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Experimental Evaluation Of Reinforced Soil For Improving Footing Bearing Capacity

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ABSTRACT

Foundations are one of the most critical components of civil engineering structures, as they safely transfer structural loads to the underlying soil. The stability and durability of a structure largely depend on the bearing capacity and settlement characteristics of the supporting soil. Weak or poorly compacted soils may result in excessive settlement, instability, and structural failure. Therefore, improving the bearing capacity of soil has become an important aspect of geotechnical engineering.

The present study focuses on the experimental evaluation of reinforced soil for improving the bearing capacity of shallow footings under controlled laboratory conditions. Model footing tests were conducted on different soil conditions, including sandy soil, clayey soil, and mixed soil. Reinforcement materials such as plastic mesh and geogrid were introduced within the soil layers to investigate their influence on load carrying capacity and settlement behavior.

The experimental program involved preparation of model footing specimens, controlled loading, and observation of load-settlement behavior. The effects of soil type, moisture content, reinforcement depth, and reinforcement layers on footing performance were examined. Workability tests and compressive strength tests were also conducted to evaluate the quality of concrete used for casting the model footing.

The results demonstrated that reinforced soil significantly improves footing performance by increasing the ultimate bearing capacity and reducing settlement. Reinforced soil exhibited gradual and controlled failure compared to sudden failure in unreinforced soil. The study also revealed that proper placement of reinforcement layers ensures uniform load distribution and improved stability of the foundation system.

The findings of this research provide practical guidance for the economical and safe design of shallow foundations, particularly in weak soil conditions. Reinforcement techniques can therefore be effectively adopted in construction projects to improve soil performance and ensure long-term structural stability.

Keywords: Reinforced soil, bearing capacity, shallow footing, settlement, geogrid, soil stabilization, load-settlement behavior.

1. INTRODUCTION

Foundations form the base of every civil engineering structure and play a significant role in ensuring structural stability and safety. The primary function of a foundation is to transfer the load of the superstructure safely to the supporting soil without causing excessive settlement or failure. Among the various types of foundations, shallow footings are widely used because of their simplicity, cost-effectiveness, and ease of construction.

The performance of shallow foundations depends largely on the engineering properties of soil, such as bearing capacity, shear strength, density, and compressibility. In practical construction conditions, soils often possess inadequate strength to safely support structural loads. Weak or loose soils may undergo excessive settlement, leading to structural cracks, instability, and even collapse. Therefore, enhancement of soil strength and bearing capacity is essential for ensuring the safety and durability of structures.

In recent years, reinforced soil technology has emerged as an effective solution for improving soil behavior. Soil reinforcement involves the inclusion of reinforcing materials such as geogrids, geotextiles, metal strips, or plastic meshes within the soil mass. These reinforcements improve interlocking action between soil particles, thereby increasing load carrying capacity and reducing settlement.

The present experimental investigation aims to study the behavior of model footings resting on reinforced and unreinforced soil under laboratory conditions. The study evaluates the influence of soil type, reinforcement arrangement, and loading conditions on footing performance. Reinforcement materials were placed at different depths within the soil bed to determine their effectiveness in improving bearing capacity.

The load-settlement relationship obtained from the experiments helps in understanding the soil-structure interaction and failure mechanism of footing systems. The findings of this study are expected to contribute toward the design of economical and stable foundations, especially in areas with weak or problematic soil conditions.

2. OBJECTIVES OF THE STUDY

The main objectives of the present study are as follows:

1. To study the behavior of shallow footings resting on different soil conditions.
2. To evaluate the effect of soil reinforcement on footing bearing capacity.
3. To compare the performance of reinforced and unreinforced soil.
4. To analyze the load-settlement characteristics of footing systems.
5. To determine the effect of reinforcement depth and layering on footing stability.
6. To study the failure behavior of footing under gradual loading.
7. To evaluate the workability and compressive strength of concrete used for model footing preparation.
8. To provide economical and practical recommendations for foundation improvement.

3. LITERATURE REVIEW

Several researchers have investigated the behavior of shallow foundations on reinforced soils. Previous studies indicate that reinforcement techniques significantly improve the engineering properties of soil and enhance foundation stability.

3.1 Model Footing Studies

Researchers observed that settlement increases with an increase in applied load. Initially, settlement occurs within the elastic range; however, rapid settlement is observed near the ultimate failure stage. The load-settlement curve is commonly used to determine the ultimate bearing capacity of soil.

3.2 Soil Behavior

Studies on sandy soils indicated higher bearing capacity but sudden shear failure. Clayey soils exhibited comparatively lower bearing capacity and larger settlement, although failure occurred gradually. Mixed soils demonstrated intermediate behavior.

3.3 Reinforced Soil

The use of reinforcement materials such as geogrids and geotextiles significantly improved soil strength. Reinforced soils showed reduced settlement, increased bearing capacity, and better load distribution characteristics. Reinforcement also transformed sudden failure into gradual failure, thereby improving foundation safety.

3.4 Research Gap

Although numerous studies have been conducted on reinforced soil systems, several limitations still exist:

- Combined effects of soil type, moisture content, reinforcement depth, and loading conditions are not comprehensively studied.
- Limited laboratory investigations are available using low-cost reinforcement materials.
- Optimization of reinforcement layer spacing and depth is not clearly defined.
- Comparative studies under identical testing conditions are limited.
- Environmental effects such as water saturation and fluctuating moisture conditions require further investigation.

The present study attempts to address these research gaps through controlled experimental investigations on reinforced footing systems.

4. MATERIALS USED

4.1 Soil

Natural river sand passing through a 2.36 mm sieve was used for experimental work. The specific gravity of the sand was found to be 2.453. Clay soil and mixed soil combinations were also prepared to study comparative footing behavior.

Soil Proportions

Soil Type	Sand (%)	Clay (%)	Water Content (%)
Sandy Soil	100	0	5–10
Clayey Soil	0	100	15–25
Mixed Soil	70	30	10–15

4.2 Reinforcement Materials

The following reinforcement materials were used:

- Geogrid
- Geotextile
- Plastic mesh (economical alternative)

The reinforcement layers were placed at varying depths below the footing to investigate their effectiveness.

Reinforcement Placement

Layer No.	Depth from Footing	Relative Depth
1	3 cm	0.3B
2	6 cm	0.6B
3	9 cm	0.9B

Where B represents the width of the footing.

4.3 Concrete Materials

Concrete materials used for footing casting included:

- Ordinary Portland Cement
- Fine Aggregate (Sand)
- Coarse Aggregate
- Water

Concrete mix proportion of 1:2:4 was adopted for model footing preparation.

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5. METHODOLOGY

The experimental investigation was conducted using a model footing setup under controlled laboratory conditions.

5.1 Preparation of Model Footing

The footing specimens were cast using a mould of size 10 cm × 10 cm × 2 cm.

Procedure for Casting Footing

1. The mould was cleaned thoroughly and lubricated with oil.
2. Concrete ingredients were mixed in the proportion of 1:2:4.
3. Water was added gradually to achieve proper workability.
4. Concrete was poured into the mould in layers.
5. Each layer was compacted using a tamping rod.
6. The top surface was levelled and finished smoothly.
7. The specimens were left undisturbed for 24 hours.
8. Demoulding was carried out carefully.
9. Footings were cured in water for 7 days.
10. After curing, specimens were dried and used for testing.

5.2 Preparation of Soil Bed

The soil bed was prepared inside the testing container with controlled density and moisture content. Reinforcement layers were inserted at predetermined depths. The model footing was then placed centrally over the prepared soil bed.

5.3 Loading Procedure

Load was applied gradually on the model footing using loading arrangements. Settlement readings corresponding to each load increment were recorded until failure occurred.

5.4 Observation Parameters

The following parameters were observed during experimentation:

- Load carrying capacity
- Settlement behavior
- Failure pattern
- Effect of reinforcement
- Effect of moisture content
- Load-settlement relationship

6. TESTS CONDUCTED

6.1 Flow Table Test

Objective

To determine the workability and consistency of the concrete mix.

Apparatus Used

- Flow table
- Mould
- Tamping rod
- Container
- Balance

Procedure

1. The table and mould were cleaned properly.
2. The mould was placed at the center of the table.
3. Concrete mix was filled in two layers.
4. Each layer was tamped uniformly.
5. Excess material was removed from the top.
6. The mould was lifted vertically.
7. The table was dropped 25 times within 15 seconds.
8. The spread diameter was measured and average value was calculated.

Workability Classification

Slump Value (mm)	Workability Level
0–25	Very Low
25–50	Low
50–100	Medium
100–175	High

6.2 Compressive Strength Test

Objective

To determine the compressive strength of concrete cubes.

Apparatus

Compression Testing Machine (CTM)

Procedure

1. Concrete cubes of standard size were prepared.
2. Specimens were removed from the mould after 24 hours.
3. Cubes were cured properly.
4. The specimen was placed centrally in the CTM.
5. Load was applied gradually without shock.
6. Failure load was recorded.
7. Compressive strength was calculated.

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7. RESULTS AND DISCUSSION

7.1 Workability Test Results

The flow table test indicated satisfactory workability of the concrete mix used for footing casting. Increased flow values represented improved consistency and ease of handling.

Combination	Flow Value (%)	Workability
Combination 1	76	Good
Combination 2	88	Very Good
Combination 3	98	Excellent

The results indicated that workability improved with increase in binding additives and water content. All combinations exhibited acceptable workability suitable for casting operations.

7.2 Compressive Strength Test Results

Specimen No.	Failure Load (kN)	Compressive Strength (N/mm²)
1	420	18.6
2	450	20.0
3	480	21.3

The compressive strength results demonstrated gradual improvement in concrete strength among different specimens. Specimen 3 exhibited the highest compressive strength, indicating better bonding and improved material performance.

7.3 Footing Behavior on Reinforced Soil

The reinforced soil system showed significantly improved performance compared to unreinforced soil. Settlement values were reduced considerably under identical loading conditions. Reinforcement layers increased the stiffness of soil and enhanced load distribution.

The following observations were made:

- Reinforced soil exhibited higher bearing capacity.
- Settlement reduction was significant in reinforced soil.
- Failure became gradual and controlled.
- Reinforcement improved overall stability.
- Uniform stress distribution was achieved.

7.4 Failure Mechanism

Unreinforced soil showed sudden shear failure near ultimate load conditions. In contrast, reinforced soil demonstrated progressive and ductile failure behavior due to improved confinement and interlocking action.

7.5 Effect of Moisture Content

Increase in water content reduced soil strength and bearing capacity. Saturated soil exhibited higher settlement compared to partially saturated conditions. Reinforcement helped in minimizing settlement even under higher moisture conditions.

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8. COST ANALYSIS

Sr. No.	Material	Quantity	Rate (Rs.)	Amount (Rs.)
1	Cement	1 kg	10	10
2	Sand	5 kg	2	10
3	Coarse Aggregate	10 kg	2	20
4	Geogrid/Plastic Mesh	1 Piece	50	50
5	Water	Lump Sum	5	5
6	Miscellaneous	Lump Sum	20	20
	Total Cost			**115**

The cost analysis indicates that reinforced soil techniques can be implemented economically using low-cost reinforcement materials such as plastic mesh. The improvement in foundation stability justifies the additional reinforcement cost.

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9. ADVANTAGES OF REINFORCED SOIL

The use of reinforced soil offers several engineering advantages:

- Improves bearing capacity of weak soil.
- Reduces footing settlement.
- Enhances foundation stability.
- Provides uniform load distribution.
- Minimizes sudden failure.
- Economical and easy to implement.
- Suitable for problematic soil conditions.
- Improves durability and service life of structures.

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10. APPLICATIONS

Reinforced soil foundations can be effectively used in:

- Residential buildings
- Highway embankments
- Retaining wall systems
- Industrial structures
- Bridge foundations
- Railway infrastructure
- Low-cost housing projects
- Foundations on weak soils

11. CONCLUSIONS

The experimental investigation on reinforced soil for improving footing bearing capacity was successfully carried out under controlled laboratory conditions. Based on the results obtained, the following conclusions can be drawn:

1. Settlement of footing increased with increase in applied load in all soil conditions.
2. Reinforced soil exhibited significantly higher bearing capacity compared to unreinforced soil.
3. Reinforcement layers effectively reduced footing settlement.
4. Load distribution became more uniform due to reinforcement.
5. Reinforced soil demonstrated gradual and controlled failure behavior.
6. Unreinforced soil showed sudden shear failure at ultimate load.
7. Proper placement of reinforcement layers enhanced foundation performance considerably.
8. Increase in water content reduced soil strength and increased settlement.
9. The concrete used for footing preparation exhibited satisfactory workability and compressive strength.
10. Reinforced soil systems provide an economical and practical solution for improving shallow foundation performance.

Overall, the study confirms that reinforcement techniques can effectively enhance the engineering behavior of soil and improve the safety, stability, and durability of shallow foundations.

12. FUTURE SCOPE

Further research may be carried out in the following areas:

- Investigation using different reinforcement materials.
- Numerical modeling of reinforced footing systems.
- Study under cyclic and dynamic loading conditions.
- Investigation of long-term settlement behavior.
- Large-scale field testing for practical validation.
- Effect of environmental and climatic conditions.
- Optimization of reinforcement spacing and depth.

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