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Comparative Study of Isolated, Combined and Raft Foundations as per Indian Standards

Prof. Kiran Sharikar[1], Tejas Dalvi[2]

[1]Faculty Civil Engineering Vidya Prasarini Sabha's College of Engineering and Technology, Lonavala

[2]Student Civil Engineering Vidya Prasarini Sabha's College of Engineering and Technology, Lonavala

ABSTRACT

The selection of an appropriate foundation system is essential for ensuring structural stability and serviceability. This study presents a comparative evaluation of isolated, combined, and raft foundations based on Indian Standard codes such as IS 456:2000, IS 6403:1981, IS 1904:1986, and IS 2950:1981. The analysis considers key parameters including bearing capacity, settlement characteristics, stress distribution, and economic feasibility. Isolated footings are found to be suitable for structures on soils with high safe bearing capacity and well-spaced columns. Combined footings are effective in cases of closely spaced columns or boundary constraints, providing better load sharing and reduced eccentricity. Raft foundations, however, exhibit superior performance in weak or compressible soils by distributing loads over a larger area, thereby minimizing differential settlement. The study concludes that while isolated and combined footings are economical under favorable conditions, raft foundations offer enhanced structural safety and long-term performance where settlement control governs design.

INTRODUCTION

Foundation engineering forms a fundamental component of civil engineering, as it ensures the safe transfer of structural loads to the underlying soil without causing excessive settlement or failure. The performance of any structure largely depends on the type of foundation adopted, which is influenced by factors such as soil properties, magnitude and distribution of loads, groundwater conditions, and permissible settlement limits. According to **IS 1904:1986**, both bearing capacity and settlement criteria must be satisfied to achieve a safe and serviceable design.

Shallow foundations are commonly used where adequate bearing strata exist near the ground surface. Among these, isolated, combined, and raft foundations are widely adopted in practice. Isolated footings are generally used for individual columns under favorable soil conditions, whereas combined footings are preferred when columns are closely spaced or located near property boundaries. Raft foundations, on the other hand, are employed in cases of low bearing capacity soils, where it becomes necessary to distribute loads over a larger area to control settlement.

With increasing urbanization and construction on marginal soils, the selection of an appropriate foundation system has become more critical. This study aims to provide a comparative analysis of isolated, combined, and raft foundations based on their structural behavior, soil interaction, and performance in accordance with relevant Indian Standard codes.

METHODOLOGY

The present study adopts a **comparative analytical methodology** to evaluate the performance of isolated, combined, and raft foundations under identical soil and loading conditions, in accordance with relevant Indian Standard codes. The analysis focuses on bearing capacity, settlement characteristics, stress distribution, and structural behavior.

1. General Approach

Initially, soil investigation parameters such as cohesion (c), angle of internal friction (φ), and unit weight (γ) are considered. The **ultimate bearing capacity** is calculated using Terzaghi's equation as per **IS 6403:1981**:

$$q_u = cN_c + \gamma D_f N_q + 0.5\gamma B N_\gamma$$

The allowable bearing capacity is determined using an appropriate factor of safety:

$$q_{allow} = q_u / FOS$$

A common structural loading system is assumed with column loads ranging from 1000–1500 kN and uniform column spacing. This ensures a consistent basis for comparison across all foundation types.

2. Methodology for Isolated Footing

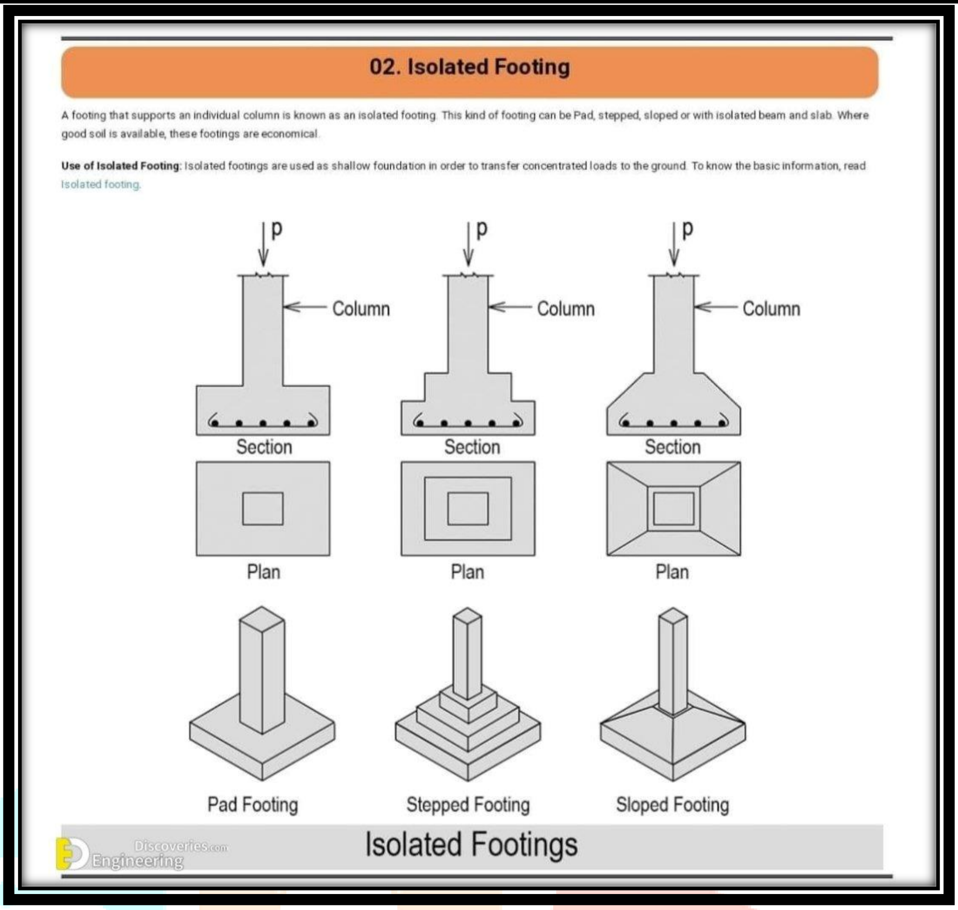
For isolated footing, each column is treated as an independent load-bearing unit. The required footing area is calculated using:

$$A = P / q_{allow}$$

The footing is proportioned (square or rectangular) and designed as per **IS 456:2000**. Structural checks include:

- Bending moment at the face of the column
- One-way shear along critical sections
- Punching shear around the column

Stress distribution beneath the footing is assumed to be uniform. However, interaction between adjacent footings is neglected. Settlement analysis is carried out individually, which often leads to **differential settlement** when soil conditions are non-uniform.



3. Methodology for Combined Footing

Combined footing is analyzed when columns are closely spaced or when one column is near a boundary. The footing is designed such that the centroid of the footing area coincides with the resultant of column loads:

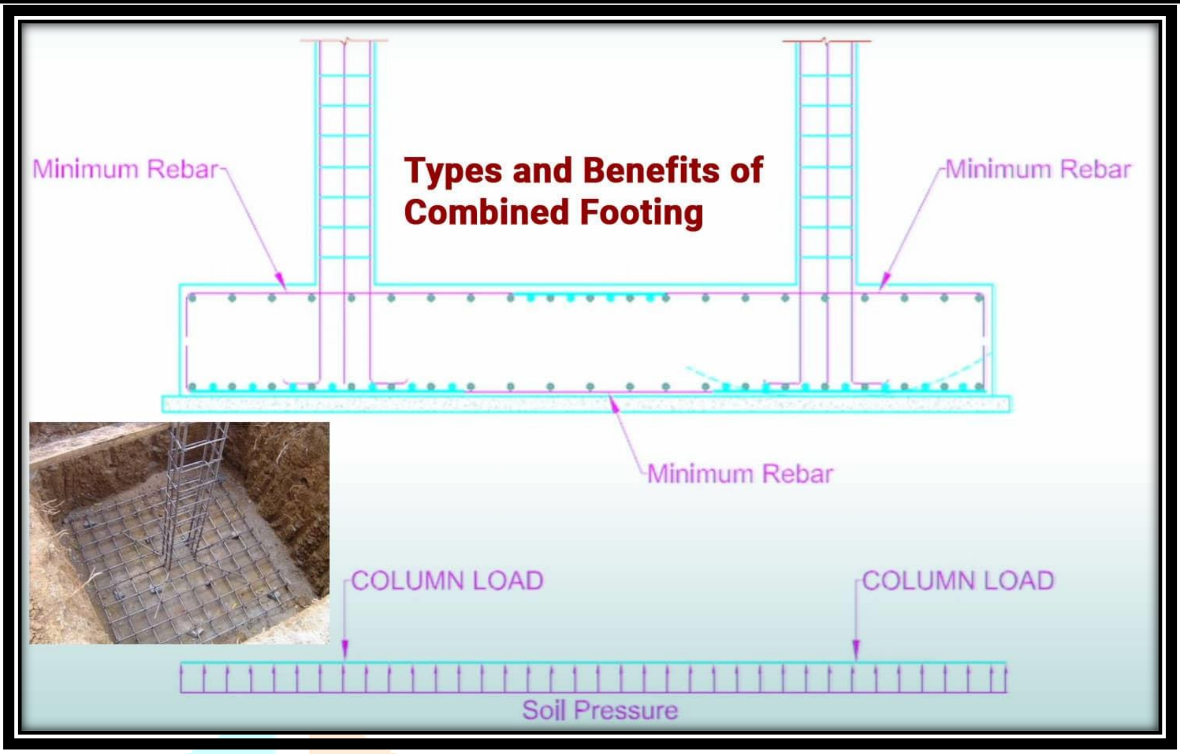
$$x = (\Sigma(P_i * x_i)) / \Sigma P_i$$

Depending on load magnitude and spacing, rectangular or trapezoidal footing is selected. The design is performed as per **IS 456:2000**, treating the footing as a slab subjected to upward soil pressure.

Structural checks include:

- Longitudinal bending moments
- Shear forces along critical sections
- Reinforcement distribution for load sharing

The stress distribution is more uniform compared to isolated footing due to overlapping pressure zones. Settlement is reduced, but not completely eliminated, as the system is only partially integrated.



4. Methodology for Raft Foundation

Raft foundation is analyzed as a **continuous slab covering the entire plan area** of the structure. The total load from all columns is distributed over the raft area:

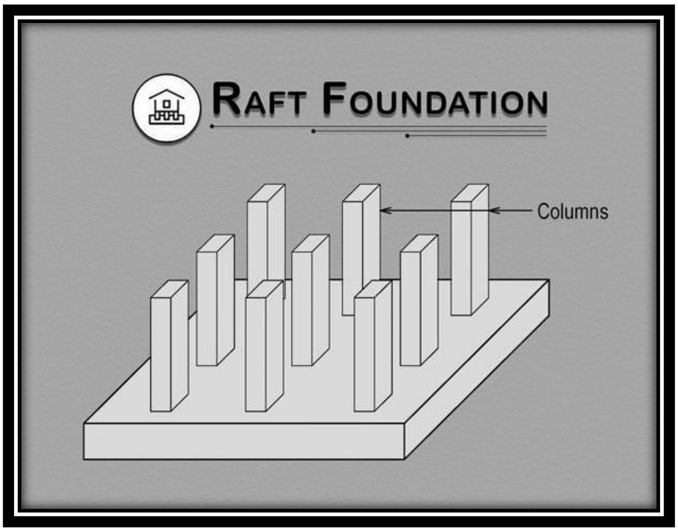
q = (ΣP) / A_raft

Design is carried out as per **IS 2950 (Part 1):1981**, considering either rigid or flexible raft behavior. Advanced analysis may involve plate theory or finite element methods.

Key considerations include:

- Uniformity of soil pressure distribution
- Bending moments in both directions
- Shear forces and punching shear at column locations
- Modulus of subgrade reaction (k) for soil-structure interaction

Settlement analysis is critical and is performed to ensure that both total and differential settlements are within permissible limits specified in **IS 1904:1986**. Due to its rigidity, raft foundation significantly reduces differential settlement by redistributing loads across the entire structure.



COMPARATIVE ANALYSIS

A comprehensive comparative analysis of isolated, combined, and raft foundations is carried out based on their performance under identical loading and soil conditions. The comparison is primarily based on bearing capacity utilization, settlement behavior, stress distribution, structural response, and economic considerations, in accordance with relevant Indian Standard codes.

1. Bearing Capacity Utilization

- **Isolated Footing:**
  Utilizes soil bearing capacity efficiently when SBC is high. However, large footing sizes may be required for heavy loads, leading to overlapping stress zones.
- **Combined Footing:**
  Provides better utilization of bearing capacity by distributing loads from multiple columns over a common area. Suitable when isolated footings overlap.
- **Raft Foundation:**
  Significantly reduces net contact pressure by spreading the total load over a large area:

  $$q = (\Sigma P) / A_{raft}$$

  Hence, it is most suitable for soils with low bearing capacity.

2. Settlement Behavior (IS 1904:1986)

- **Isolated Footing:**
  High संभावना of differential settlement due to independent behavior of each footing.
- **Combined Footing:**
  Reduces differential settlement by connecting columns, but some variation still exists.
- **Raft Foundation:**
  Provides nearly uniform settlement due to its rigidity and load redistribution capability.

Observation: Raft foundation best satisfies permissible settlement limits.

3. Stress Distribution

- **Isolated Footing:**
  Produces localized stress bulbs beneath each column, leading to stress concentration.
- **Combined Footing:**
  Stress bulbs partially overlap, improving load distribution.
- **Raft Foundation:**
  Creates a continuous stress field, minimizing stress concentration.

Engineering Insight: Raft converts discrete loads into uniformly distributed pressure.

4. Structural Behavior

- **Isolated Footing:**
  Acts as independent structural units with no interaction.
- **Combined Footing:**
  Semi-rigid system allowing partial load redistribution.
- **Raft Foundation:**
  Acts as a rigid or semi-rigid slab, enabling full load redistribution across columns. Raft foundation provides maximum structural stability.

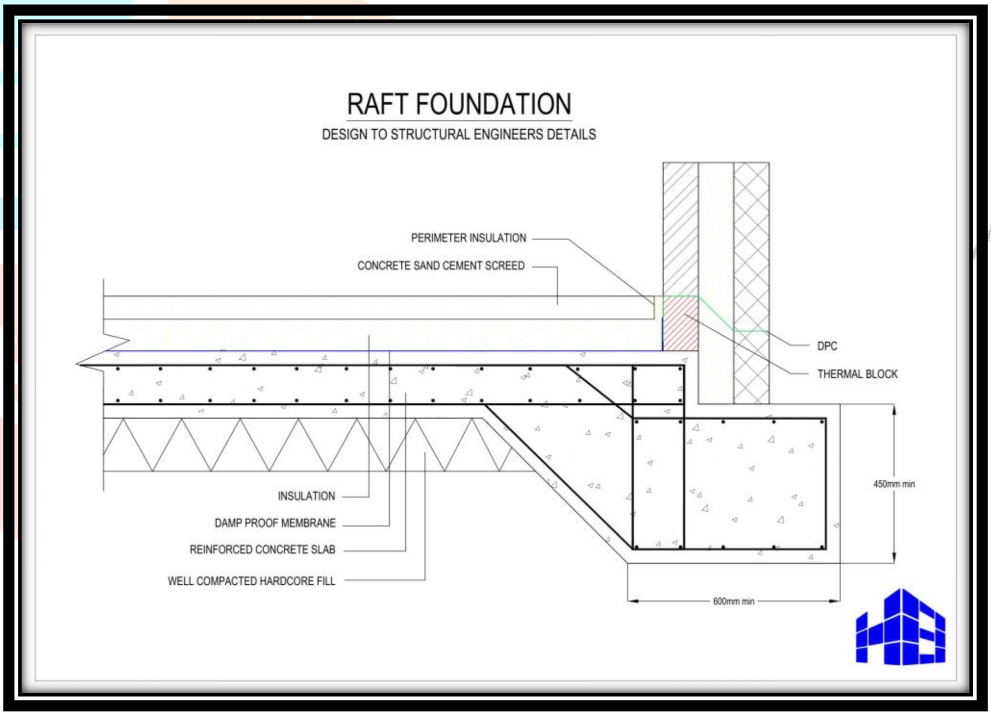
5. Suitability Based on Soil Conditions

Soil Condition	Suitable Foundation
High SBC	Isolated Footing
Medium SBC	Combined Footing
Low SBC	Raft Foundation

6. Economic Comparison

- **Isolated Footing:**
  Most economical for low-rise structures on good soil.

- **Combined Footing:**
  Moderate cost due to increased size and reinforcement.
- **Raft Foundation:**
  High initial cost but economical in long term due to reduced maintenance and settlement issues.



7. Codal Interpretation

- **IS 6403** → Governs bearing capacity
- **IS 1904** → Governs settlement criteria
- **IS 2950** → Recommends raft foundation for weak soils

Design is controlled more by **serviceability (settlement)** than strength.

Overall Performance Comparison

Criteria	Isolated	Combined	Raft
Load Distribution	Poor	Moderate	Excellent
Settlement Control	Poor	Moderate	Excellent
Structural Behavior	Independent	Semi-integrated	Fully integrated
Cost	Low	Medium	High
Suitability	Strong soil	Moderate conditions	Weak soil

Final Interpretation

From the comparative study, it is evident that:

- Isolated footing is efficient but limited to favorable soil conditions
- Combined footing is mainly a solution for geometric constraints
- Raft foundation offers superior performance in terms of **uniform stress distribution, settlement control, and structural safety**

Thus, modern engineering practice increasingly favors raft foundations, especially in urban construction where soil conditions are often unfavorable.

Results and Discussion

Comparative Results under Uniform Conditions

For analytical comparison, all three foundation types are evaluated under identical parameters:

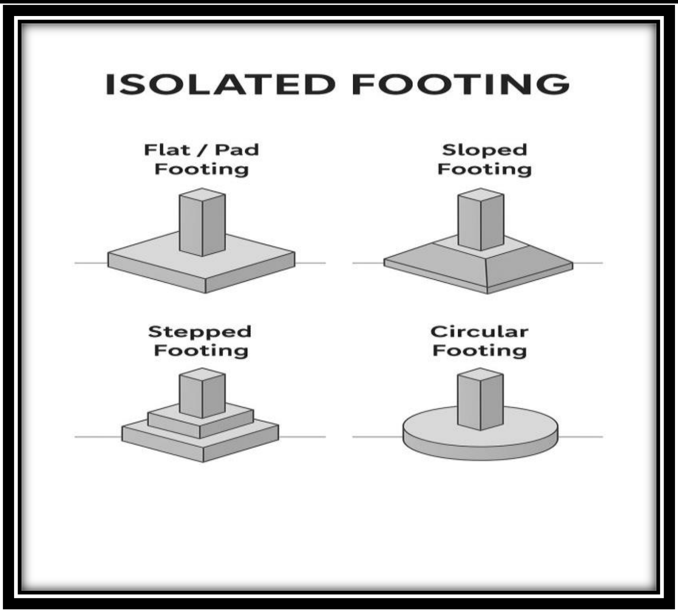
- Column load (P) = 1000–1500 kN
- Safe Bearing Capacity (SBC) = 100 kN/m² (medium soil)
- Column spacing = 3–5 m
- Soil type = Cohesive (clay)

Footing Area Requirement

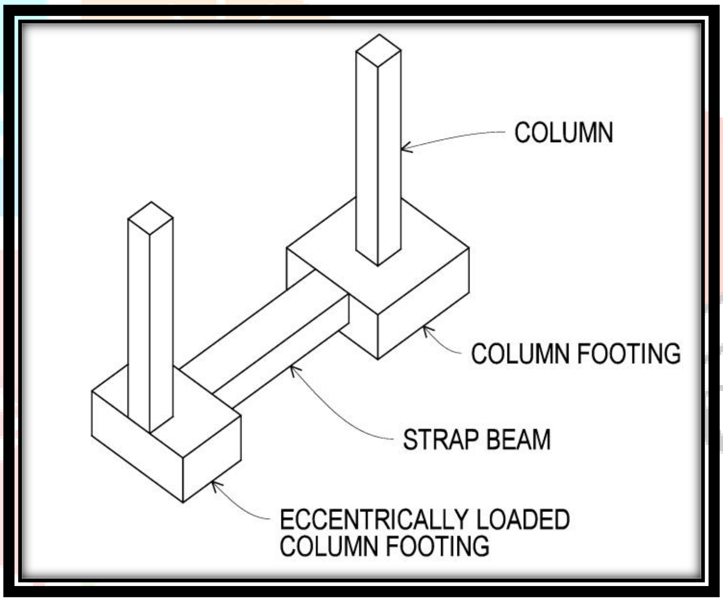
- **Isolated Footing:**
  Required area increases significantly with load:

  A = P / q_allow ⇒large individual footings

  Leads to overlapping stress zones when spacing is small.



- **Combined Footing:**
  Total area slightly optimized due to shared load:
  - Reduction in eccentricity
  - Better utilization of available area



- **Raft Foundation:**
  Entire plan area utilized:
  - Contact pressure reduced significantly
  - Efficient load spreading across soil mass

Result: Raft foundation shows the lowest contact pressure for the same loading condition.

Stress Distribution Behavior

- **Isolated Footing:**
  Produces independent **stress bulbs**, causing:
  - High stress concentration beneath each column
  - Overlapping of pressure zones when spacing is inadequate
- **Combined Footing:**
  Partial merging of stress bulbs:
  - More uniform pressure distribution than isolated footing
  - Still susceptible to edge pressure variation

- **Raft Foundation:**
  Acts as a continuous slab:
  - Uniform stress distribution across entire base
  - Reduction in peak stresses

Engineering Interpretation:
Raft transforms discrete load transfer into a **continuous stress field**, reducing soil overstressing.

Settlement Analysis (as per IS 1904 & IS 2950)

Total Settlement

- Isolated footing: 40–60 mm (varies per column)
- Combined footing: 30–50 mm
- Raft foundation: 25–40 mm

Differential Settlement

- Isolated footing: High (non-uniform soil response)
- Combined footing: Moderate
- Raft foundation: Minimal

Result:
Raft foundation satisfies **permissible differential settlement limits (≤ 1/500 span)** more effectively.

Effect of Soil Bearing Capacity

High SBC (>150 kN/m²):

- Isolated footing → most economical
- Combined footing → unnecessary unless constrained

Medium SBC (75–150 kN/m²):

- Combined footing → practical solution
- Isolated footing may still be used with spacing control

Low SBC (<75–100 kN/m²):

- Raft foundation → preferred (as per IS 2950)

Result:
Foundation selection is **SBC-driven**, with raft becoming essential in weak soils.

Parameter	Isolated	Combined	Raft
Concrete Quantity	Low	Medium	High
Steel Requirement	Low	Medium	High
Excavation	Minimal	Moderate	Extensive
Construction Time	Short	Moderate	Long
Maintenance Cost	High (due to settlement issues)	Moderate	Low

Practical Field Observations

- Isolated footings often fail due to **unequal settlement**, not bearing failure
- Combined footings are frequently used in **urban plots with boundary constraints**
- Raft foundations are widely adopted in:
  - High-rise buildings
  - Soft clay regions
  - Areas with fluctuating groundwater

Criteria	Best Foundation Type
Economy (good soil)	Isolated
Space constraint	Combined
Weak soil / high load	Raft
Settlement control	Raft
Structural safety	Raft

Final Discussion Summary

From both analytical and codal perspectives, raft foundations outperform isolated and combined footings in terms of **load distribution, settlement control, and structural integrity**, especially in weak soil conditions. However, isolated and combined footings remain relevant due to their economic advantage under favorable soil conditions.

Conclusion

The comparative study of isolated, combined, and raft foundations highlights that foundation selection is primarily governed by soil conditions, loading characteristics, and settlement criteria as per Indian Standards. Isolated footings are economical and effective for structures on soils with high bearing capacity and adequate column spacing. Combined footings serve as a practical solution under space constraints and boundary limitations, offering improved load distribution. However, raft foundations demonstrate superior performance in weak or compressible soils by ensuring uniform stress distribution and minimizing differential settlement. Although initially costlier, raft foundations provide better long-term stability and serviceability, making them the most suitable choice where settlement control is critical.

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