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Investigation of the Load Settlement Behaviour of Shallow Foundation on Latex-Coated Coir Needle Felt Reinforced Soil Bed

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Abstract: For a sustainable planet, the need for geosynthetics has been increasing day by day. Also, geosynthetics plays a crucial part in enhancing soil properties and can effectively improve bearing capacity of structures erected on sandy ground. Therefore, the study aims to investigate effect of latex-coated coir needle felt reinforcement on BCR (Bearing Capacity Ratio) and SRF (Settlement Reduction Factor) of shallow foundation in a sand bed. A square footing with a thickness of 25mm and a size of 200mm was employed to conduct model plate load experiments on a sand bed that was reinforced with uncoated, single side latex-coated, double side latex-coated coir needle felt each having 1000 GSM in a test tank of dimension 500 x 500 x 500 mm. The number of layers of coir needle felt in planar, wave and looped configurations were the parameters that were examined. Bearing capacity (BC) of reinforced sand was approximately 30.43%-67.34% greater than that of unreinforced sand. SRF of reinforced sand has been elevated by approximately 15% to 43.22% in comparison to unreinforced sand.

Keywords: Sand Bed, Bearing Capacity, Coir Needle Felt, Latex-Coated, Settlement

I. INTRODUCTION

Geosynthetics are being utilized more frequently in the development of sustainable geosynthetic-reinforced soil foundations (GRSFs) in modern construction. The primary objective of incorporating geosynthetic reinforcement into foundation soil is to increase its load-BC as well as minimize settlement. Consequently, it is imperative to conduct a precise assessment of the load-BC to ensure the safety and longevity of GRSFs. The practice of reinforcing unstable soil has been in existence since ancient times; however, the most significant advancements in soil reinforcement systems occurred during the 1960s and 1970s [6]. Modern techniques emerged in the mid-1970s with the research of Binquet and Lee [4], who examined the load-bearing behavior of reinforced sandy soil. Since then, extensive studies have been carried out using both experimental and numerical methods to evaluate the load-BC “of GRSFs. The main goal of this research has been to identify, analyze, as well as optimize critical factors that significantly impact the load-bearing performance of GRSFs. The key parameters analyzed include the depth of the first reinforcement (u), the width of the reinforcement (b), the number of reinforcement layers (N), the width of the footing (B), the type of reinforcement and the vertical distance between consecutive reinforcement” layers (h).

Most cost-effective method among all ground enhancement techniques is the reinforcement of weak soils with geosynthetics [17]. Additionally, it offers advantages such as improved resistance to chemical reactions and corrosion. Consequently, geosynthetic-reinforced soil structures are extensively employed in a variety of geotechnical applications, like bridge foundations, slopes, highways, as well as more [19]. Because of their biodegradable and environmentally favorable properties, natural geotextiles are becoming more popular than synthetic alternatives [18]. Although natural geotextiles possess robust mechanical properties, they might not be adequate for adverse loading conditions [25]. Coir and jute, which were natural geotextiles, are frequently combined with other materials to withstand large loads. The utilization of natural polymers as bonding agents as a result of their environmentally favorable properties and reduced carbon footprint has been the focus of recent advancements in geotechnical engineering [1]. Latex, a natural polymer extracted from rubber plants, is valued for its durability. Coir Needle Felt (CNF) is a non-woven geotextile produced by needle-punching coir fibers. When coated with latex, Coir Needle Felt integrates the benefits of both geotextiles and natural polymers, providing the mechanical strength of coir fibers along with the durability of latex [14]. The usage of these materials can be intricate, as it is contingent upon the properties as well as configuration of the reinforcement [17] and the soil's characteristics [22]. Therefore, a comprehensive understanding of the soil-geosynthetic interaction mechanism is essential for effective implementation. In this study, the impact of using Uncoated Coir Needle Felt, Single-Side Latex-Coated Coir Needle Felt, and Double-Side Latex-Coated Coir Needle Felt for shallow foundations in sandy soil is examined.

II. MATERIAL CHARACTERISTICS

A. *Sand*

The sand utilized for current investigation has been locally derived from Menamkulam in the Thiruvananthapuram district and was collected from a depth of 1.5m below the surface. The sample was subjected to a variety of tests, such as direct shear tests, specific gravity, relative density, and grain size distribution (GSD), by the relevant sections of IS 2720. The direct shear test was employed to estimate the shear strength parameters. The graph of the sediment's particulate size distribution is depicted in Fig. 1. The soil is classified as inadequately graded sand (SP) by the Indian Standard Classification System. Table 1 summarizes the attributes of sand.

TABLE 1
PROPERTIES OF SAND

Property	Value
IS Classification	SP
Cohesion, c (kg/cm^2)	0.15
Minimum void ratio, e_{min}	0.41
Maximum void ratio, e_{max}	0.63
Percentage of coarse sand (%)	0.9
Curvature coefficient, Cc	1.1
Uniformity coefficient, Cu	1.43
Specific Gravity, G	2.5
Initial moisture content (%)	5.58
Relative Density (%)	30
Angle of internal friction, ϕ	39°
Percentage of medium sand (%)	39.3
Percentage of fine sand" (%)	59.8

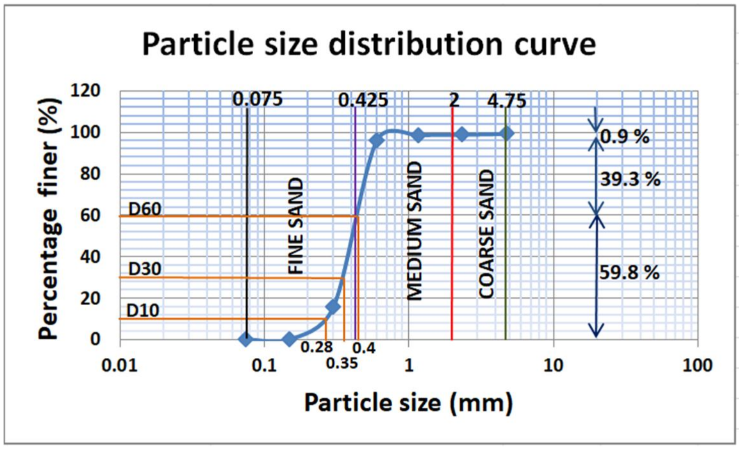


Fig. 1 Particle size distribution of sand

B. *Coir Needle Felt (CNF)*

Coir Needle Felt was obtained from a small-scale industry, Neyyattinkara Coir Cluster, in Trivandrum. An image of the collected Coir Needle Felt is shown in Fig. 2. Properties of material were analyzed, as well as resulting values were provided in Table 2. Properties of material were analyzed, as well as resulting values were provided in Table 2.

Fig. 2 Coir Needle Felt (CNF)

TABLE 2
PROPERTIES OF COIR NEEDLE FELT

Type	**Thickness (mm)**	**Tensile strength (kN/m)**	**Mass per unit area (g/m^2)**	**Puncture resistance (mm)**
Uncoated Coir Needle Felt	10	15	1000	2.66
Single Side Latex Coated Coir Needle Felt (SSC)	8.5	16	1000	2.55
Double Side Latex Coated Coir Needle Felt (DSC)	7	16.5	1000	2.33

(Source: Neyyattinkara Coir Cluster, Trivandrum)

These values were determined following the guidelines specified in IS 15340:2003, IS 13102 (Part 5):1992, and IS 13162 (Part 4):1992.

C. Latex

Prevulcanised latex was obtained from KA Prevulcanised Latex Pvt. Nagercoil. Prevulcanised latex was used to coat the CNF to obtain SSC and DSC with latex content of 5% and 10 % respectively. The properties of latex were summarized in Table 3.

TABLE 3
PROPERTIES OF LATEX

Property	Value
Alkalinity as ammonia (%)	0.71
Coagulum content (ppm)	13
Mechanical stability time (s)	698
pH	10.99
Total solid content (%)	59

(Source: KA Prevulcanised Latex Pvt. Ltd., Ltd., Nagercoil)

III. EXPERIMENTAL STUDIES

Experimental setup includes reaction beam, proving ring, hydraulic jack, test tank, dial gauge and model footing. Fig. 3 displays the experimental setup utilized in this study, while Fig. 4 presents schematic representation of experimental test setup.

Fig. 3 Experimental test setup

Fig. 4 Schematic representation of Experimental test setup

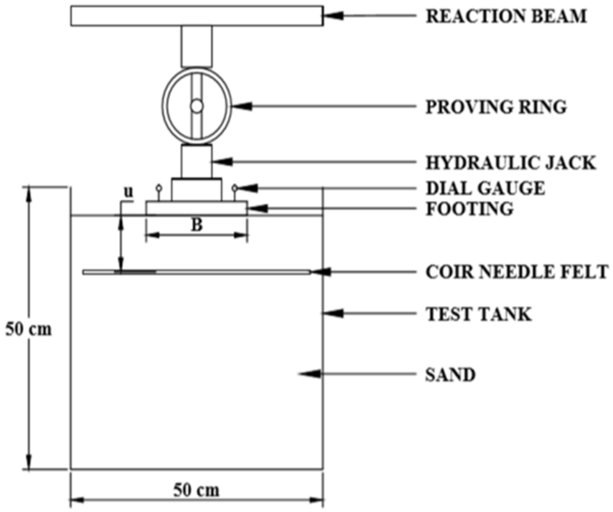


Fig. 5 Test tank utilized in the research

A. Test Procedure

Conducted as per IS 1888:1982. A mild steel test tank with dimensions of 50×50×50 cm was used to assess the settlement behavior under different loads. The reservoir was filled with the necessary soil at a relative density of 30%. The foundation bed's surface has been meticulously levelled, as well as a 20×20 cm square plate was positioned in levelled bed's center, aligning with upper layer (center) of Coir Needle Felt. To investigate the load-settlement performance of a shallow foundation on a latex-coated Coir Needle Felt reinforced sand bed under varying end conditions, a series of model plate load experiments has been conducted following the standard codal procedure [8]. The specimen was subjected to a load via a loading frame, and settlement readings were obtained utilizing a dial gauge with a minimum count of 0.01mm. Following are the notations employed in this investigation.

u: Distance from topmost reinforcement layer to foundation base
B: Width of footing
N: Number of Coir Needle Felt layers
h: Vertical spacing between successive Coir Needle Felt layers

(a) (b) (c)

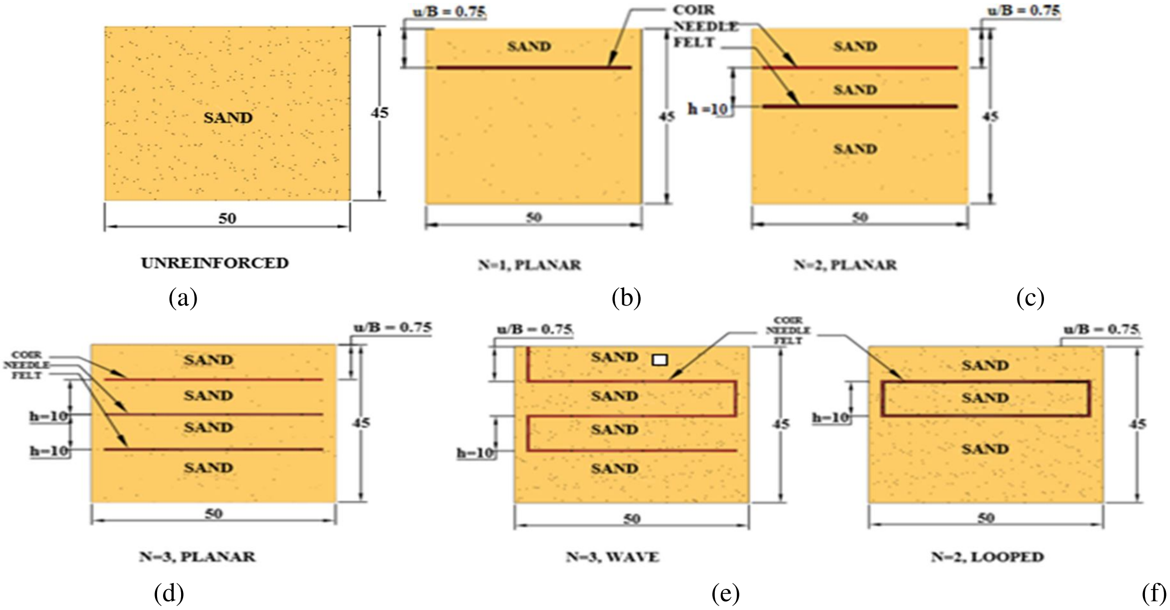
Fig. 6 (a) Placement of Coir Needle Felt, (b) Experimental set up after filling the tank, (c) Plate load setup before loading

B. Configuration Layout

Model plate load tests were conducted under plane strain conditions to examine how uncoated, single side latex coated and double side latex coated Coir Needle Felt affect the BC as well as settlement of footing. These effects have evaluated using BCR and SRF, respectively, under variable end conditions. To create these end conditions, three distinct Coir Needle Felt layouts were utilized: planar, wave, as well as looped layouts, as illustrated in Fig.7.

1) Planar Layout

In the planar layout, Coir Needle Felt layers were arranged horizontally with free ends, as depicted in Fig. 7 (b,c,d). Here the reinforcement width was consistently kept as 45 cm.



(a) (b) (c)

(d) (e) (f)

Fig. 7 Plate load test configuration layout

2) *Wave Layout*

In the wave layout, a single layer of Coir Needle Felt was installed with one end wrapped, preventing lateral slippage in direction of foundation settlement (plastic deformation), as illustrated in Fig7 (e). Length of layer was determined using the following equation:

$$L_W = 3H_L + 2W_L$$

Here, L_W represents total length of Coir Needle Felt layer in wave layout, H_L represents horizontal section's length, as well as W_L is length of wraps.

3) *Looped Layout*

In the looped layout, two layers of Coir Needle Felt has been placed with both ends wrapped as well as connected, preventing lateral slippage on both sides, as represented in Fig7(f). Each layer's length was calculated as:

$$"L_L = 2H_L + 2W_L"$$

Here, L_L denotes total length of Coir Needle Felt layer in the looped layout, H_L represents length of horizontal section, as well as W_L is length of wraps.

C. *Results and Discussion*

16 tests have been conducted on a model square footing. The first test has been performed on unreinforced soil, while the remaining tests were conducted on a sand bed reinforced with Coir Needle Felt. The study focused on different types of reinforcement, including Uncoated Coir Needle Felt, Single-Side Latex Coated Coir Needle Felt, and Double-Side Latex Coated Coir Needle Felt. The effect of Coir Needle Felt layers were analyzed in planar, wave and looped layouts, with the first layer positioned at a depth of 0.75 times the footing width, which is equal to 15 cm and a vertical spacing of 10 cm between consecutive layers. A detailed sketch showing the arrangement of the Coir Needle Felt layers is provided in Fig. 7. A pressure-settlement graph was plotted, with pressure (kPa) on X-axis as well as settlement (mm) on Y-axis, to assess results.

The first test in this study was carried out on unreinforced soil, and a graph was plotted to illustrate relationship between kPa as well as settlement (mm). Ultimate BC as well as corresponding settlement had found to be 400kN/m² as well as 90mm similarly. The improvement factors for different reinforcements, including Uncoated Coir Needle Felt, Single-Side Latex Coated Coir Needle Felt and Double-Side Latex Coated Coir Needle Felt, in planar, wave and looped layouts, were calculated by varying number of reinforcement layers. Ultimate BC of unreinforced soil and its corresponding settlement was used as a reference for these calculations. Current study, reinforcement width was consistently kept at 45cm.

Table 4 Details of the model plate load test

Test No.	**Reinforcement**		**N**	**Bearing Capacity (kPa)**	**Settlement (mm)**	**Bearing Capacity Ratio (BCR)**	**Settlement Reduction Factor (SRF) %**
	Type	**Layout**					
1	Unreinforced			400	90.0		
2	Uncoated Coir Needle Felt	Planar	1	575	76.5	1.44	15.00
3			2	650	73.5	1.63	18.33
4			3	900	71.2	2.25	20.89
5	Single-Side Latex Coated Coir Needle Felt		1	650	68.1	1.63	24.33
6			2	750	66.4	2.06	26.22
7			3	1000	65.0	2.50	27.77
8	Double-Side Latex Coated Coir Needle Felt		1	750	65.7	1.88	27.00
9			2	825	61.8	2.06	31.33
10			3	1125	58.5	2.81	35.00
11	Uncoated Coir Needle Felt	Wave	3	1075	68.2	2.69	24.22
12	Single-Side Latex Coated Coir Needle Felt			1125	60.0	2.81	33.33

13	Double-Side Latex Coated Coir Needle Felt			1225	51.1	3.06	43.22
14	Uncoated Coir Needle Felt	Looped	2	750	70.3	1.88	21.89
15	Single-Side Latex Coated Coir Needle Felt			825	61.9	2.06	31.22
16	Double-Side Latex Coated Coir Needle Felt			950	53.0	2.38	41.11

1) Planar Layout

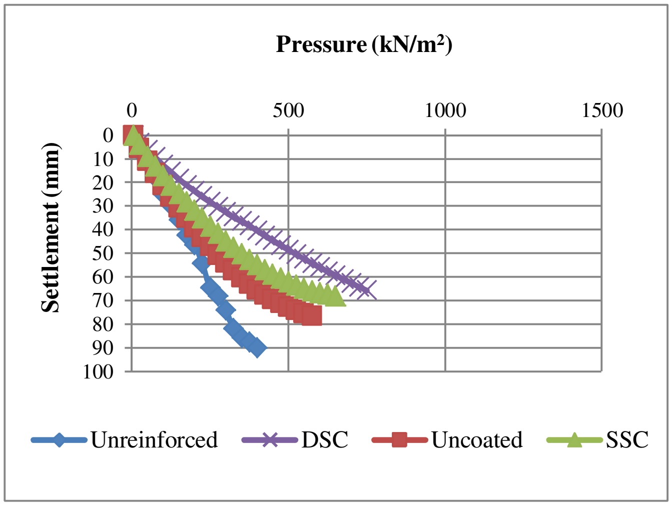


Fig. 8 Pressure- Settlement Curve for u/B = 0.75, N = 1, Planar

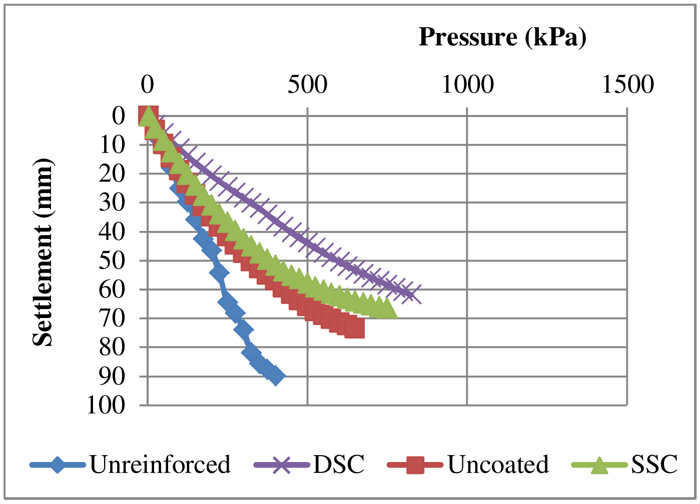


Fig. 9 Pressure-Settlement Curve for u/B = 0.75, N = 2, Planar

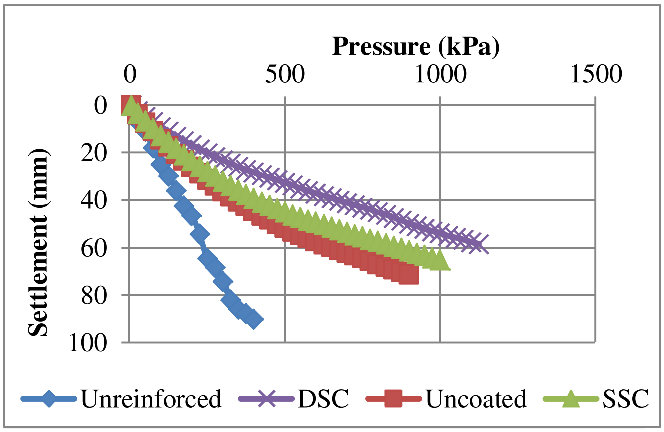


Fig. 10 Pressure-Settlement Curve for u/B = 0.75, N = 3, Planar

In planar layout, for a single layer of various reinforcements, the fluctuation in the pressure (kPa) versus settlement (mm) curve is represented in Fig. 8. For a single layer of Coir Needle Felt, the BCR and SRF showed improvement compared to the unreinforced condition. This enhancement is attributed to the membrane effect and confinement effect provided by the Coir Needle Felt [4]. For tests using multiple layers of Coir Needle Felt, the vertical spacing among consecutive reinforcement layers (h) had been consistently set at 10cm throughout the study. When two layers of Coir Needle Felt were used, the variations in pressure (kPa) versus settlement (mm) for the three types of reinforcement were illustrated in Fig. 9. The highest ultimate BC recorded was 825 kN/m² for Double-Side Latex Coated Coir Needle Felt, with a corresponding settlement of 61.8 mm. This could be attributed to random fiber distribution within the Coir Needle Felt. The addition of latex on both sides fills the voids within the Coir Needle Felt. The addition of latex on both sides fills the voids within the felt, resulting in more closely packed fibers. Consequently, the thickness of the Coir Needle Felt decreases while its tensile strength increases [15]. Similarly, when three layers of Coir Needle Felt were used, the variations in pressure (kPa) versus settlement (mm) for the three reinforcement types are presented “in Fig. 10. The maximum value of ultimate bearing capacity” recorded has been 1125 kN/m² for Double-Side Latex Coated Coir Needle Felt, with a corresponding settlement of 58.5 mm. This increase “in ultimate bearing capacity is due to greater number of reinforcement layers, which enhanced the overall load-bearing performance [23, 24]. The BCR as well as SRF were improved from 30.43 - 64.4 % and 15 - 35 % respectively, as shown in Fig.13 and Table 4. This improvement could be attributed to restriction of lateral movement of soil particles around the reinforcement surface, caused by frictional interaction and bearing resistance between the soil as well as Coir Needle Felt surface”, as well as the lateral sides of the Coir Needle Felt ribs. Similar research in literature has shown a significant rise in BC along with a deduction in settlement when geosynthetic reinforcement was layered within the soil bed [20, 21]. In the case of a planar layout with Coir Needle Felt layers, central portion of soil situated among footing as well as topmost Coir Needle Felt layer, as well as between two Coir Needle Felt layers, may not contribute effectively to enhancing BCR and SRF. This is due to insufficient lateral confinement, which limits its ability to resist deformation [2]. As a result, the efficiency of Coir Needle Felt reinforcement may be reduced. To address this issue, geosynthetic reinforcement with wrap-around ends had been explored as a means to enhance the effectiveness of reinforced foundations [3].

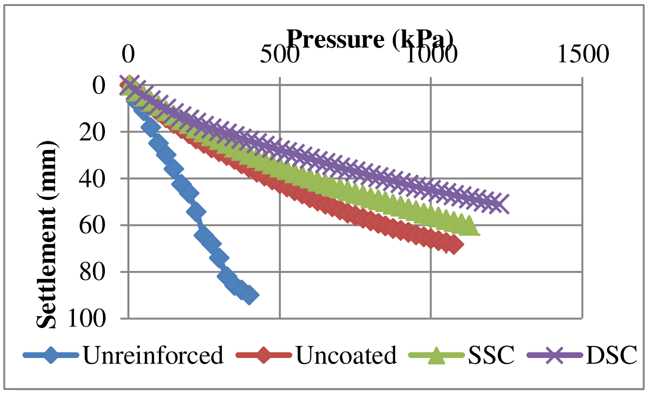


Fig. 11 Pressure-Settlement Curve for u/B = 0.75, N = 3, Wave

2) Wave Layout

In wave layout, one end of the Coir Needle Felt is wrapped around soil layer, with height of wrap matching distance between 2 Coir Needle Felt layers. When three layers of Coir Needle Felt were used in wave layout, the variations in pressure (kPa) versus settlement (mm) for the three reinforcement types are presented in Fig. 11. The maximum value of ultimate bearing capacity recorded as 1225 kN/m² for Double-Side Latex Coated Coir Needle Felt, with a corresponding settlement of 51.1mm. The BCR and SRF were improved from 62.8 - 67.3 % and 24.22 - 43.22 % respectively, as shown in Fig. 15 and Table 4. In addition to the reinforcing effect provided by the horizontal section, the wraps offered greater lateral confinement. When vertical pressure was applied through the plate loads, the horizontal Coir Needle Felt layers experienced elastic deformation, causing them to move downward. Since the layers were interconnected through the wraps, the ends of the wraps also moved toward the footing due to the resulting tension. This mechanism provided extra confinement to the soil. It was similar to manually wrapping the Coir Needle Felt around the soil layers, which introduced a slight amount of pre-stress to the Coir Needle Felt layers. As a result, the entire system functioned as a single, unified structure, effectively reducing deformation at smaller settlements [2].

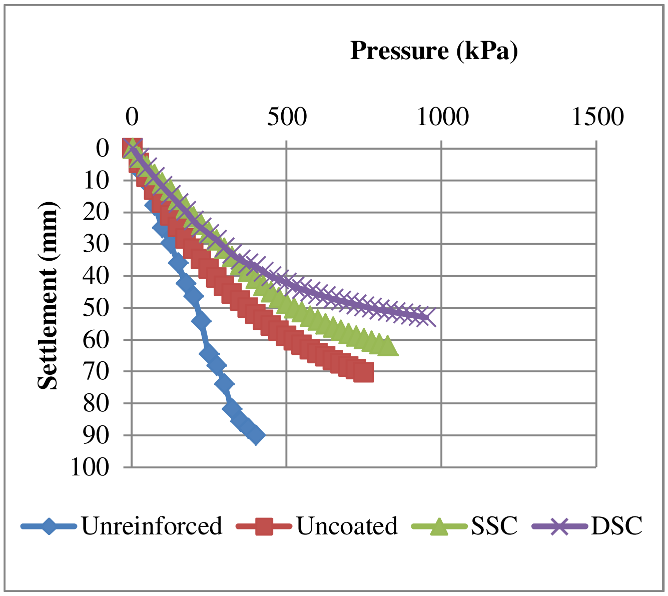


Fig. 12 Pressure - Settlement Curve for u/B = 0.75, N = 2, Looped

3) Looped Layout

In looped layout (Fig. 7(f)), the wraps on both sides of Coir Needle Felt provide additional confinement to the soil layer. When two layers of Coir Needle Felt were used in looped layout, the variations in pressure (kPa) versus settlement (mm) for the three types of reinforcement are illustrated in Fig. 12. The highest ultimate BC recorded was 950 kN/m² for Double - Side Latex Coated Coir Needle Felt, with a corresponding settlement of 53 mm. BCR as well as SRF have been improved from 46.67 – 57.89 % and 21.89 – 41.11 % respectively, as shown in Fig. 14 and Table 4. This is a result of the Coir Needle Felt's wrapping on both sides, which provide the soil layer with additional confinement in comparison to the planar layout. Similar findings have been reported by several researchers [e.g. 3, 16].

IV. SUMMARY AND CONCLUSION

This study investigates the efficient utilization of Coir Needle Felt-reinforced sand foundations through laboratory model tests on square footings. It analyzes the effects of several reinforcement layers(N) as well as latex coating in different reinforcement layouts – planar, wave and looped layouts. Based on the findings, the influence of these parameters is summarized below.

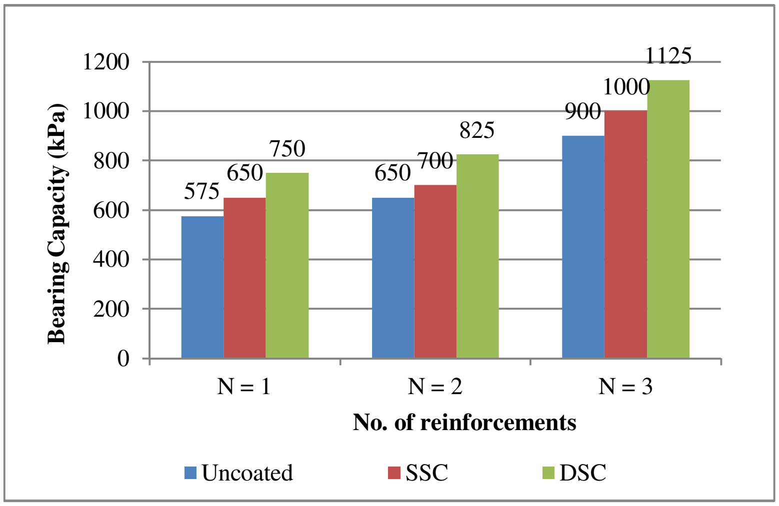


Fig. 13 Variation of Bearing Capacity for planar

A. *Number of Reinforcement Layers (N)*

Laboratory tests have been conducted on reinforced sand using model footings, with number of reinforcement layers varying from N=1-N=3. When a single layer of Coir Needle Felt was used, the ultimate BC reached was 750 kN/m² in planar layout; while incorporating two layers of Coir Needle Felt, the ultimate load capacity was increased to 950 kN/m² in looped layout; while incorporating three layers of Coir Needle Felt, the ultimate load capacity was increased to 1225 kN/m² in wave layout. The corresponding settlements for these cases were 65.7 mm, 53 mm and 51.1 mm respectively. However, the optimal number of reinforcement layers depends on factors including spacing between layers, depth of top layer, the reinforcement layout and whether a latex coating is applied. These aspects play vital part in determining effectiveness of reinforcement, as its placement within the influence zone beneath the footing significantly impacts performance.

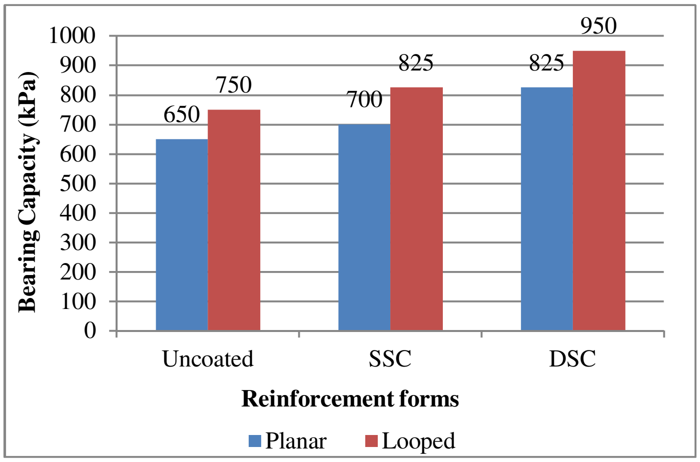


Fig. 14 Variation of Bearing Capacity for N = 2

B. *Impact of Latex Coating*

When a single layer of Coir Needle Felt was used for reinforcement, applying latex coating improved its performance. Ultimate BC increased from 575kN/m² - 650kN/m² when coated on one side and further rose to 750 kN/m² when coated on both sides. Similarly, settlement decreased from 76.5 mm to 68.1 mm with a single-side coating and further reduced to 65.7 mm with coating on both sides. This improvement is attributed to the random fiber arrangement in Coir Needle Felt. When latex is applied to both sides, it fills the voids, bringing the fibers closer together. As a result, the material becomes thinner while its tensile strength improves [15].

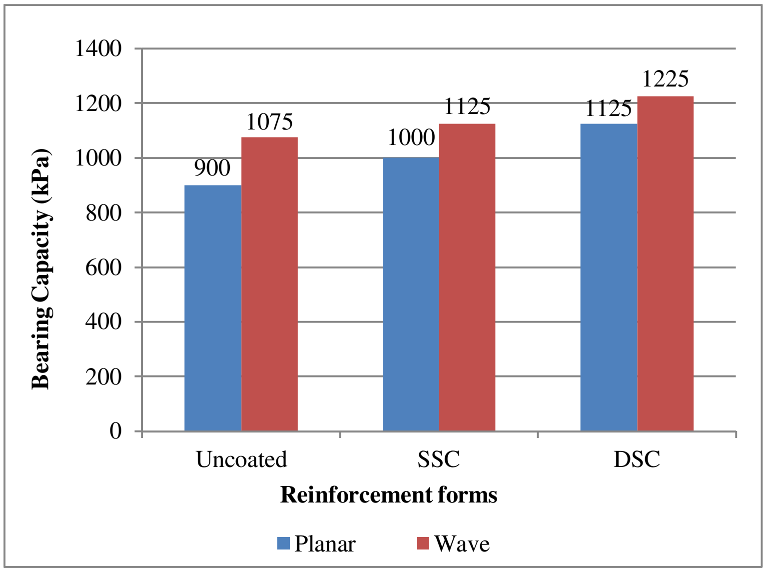


Fig. 15 Variation of Bearing Capacity for N = 3

- The load-settlement response of a square footing on sand reinforced with Coir Needle Felt remains almost linear up to 200 kPa.
- For optimal reinforcement benefits, it should be positioned within the influence zone beneath the footing.
- Double-Side Latex Coated Coir Needle Felt demonstrates superior performance compared to both Uncoated Coir Needle Felt and Single-Side Latex Coated Coir Needle Felt.
- The BC of sand reinforced with Coir Needle Felt exhibits a significant improvement compared to unreinforced sand. Due to its high tensile strength, Coir Needle Felt effectively distributes forces over a larger soil area.
- This strength is further enhanced with latex coating, making coated felts stronger in tension than uncoated ones.
- Additionally, increasing number of reinforcement layers results in greater BC as well as reduced settlement.
- BCR of reinforced sand increased by approximately 30.43 – 67.34% compared to unreinforced sand, while the SRF improved by 15 – 43.22%.
- Among different reinforcement layouts, wave and looped configurations proved to be more efficient than the planar layout.
- Most effective reinforcement system was the Double-Side Latex Coated Coir Needle Felt in a wave layout. Under these conditions, BCR increased by 67.34%, as well as SRF improved by 43.22% compared to unreinforced sand.

V. AKNOWLEDGEMENT

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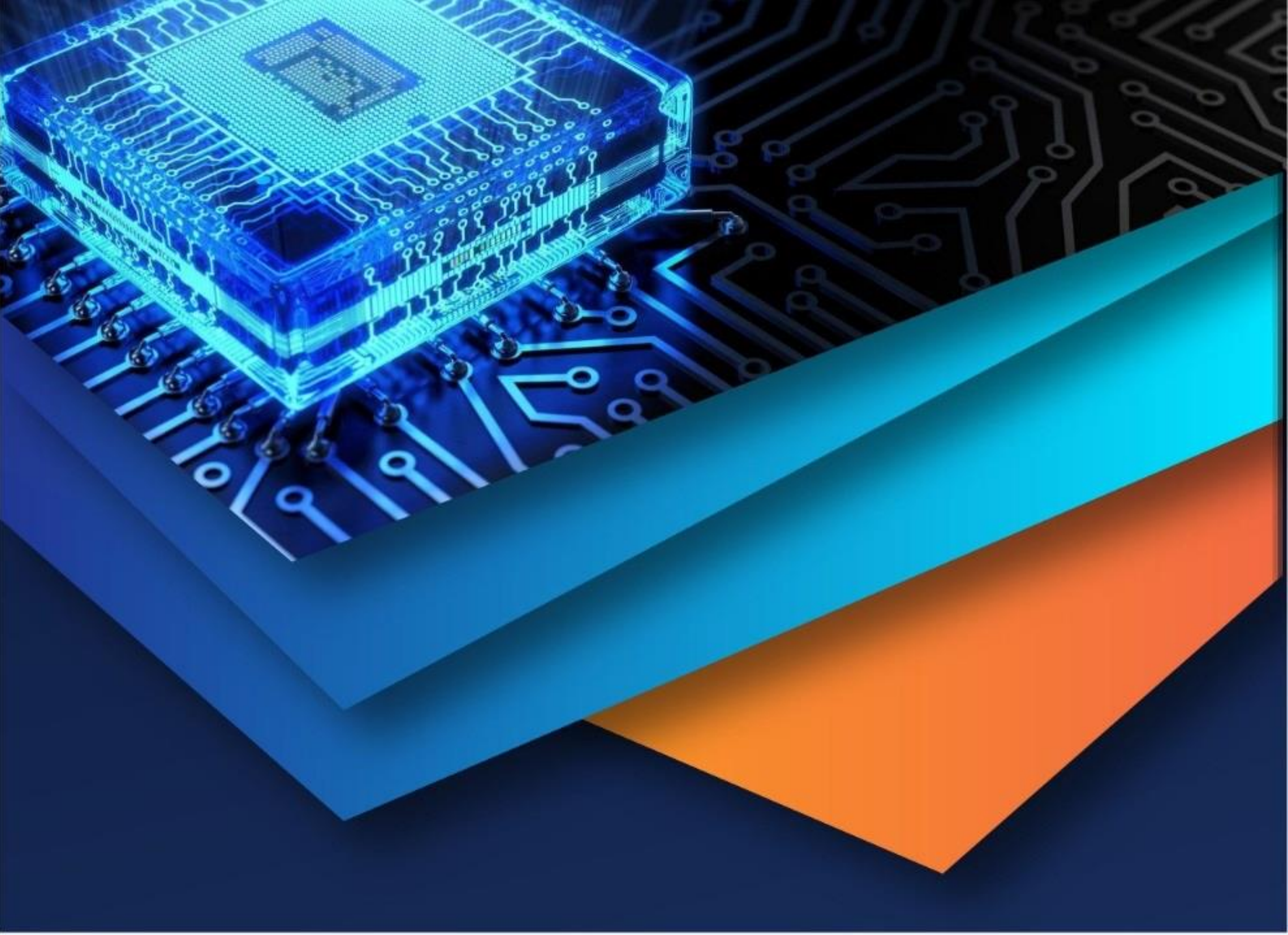

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