Columns Load = 2 kN/m² per floor
- Live Load (Residential) = 2 kN/m² per floor

Total Load per floor:

(6+4+2+2)=14 kN/m²

For 4 floors:

14×4=56 kN/m²

Assuming raft footing area per column = 4 m²

Total Load per column:

56×4=224 KN

Including Footing Weight (Raft Thickness = 0.5 m, Concrete Density = 24 kN/m³):

224+(4×0.5×24) =272

Foundation Area Required

Using Bearing Capacity with Factor of Safety:

Q safe=qn / FoS=48/2=24 kN/mA²

Required foundation area:

A=272 / 24=11.33 m²A

Choose footing dimensions:

- New raft slab size = 3.5m×3.5m
- Depth of footing = To be calculated using settlement control.

Settlement Check (Terzaghi's Formula)

$\Delta s = q\ \text{new}\ B(1-\nu^2) / E$

where:

Q new = 24 kN/m²
B = 3.5 m
ν (Poisson's Ratio for Clay) = 0.3
E (Elastic Modulus of Clay) = 10,000 kN/m²

$\Delta s = (24\times3.5)(1-0.3^2)/10{,}000$

Δs = 84x 0.91/10,000

Δs =0.0077 m = 7.7 mm is less than 25 mm

✓ OK, Settlement is within limits.

Structural Reinforcement Design

Raft Thickness Calculation:

Using bending moment equation for raft (Two-way slab behavior):

$M=qL^2/8$ = {(24)(3.5^2)}{8} = 36.75

For M20 Concrete (fc=20 MPa) and Fe500 Steel (fy=500 MPa):

Required steel area:

As=M / 0.87fy d

Assuming d =0.4m (effective depth):

$As=(36.75\times10^6)/(0.87\times500\times400)$mm²/m

As=211 mm²/m

Use 12 mm dia @ 150 mm c/c (As = 226 mm²/m, Safe).

Reinforcement Details

- Raft Thickness = 500 mm
- Main Bars = 12 mm dia @ 150 mm c/c (Fe500 Steel)
- Distribution Bars = 10 mm dia @ 200 mm c/c
- Column Pedestals = 450 mm x 450 mm x 600 mm
- Reinforcement in Pedestals = 8 bars of 16 mm dia

Underpinning Execution Steps

1. Excavation under existing foundation in small sections (1.5 m width at a time).
2. Install reinforcement and cast RC pedestals & raft extension.
3. Allow curing for 28 days before shifting structural load.
4. Monitor settlement using dial gauges for 3 months.
5. Complete waterproofing & drainage improvements.

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Summary

a. New Raft Footing: 3.5 m × 3.5 m × 0.5 m (thickness)
b. Settlement is controlled (7.7 mm < 25 mm)
c. Reinforcement provided is safe (12 mm dia @ 150 mm c/c)
d. Underpinning executed in phases to prevent collapse

Retrofitting/ Underpinning for additional 25 Years

e. Material Upgrades: High-strength concrete (fc ≥ 35 MPa) and corrosion-resistant reinforcement.
f. Load Redistribution: Transfer structural loads to deeper layers via piles or micro-piles if needed.
g. Waterproofing: Ensure subsoil drainage and waterproof coatings to protect foundations.
h. Inspection Schedule: Bi-annual settlement and crack monitoring.

By applying empirical rational formulas, we can determine foundation strengthening depth, settlement limits, and structural reinforcement. The Beam & Base method or Micro-piling ensures stability for 25+ years.

In summary, underpinning techniques are vital for maintaining and enhancing the structural integrity of buildings, especially in regions like Punjab, Pakistan, where soil conditions and seismic activity pose challenges. Experimental studies have demonstrated the effectiveness of methods like ferrocement overlay and grout injection in retrofitting unreinforced masonry structures, offering cost-effective solutions to improve building resilience.

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