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Original Article

Machine Twine Coconet Reinforcement in Sandy Backfill for Mechanically Stabilized Earth Applications

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Abstract - *This study was conducted to investigate the pullout behavior of machine twine coconets reinforcement embedded in sandy backfill. It is aimed at readily available substitutes for geosynthetics for specific applications in civil engineering, like Mechanically Stabilized Earth (MSE) walls and other ground improvement techniques. The study employed an experimental research design by using four experimental phases to achieve an empirical model of the pullout interaction coefficient* (C_i) *of coconet for use in the design of the MSE wall. The effects of various normal pressures* (σ_n) *and various specimen lengths* (L_e)*, on the pullout behavior of the three different coconet specimens was investigated and characterized. Results of laboratory pullout simulations revealed that the pullout resistance-displacement behavior of coconets is affected by the applied normal pressure, the type of coconet, and the specimen lengths. The stiffer coconet, such as coconet 700, requires the longest specimen length of 50 cm under the highest applied normal pressure of 31.20 kPa to attain its maximum pullout resistance of about 8.5 kN/m. While the less stiff coconet 400 attains its average pullout resistance of 6.87 kN/m at an applied normal pressure of 31.20 kPa for the specimen lengths of 30, 40, and 50 cm. In addition, the* (C_i) *values were found to slightly decrease with increasing specimen length. Also, the stiffer coconet, such as coconet 700, has slightly higher values of* (C_i) *than the other coconet specimens. Interestingly, the values of* (C_i) *are dominantly affected by the applied normal pressures, and the values tend to decrease with increasing normal pressures. On average,* (C_i) *values vary from around 1.3 at a normal pressure of 10 kPa to around 0.80 at a normal pressure of 30 kPa. Furthermore, an empirical model of* (C_i) *with the normal pressure is proposed for use in the design of MSE using coconet reinforcement. Finally, this study has concluded that coconet, as far as its mechanical properties, such as the pullout resistance, can be a potential soil reinforcement for MSE applications, especially the stiffer coconet, such as the locally available coconet 700 used in this study.*

Keywords - *Pullout tests, Pullout resistance, Pullout interaction coefficient, Coconet, Soil reinforcement.*

1. Introduction

The stability of civil engineering structures depends on the bearing capacity, strength, and deformation characteristics of the supporting soil [1]. In areas where soils have poor strength, low friction resistance, or high compressibility, ground improvement techniques like soil reinforcement are essential [2]. The term Mechanically Stabilized Earth (MSE) wall refers to reinforced soil [3].

The basic concept of reinforced soil being practiced in ancient times was the ziggurat's wall in Iraq, which was reinforced with woven mats of reeds with plaited rope of the same material in sand and gravel [4-6]. The Great Wall of China was reinforced with Tamarisk branches in clay and gravel [7]. Additionally, Henry Vidal, a French architect and engineer, developed a modern form of reinforced soil from the basic concept of reinforced soil [8]. The modern MSE systems evolved from the concepts through welded meshes, steel strips, and geosynthetics. Geosynthetic reinforcement materials, like geogrids and geotextiles, have significantly enhanced the reliability and performance of MSE structures. However, these materials are typically costly and imported, limiting their adoption in developing countries like the Philippines. This challenge has encouraged interest in locally sourced and eco-friendly materials such as coir, jute, sisal, and other natural fibers. Coconut fiber (coir), in particular, is abundant in the Philippines, highly durable, and known for its high lignin content, making it more resistant to biodegradation compared to other natural fibers [9].

Machine twine coconet, a woven mat produced from coir fibers, has been widely used for erosion control, but its mechanical behavior as reinforcement for MSE walls remains underexplored. Several studies have examined the tensile behavior, durability, and soil interaction characteristics of natural fiber reinforcements [10]. There is limited research specifically investigating the pullout behavior and interaction coefficients of machine twine coconet embedded in granular backfill [3, 11, 12]. Existing studies on natural fiber geotextiles often focus on jute and coir mats for erosion control, not on their structural application in reinforced earth systems [5, 13]. Furthermore, no empirical pullout interaction coefficient (Ci) model has been developed for machine twine coconets when subjected to varying normal pressures and reinforcement lengths-key parameters for MSE wall design.

2. Conceptual Framework of the Study

The conceptual model presented four corresponding experimental phases or models that show the relationship between the independent and dependent variables and the corresponding processes. The interplay of these four experimental phases has been extended to formulate an empirical model to estimate the value of the pullout interaction coefficient C_i at various levels of coconet reinforcement in Mechanically Stabilized Earth (MSE) wall applications, as shown in Figure 1.

Independent Variables	Methodology	Dependent Variables
• Type of material to be tested • Tensile strength of Coconet • Anticipated Normal Pressure to be applied on the reinforcement • Existing design of Pullout Box available in the literature	• Design and fabrication of Pullout Box structure (Size, Shape and Cover) • Design and installation of mechanical pulling equipment system • Design and installation of electronic instrumentation apparatus • Testing the capacity of pulling system	• Pullout Box Machine

(a) Phase I

• Sampling of Sandy Backfill • Sampling of Coconet Reinforcement	• Compaction Test • Direct Shear Test • Determination of mass per unit area • Determination of nominal number of twines per unit width and length	• Compaction Curve of Sandy Backfill • Shear strength envelope of Sandy Backfill • Physical Properties of Coconet Reinforcement

(b) Phase II

• Pullout Box Machine • Coconet lengths of 30, 40, and 50 cms. • Normal pressures of 10.50, 17.40, 24.30, and 31.20 kPa • Type of Coconets: Coconet 700, Coconet 500, and Coconet 400 • Compaction Curve of Sandy Backfill	• Series of pullout simulations • Plotting of pullout-displacement curves	• Pullout Behavior of Coconet 700, Coconet 500, and Coconet 400

(c) Phase III

• Pullout Behavior of each Coconut Type for different Normal Pressures and Reinforcement Lengths	• Analysis of the behavior of Pullout Interaction Coefficient (C_i) with different Coconet type, Normal pressures and Reinforcement lengths • Regression Analysis	• Empirical Model on Pullout Interaction Coefficient(C_i) for use in the design of MSE wall with coconet reinforcement

(d) Phase IV

Fig. 1 Conceptual framework of the study

2.1. Materials and Equipment Used in the Study

2.1.1. Pullout Box

The pullout box has been designed and fabricated for the conduct of pullout tests of machine twine coconet embedded in sandy backfill. The fabricated pullout box contains mechanical pulling equipment, facilities, and electronic devices as box components. The pullout box dimension was 610 mm wide x 460 mm tall x 1220 mm long. It was made from a 13mm thick steel plate, fully welded at the connection to avoid distortion during the pullout tests.

It is movable using its roller stands to facilitate easy moving from one place to another (Figures 2 and 3). The design analysis of the attached mechanical pulling system starts from the motor output speed of 1400 rpm going to the reducing gearbox with the ratio of 100:1.

Furthermore, from the output speed of the reducing gearbox, the system shifted to a smaller driver sprocket (16 teeth) to a bigger driven sprocket (36 teeth) to have a constant pullout rate of the screw jack of 1.97 mm/min (Figures 4, and 5).

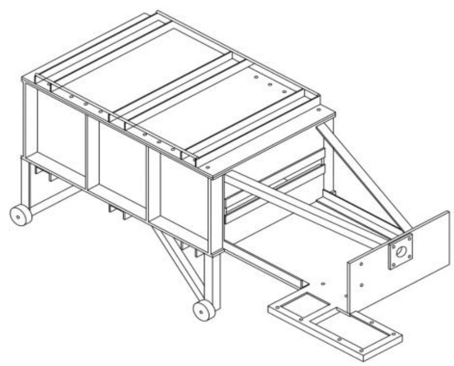

Fig. 2 Perspective view

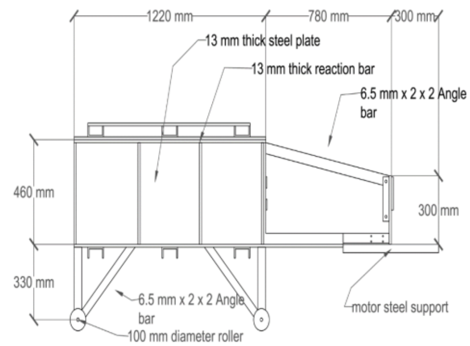

Fig. 3 Left side view

Fig. 4 Fabricated pullout box

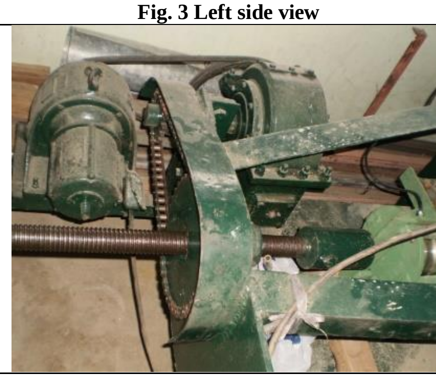

Fig. 5 Mechanical pulling facilities

Fig. 6 Inflatable airbag (interior tire)

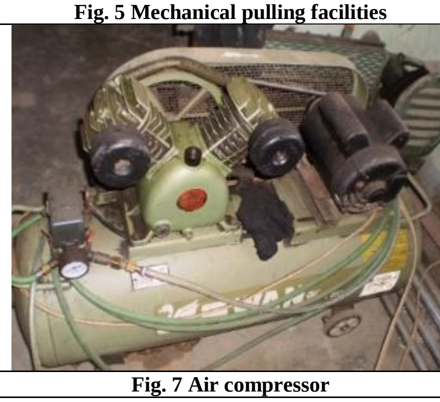

Fig. 7 Air compressor

2.2. Mechanical Components

2.2.1. Inflatable Airbag and Air Compressor

The inflatable airbag was made of a rubberized interior tire expandable material. It was almost the same volume dimension as the inside volume of the pullout box.

The attached hose drives the air pressure from the air compressor (Figure 7) to the rubberized airbag and serves as an applied normal pressure during the pullout tests.

2.2.2. Sandy Backfill Soil

The sandy backfill soil used in this research is readily available in the Hinaplanon River, Iligan City, Philippines. This type of sandy backfill was used in the construction industry.

Table 1. Electronic devices used for the study

Quantity	Unit	Description	Purposed
1	pc	Load Cell	Measure the Pullout Force
2	pcs	LVDT	Measure the Displacement
1	pc	Pressure Gauge	Measure the Air Pressure
1	set	National Instrument Model NI cDAQ-9178	Data Recording
2	set	Voltage Regulator	Regulate the Output Voltage
1	set	Computer Device Model MSI Intel Core i7 with LabVIEW Program	Actual data acquisition, data reading, and the pattern of output display

Fig. 8 Sandy soil used for backfill

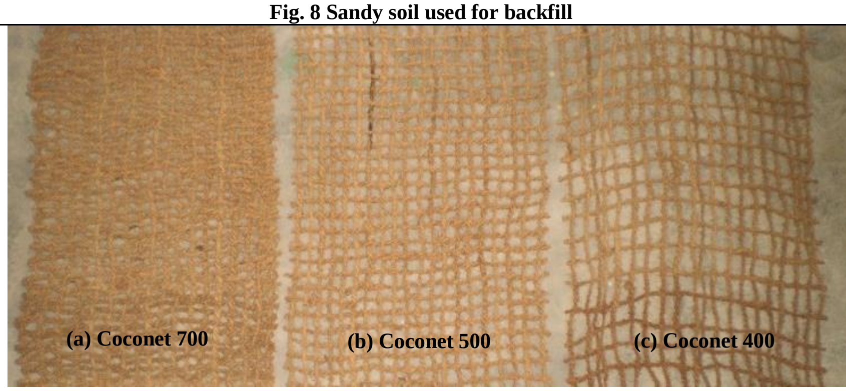

Fig. 9 Type of coconets

Table 2. Properties of coconets used in the study

Type of Coconet	Width (m) x Length (m)	Nominal Number of Twine		Mass / Unit Area (g/m²)	Thickness(mm)
		Lengthwise	Crosswise		
Coconet700	0.40 x 0.30	20	22	2,110.76	7.62
	0.40 x 0.40	20	30		
	0.40 x 0.50	20	37		
Coconet500	0.40 x 0.30	20	20	1,790.17	7.62
	0.40 x 0.40	20	24		
	0.40 x 0.50	20	28		
Coconet400	0.40 x 0.30	20	11	1,629.51	7.62
	0.40 x 0.40	20	15		
	0.40 x 0.50	20	18		

2.3. Machine Twine Coconet Specimens

The machine twine coconets are commercially manufactured and produced by Blue Diamond Coconut Fibers & Peat Mgf. Corporation in Tacub, Kauswagan, Lanao del Norte, Philippines. According to the PCA research center, the variety of coconut being processed for coconet geotextile is from San Ramon, Zamboanga City. The type of commercially manufactured coconet depends on the number of longitudinal and lateral elements interlaced at right angles every 1-meter length. The laboratory pullout tests are performed on three types of coconets: Coconet 700, Coconet 500, and Coconet 400, as shown in Figure 9. The coconet samples are presented in Table 2.

3. Methods

3.1. Standard Proctor Compaction Test

The soil was compacted in a mold using energy levels comparable to those applied in field conditions. A laboratory compaction test was conducted to establish the relationship between dry density and moisture content. The maximum dry unit weight obtained from this test served as the benchmark for determining the relative compaction of soil in the field. The calculated dry unit weight and moisture content data were plotted on a graph to facilitate the identification of the maximum dry unit weight and the corresponding optimum moisture content of the compacted soil.

3.2. Direct Shear Test

The direct shear test on soil was conducted by correlating the shear stress at failure with the applied normal stress. This test aimed to determine the effective shear strength parameters of the soil, specifically cohesion *(c')*, and the angle of internal friction *(ϕ)*. These parameters were subsequently used to calculate the soil's bearing capacity and assess slope stability. For this study, normal loads of 50 kPa, 100 kPa, and 200 kPa were applied during the direct shear tests. Shearing was performed until the desired displacement was achieved, with measurements of shear load, shear displacement, and normal displacement recorded throughout the process.

3.3 Laboratory Pullout Tests

The laboratory pullout tests are conducted to determine the pullout resistances of the machine twine coconet embedded on sandy backfill using a fabricated pullout box. The testing box was equipped with mechanical pulling facilities to determine the pullout force. Normal pressure was applied using an inflatable airbag connected to an air compressor. Linear Variable Displacement Transducers (LVDTs) were used to monitor displacements, while a load cell was employed to measure the pullout force exerted on the coconet specimen. An automated data acquisition system (National Instrument) was used in measuring and recording the pullout load, and the horizontal displacements through the attached load cell and LVDTs, respectively. The data are recorded through the LabVIEW program and saved and viewed on the computer unit. The coco-net specimen was pressurized to the specified normal pressure and then pulled to a constant pullout rate of 1.97mm/min until its peak pullout resistance was obtained. After the desired displacement or peak load was reached, either pullout failure or pullout rupture, the motor was stopped, or the button was pushed to the backward position to unload the specimen. Furthermore, once all the tests had been completed, the box was unpressurized and opened, and then the compacted sandy backfill and the coco-net specimen were removed. Therefore, when the materials inside the box were removed, another set of pullout tests was performed with the entire setup, and pullout tests were repeatedly conducted.

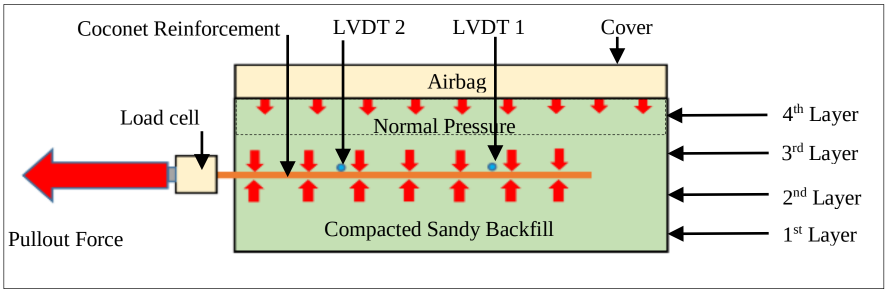

Fig. 10 Schematic diagram of the laboratory pullout test

Fig. 11 Placement of LVDTs

Fig. 12 Placement of load cell

4. Results and Discussions

4.1. Fabrication of Pullout Box

From the review of the literature as presented in Table 3, different research findings have been presented on the effect of the pullout rate on the pullout resistance. More researchers held the view that the increase in pullout rate would result in the reduction of pullout resistance; the peak pullout load was higher at slower displacement rates. The designed pullout displacement rate of the fabricated pullout box is comparable with the pullout displacement rate used by other researchers. Therefore, it is sufficiently utilized in any laboratory pullout evaluation.

Table 3. Comparison of pullout displacement rate used by different researchers

Type of Pullout Box	Pullout Displacement Rate (mm/min.)	References
0.76m x 0.90m x 1.52m	1.8	[14]
0.60m x 0.65m x 1.1m	2.5	[15]
0.40m x 0.40m x 0.60m	1.0	[11]
11 in x 18 in x 87 in	1.0	[10]
18.0 in x 24.0 in x 48.0 in	1.52	[16]
0.28m x 0.61m x 1.52m	2.0	[17]
0.46m x 0.61m x 1.22m	1.97	this study

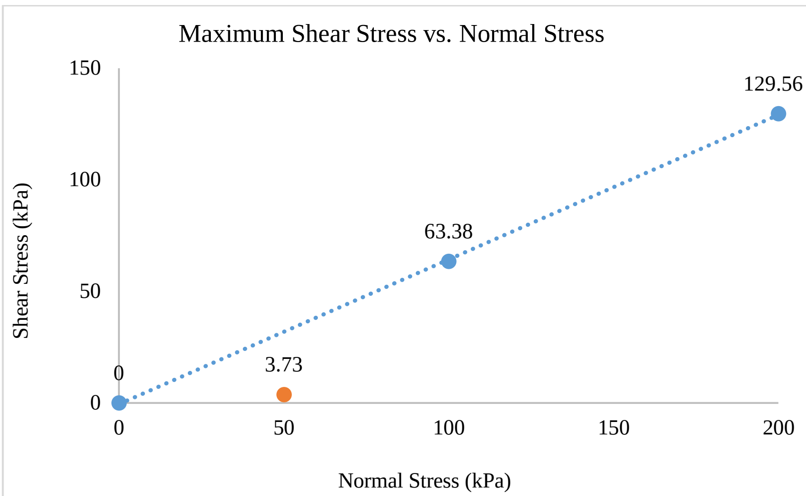

Fig. 13 Graph of time vs Shear stress

Table 4. Results of the Direct Shear Test of Sandy Backfill

Test No.	Normal Stress (kPa)	Shear Stress (kPa)	Angle of Friction ∅
1	50	3.73	4.27
2	100	63.38	32.37
3	200	129.56	32.94
		Average	23.20

4.2. Sandy Backfill

The locally available sandy backfill has a maximum dry density of 16.78 kN/m^{3,} and an optimum moisture content of 18.65% was used for the pullout test. The maximum dry density and the optimum moisture content obtained from the compaction tests were used as a reference in controlling the compaction energy required to obtain the target dry unit weight of the sandy backfill in the conduct of laboratory pullout tests of the machine twine coconets as the reinforcement. The tests utilized three normal stresses, namely, 50, 100, and 200 kPa. Finally, the test revealed that the sandy backfill has an average friction angle of 23.20 degrees, as presented in Table 4.

4.3. Effect of Normal Pressures on the Behavior of the Three Types of Coconets

The laboratory pullout tests were conducted on the three (3) types of machine twine coconets: the Coconets 700, Coconets 500, and Coconets 400. The machine twine coconets reinforcing specimen was extended into three different lengths of 30cm, 40cm, and 50cm, and each length was tested at confining pressures of 10.50, 17.40, 24.30, and 31.20 kPa.

The results of the pullout tests are shown in Figures 14 to 16 for Coconets 700, Figures 17 to 19 for Coconets 500, and Figures 20 to 22 for Coconets 400.

Figures 14 to 22 indicate the results on the effect of normal pressures on the pullout behavior of the three types of coconets for various confining pressures of 10.50, 17.40, 24.30, and 31.20 kPa, at specimen lengths of coconet of 30 cm, 40 cm, and 50 cm, respectively. It can be seen from the graphs shown in Figures 14 to 22 that at a certain effective length, the pullout resistance per meter width (P_r) of the three types of coconets specimens increases with increasing normal pressure(σ_n). Furthermore, the displacement at failure tends to be smaller at higher confining normal pressure(σ_n). This indicates similarly that at a higher normal pressure, the three types of coconet specimens tend to fail by tensile rupture. It was also observed in the Pullout Resistance-Displacement curve that the pullout resistance is equal to friction plus the elongation of the specimen before tending to fail by pullout failure or tensile rupture. Therefore, the normal pressure(σ_n) has a great effect on the pullout behavior of the three types of coconet, as it affects both the magnitude and type of pullout failure. The Coconet 700 on a 50 cm specimen underwent rupture failure under the normal pressure of 31.20 kPa with corresponding pullout resistance of 8.94 KN per meter as presented in Figure 16.

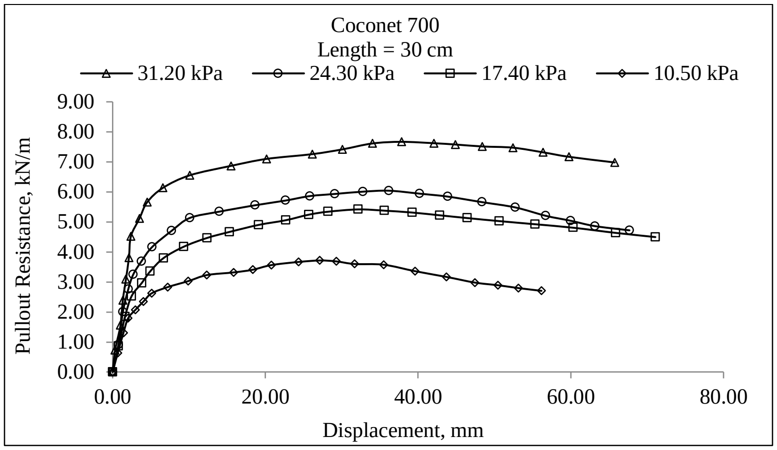

Fig. 14 Laboratory pullout tests results

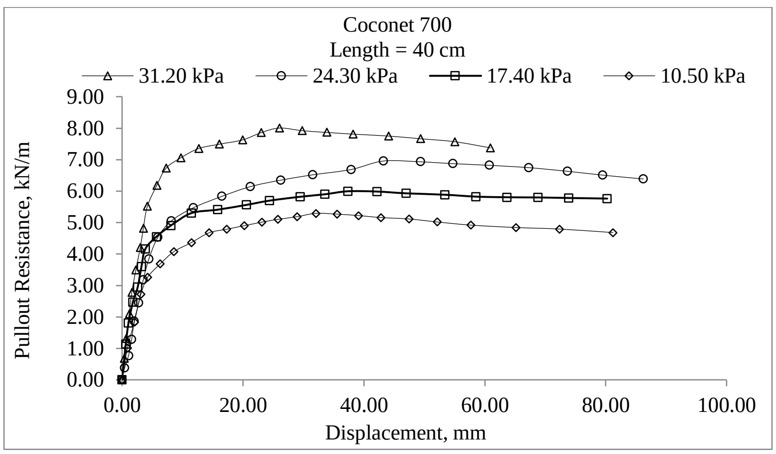

Fig. 15 Laboratory pullout test results

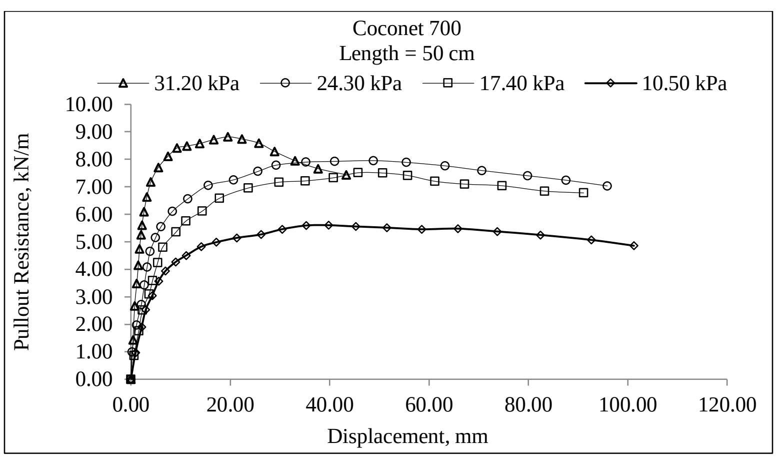

Fig. 16 Laboratory pullout test results

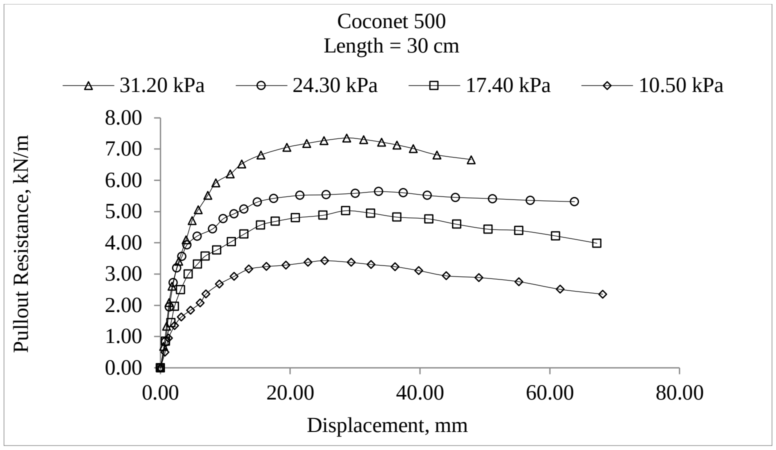

Fig. 17 Laboratory pullout tests results

Table 5. Comparison of pullout resistance of coconet 700

Normal Pressure (kPa)	Specimen Length (cm)		
	30	40	50
10.50	3.73	4.96	5.67
17.40	5.50	6.07	7.57
24.30	6.16	7.06	8.01
31.20	7.69	8.13	8.53

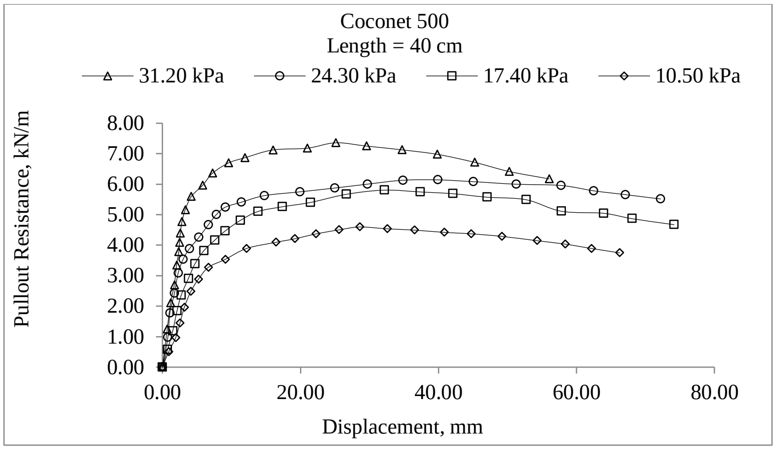

Fig. 18 Laboratory pullout tests results

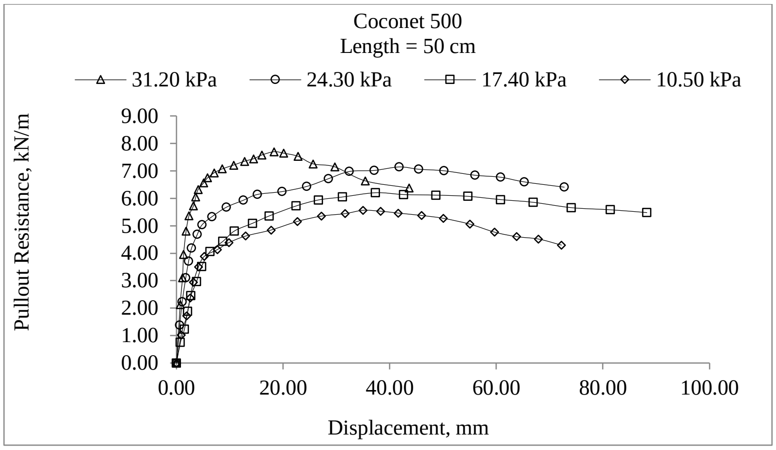

Fig. 19 Laboratory pullout tests results

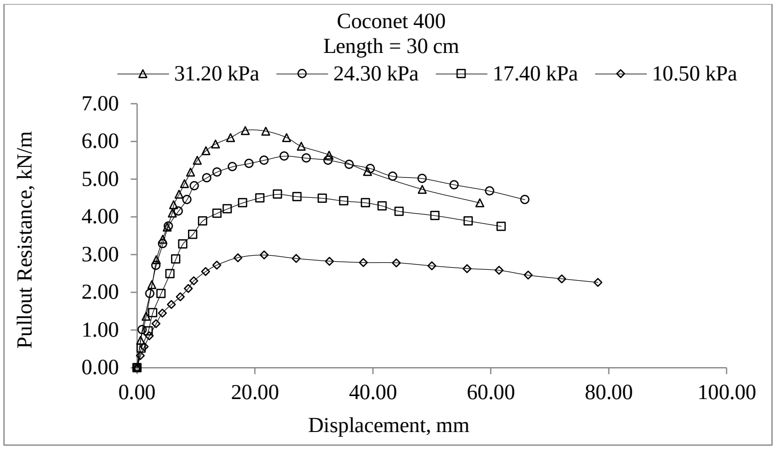

Fig. 20 Laboratory pullout tests results

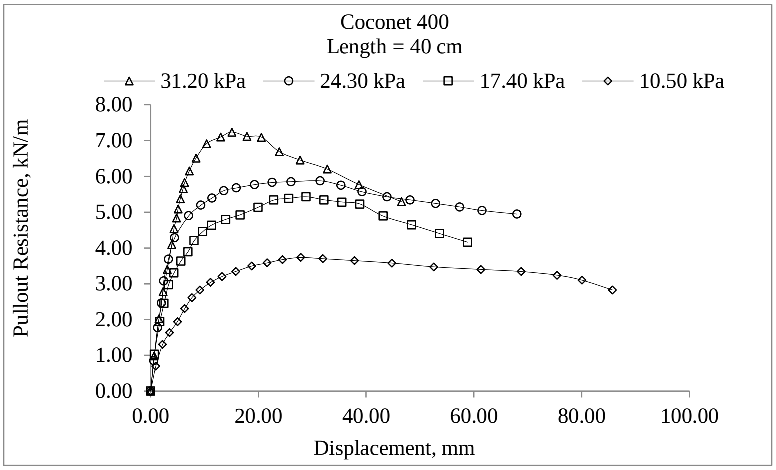

Fig. 21 Laboratory pullout tests results

Table 6. Comparison of pullout resistance of coconet 500

Normal Pressure (kPa)	Specimen Length (cm)		
	30	40	50
10.50	3.50	4.66	5.60
17.40	5.15	6.13	6.33
24.30	5.85	6.27	7.25
31.20	7.44	7.46	7.54

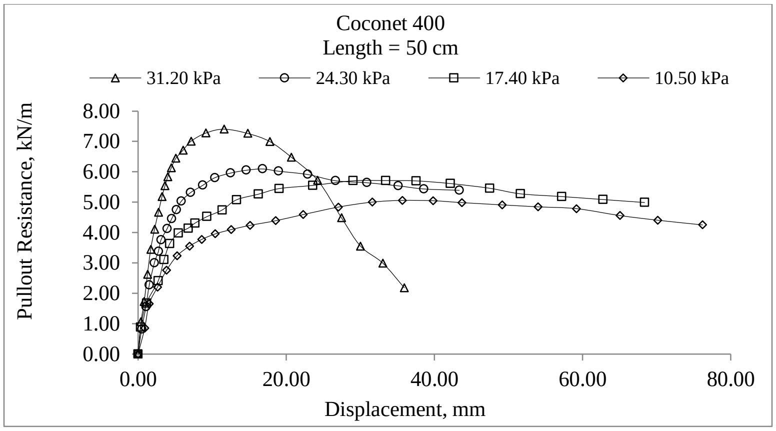

Fig. 22 Laboratory pullout tests results

Table 7. Comparison of pullout resistance of coconet 400

Normal Pressure (kPa)	Specimen Length (cm)		
	30	40	50
10.50	3.05	4.04	5.26
17.40	4.69	5.63	5.88
24.30	5.78	5.99	6.25
31.20	6.13	6.73	6.87

Furthermore, the Coconet 500 ruptured at a normal pressure of 31.20 kPa for a specimen length of 50 cm, with corresponding pullout resistance at rupture of 7.83 KN per meter (Figure 19). The Coconet 400 underwent rupture failure at a normal pressure of 31.20 kPa for all specimen lengths, with corresponding average pullout resistance at rupture of 7.14 KN per meter (Figures 19, 20, and 21).

4.4 Comparison of Pullout Resistance

The summary of the pullout resistances for Coconet 700, Coconet 500, and Coconet 400 is presented in Tables 5, 6, and 7, respectively. The tables show the effects of the pullout resistance for the various types of normal pressures in a particular specimen length. It can be seen that a certain length of specimen with a higher normal pressure had significantly higher pullout resistance than one with the same length of specimen with a smaller normal pressure. It can also be observed that the specimens with longer lengths have higher pullout resistance compared to those with shorter lengths at lower normal pressures. However, at higher normal pressure, the specimens tend to yield at the same pullout resistance, which is indicative of a tensile rupture of the specimen. Therefore, the results also indicate that at a higher normal pressure, the specimen tends to fail by tensile rupture. Furthermore, Table 8 indicates the average pullout resistance for various specimen lengths of the three types of reinforcing coconets at various normal pressures. It can also be observed from (Figure 23) that Coconet 700 had significantly higher average pullout resistance than the other types of coconets. Therefore, the Coconet 700 had the largest pullout strength, followed by the Coconet 500 and the Coconet 400.

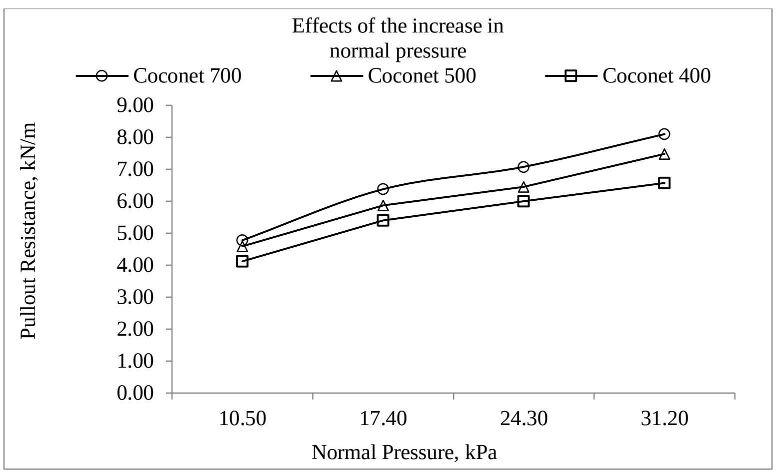

Fig. 23 Plot of average pullout resistance on the three types of coconet specimen at various normal pressures

Table 8. Average pullout resistance of coconets 700, 500, and 400

Normal Pressure (kPa)	Coconet 700	Coconet 500	Coconet 400
10.50	4.78	4.59	4.12
17.40	6.38	5.87	5.40
24.30	7.08	6.45	6.01
31.20	8.10	7.48	6.58

4.5. Comparison of Pullout Interaction Coefficient C_i using Various Normal Pressures

The results of laboratory pullout tests were used to calculate the pullout interaction coefficient at various normal pressures at a specific length of Coconet 700, Coconet 500, and Coconet 400, as shown in Tables 9, 10, 11, and 12. The tables show the variation in the values of C_i with normal pressures, specimen lengths, and Coconet types. The tables indicate that an increase in the normal pressure for every specific specimen length resulted in a decrease in the values of C_i. Furthermore, the value of C_i tends to reduce with longer specimen lengths. This can be attributed to the tendency of the specimen with longer lengths to fail prematurely by tensile rupture. Using equation 1, from the obtained pullout resistance at normal pressure and specified length of the reinforcement, it is possible to calculate the pullout interaction coefficient C_i. Thus, in this study, an empirical model for the pullout interaction coefficient C_i of the machine twine coconet is proposed.

$$C_i = \frac{P_{(pullout)ult.}}{2WL(\sigma_n \tan \emptyset + c)} \quad (1)$$

Table 9. Pullout coefficient at various normal pressures of coconet 700

Normal Pressure (kPa)	Effective Length (cm)		
	30	40	50
10.50	1.39	1.38	1.27
17.40	1.23	1.02	1.02
24.30	0.99	0.85	0.77
31.20	0.96	0.76	0.68

Table 10. Pullout coefficient at various normal pressures of coconet 500

Normal Pressure (kPa)	Effective Length (cm)		
	30	40	50
10.50	1.30	1.30	1.25
17.40	1.16	1.03	0.85
24.30	0.94	0.76	0.70
31.20	0.93	0.70	0.57

Table 11. Pullout coefficient at various normal pressures of coconet 400

Normal Pressure (kPa)	Effective Length (cm)		
	30	40	50
10.50	1.14	1.13	1.17
17.40	1.05	0.95	0.79
24.30	0.93	0.72	0.60
31.20	0.77	0.63	0.52

Table 12. Pullout coefficient on three type of coconet at various normal pressures

Normal Pressure (kPa)	Coconet 700	Coconet 500	Coconet 400
10.50	1.35	1.28	1.15
17.40	1.09	1.01	0.93
24.30	0.87	0.80	0.75
31.20	0.80	0.73	0.64

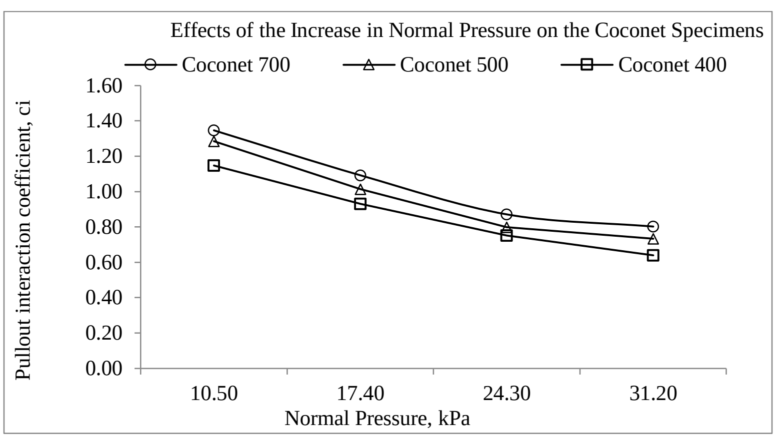

Fig. 24 The plot of the pullout interaction coefficient on the three types of coconet specimen at various normal pressures

4.6. Effect of Specimen Lengths on the Pullout Behavior of Coconet 700, Coconet 500, and Coconet 400

Figures 14 to 22 also showed the results of the pullout tests of three types of coconets for various effective lengths of 30 cm, 40 cm, and 50 cm, corresponding to normal pressures of 10.50, 17.40, 24.30, and 31.20 kPa, respectively. It can be seen from the graphs shown in Figures 14 to 22 that at a certain normal pressure(σ_n) for the three types of coconet, the pullout resistance per meter width (P_r) of the coconet specimen increases with increasing effective length(L_e). Furthermore, the displacement at failure tends to be smaller at a higher effective length, which also indicates that at a higher effective length, the specimen tends to fail by tensile rupture. It was observed in the Pullout Resistance-Displacement curve that the pullout resistance is equal to friction plus the elongation of the specimen before tending to fail by pullout failure or tensile rupture. Therefore, the effective length also has a great effect on the pullout behavior, as it affects both the magnitude and type of pullout failure.

Moreover, it can be observed that those specimens subjected to higher normal pressure tend to have similar pullout displacement behavior regardless of specimen lengths, which is indicative of the tendency of the specimen to fail by tensile rupture at higher normal pressures.

4.7. Comparison of the Effect of Specimen Lengths on the Pullout Resistance

The results of laboratory pullout tests were used to calculate the pullout resistance at various specimen lengths of Coconet 700, Coconet 500, and Coconet 400 and specific normal pressure, shown in Tables 5, 6, and 7, respectively. Figures 14 to 22 show the effects of the pullout resistance for the various types of specimen lengths at various normal pressures for Coconet 700, Coconet 500, and Coconet 400, respectively. Figure 25 shows the variation of the average pullout resistance of the three types of coconets with specimen lengths for the range of normal pressures used in the tests.

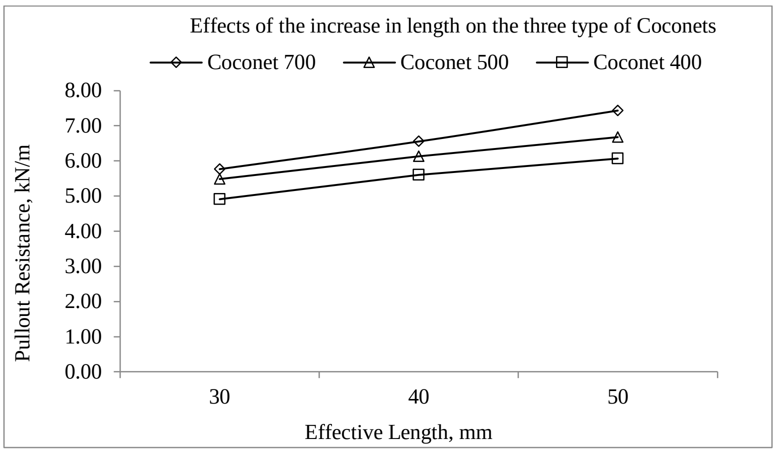

Fig. 25 Plot of the pullout resistance on the three types of coconut at various specimen lengths

Table 13. Pullout resistance of coconet at various specimen length

Effective Length (cm)	Coconet 700	Coconet 500	Coconet 400
30	1.14	1.08	0.97
40	1.01	0.95	0.86
50	0.94	0.84	0.77

Table 14. Pullout coefficient on the three types of coconets

Effective Length (cm)	Coconet 700	Coconet 500	Coconet 400
30	5.77	5.49	4.91
40	6.55	6.13	5.60
50	7.43	6.68	6.06

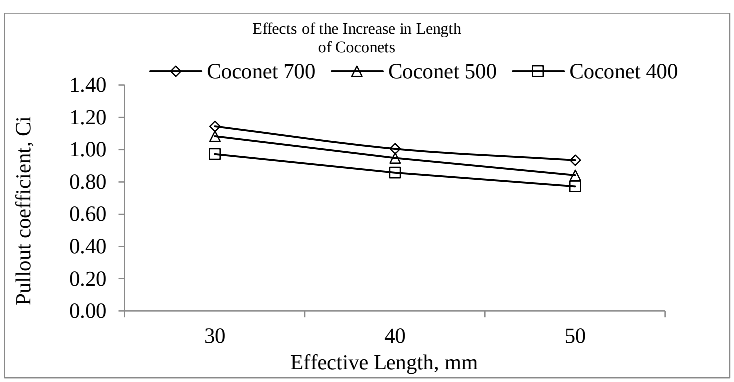

Fig. 26 Plot of pullout coefficient on the three types of coconet at various specimen lengths

Table 15. Comparison of C_i values obtained by different researchers

Type of Soil	Type of Reinforcement	C_i from pullout tests
Coarse-sand	Woven geotextile	1.00
Uniformly fine sand	Woven geotextile and woven geogrid	0.80 – 1.00
Sand	Geotextile	≥ 1.00
Sand (coarse, medium, and fine)	Needle-punched non-woven geotextile	0.70 – 1.60
Fine sand	Non-woven geotextile	0.54 – 1.26
Saturated sand	Jute geotextile	0.83 – 0.90
Dredged sand	Jute geotextile (Wool Pack and DW Twill)	0.76-0.94 (Wool Pack) 0.92-0.96 (DW Twill)
Coarse sand	Coconet 700 Coconet 500 Coconet 400	0.87 – 1.24 0.79 - 1.18 0.71 – 1.06

4.8 Comparison of the Effect of Specimen Lengths on Pullout Coefficient C_i

The results of laboratory pullout tests were used to determine the pullout interaction coefficient at various specimen lengths of Coconet 700, Coconet 500, and Coconet 400, as shown in Tables 5, 6, and 7, respectively. The corresponding plots of specimens on the effect of specimen lengths on the value of C_i are shown in Figures 14 to 22, respectively.

Moreover, the average values of C_i with varying specimen lengths for the range of normal pressures considered is plotted in Figure 26, which indicates that the C_i value is not very much affected by the specimen length. Furthermore, the range of C_i values obtained in this study are within the range of values of C_i of similar reinforcement materials obtained by different investigators, as shown and compared in Table 15.

4.9 Effects of Normal Pressures on the Pullout Interaction Coefficient, C_i

The scattered plot of the pullout interaction coefficient, Ci, versus normal pressure is shown in Figure 27. The line in the plot represents the regression line for different values of the pullout interaction coefficient as a function of normal pressure. A higher value of the pullout coefficient Ci indicates either that the total pullout resistance is high or that the applied normal pressure is low. From Figure 27, the proposed empirical model of C_i with the normal pressure (σ_n) is given in the following equation:

$$C_i = 4.3314\sigma^{-0.521} \quad (2)$$

Where σ is the normal pressure acting on the specimen or reinforcement in kPa, with Equation 2, it is possible to estimate the value of C_i at various levels of Coconet reinforcement in the Mechanically Stabilized Earth (MSE) wall applications.

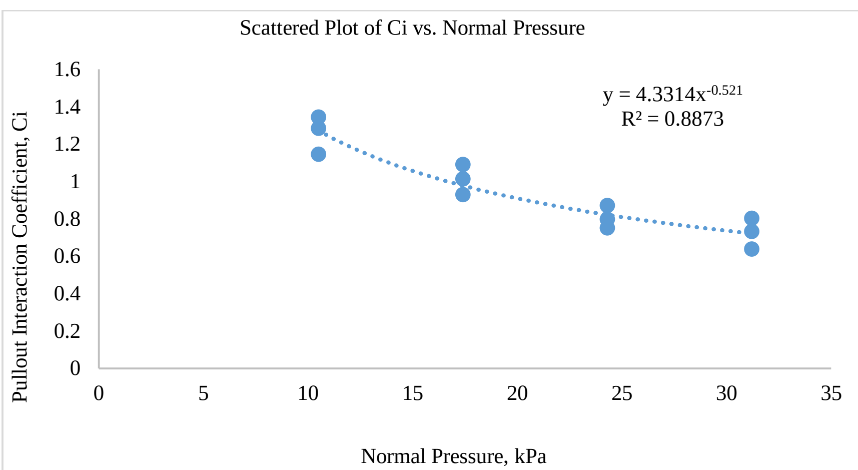

Fig. 27 Proposed Empirical model on pullout interaction coefficient of coconet reinforcement

5. Findings of the Study

5.1. Design and Fabrication of a Pullout box with Mechanical Pullout Facilities

A pullout box was successfully designed and constructed for performing the laboratory pullout tests to simulate the interaction between soil and the three types of Coconets used in this study. It is equipped with mechanical equipment pulling system that provides a constant pullout rate of 1.97 mm/min, an air pressure system that enables the application of a range of normal pressures on top of the backfill soil, a load cell that measures the pullout force, and two Linear Variable Differential Transducers (LVDT) that measure the displacement of the coconet reinforcement during the pullout tests. During the test, the load cell and LVDTs were measured in real time using a data logger from National Instruments.

The constant pullout displacement rate of 1.97 mm/min of the fabricated pullout box is comparable with other existing Pullout boxes used by other researchers. Furthermore, the fabricated pullout box has proven its effective performance through a series of successful pullout tests conducted. Therefore, this fabricated pullout box with installed mechanical equipment pulling facilities can be sufficiently utilized in any laboratory pullout evaluation.

5.2. Pullout Behavior of the Three (3) Types of Machine Twine Coconets

The laboratory pullout resistance under normal pressures from 10.50 to 31.20 kPa ranges from 3.73 kN/m to 8.01 kN/m for Coconet 700, from 3.50 kN/m to 7.54 kN/m for Coconet 500, and from 3.05 kN/m to 6.87 kN/m for Coconet 400. Coconet 700 had significantly higher average pullout resistance than the other types of coconets. Therefore, the Coconet 700 is the most appropriate type of coconet among the three types for soil reinforcement application.

The maximum pullout resistance of Coconet 700 was 8.48 kN/m, while its pullout rupture was 8.94 kN/m and was attained at a higher normal pressure of 31.20 kPa and a specimen length of 50 cm. Similarly, the maximum pullout resistance of Coconet 500 was 7.54 kN/m, and its pullout rupture was 7.83 kPa, attained at a higher normal pressure of 31.20 kPa and a specimen length of 50 centimeters. However, the coconet 400 experienced maximum pullout resistance of 6.87 kN/m at lower normal pressure, and it experienced an average pullout rupture of 7.14 kN/m at normal pressure of 31.20 kPa for all specimen lengths of 30, 40, and 50 cm.

The laboratory pullout behavior of Coconet 700, Coconet 500, and Coconet 400 specimens at various confining pressures indicates that at a certain effective length, the pullout resistance increases with increasing normal pressure. This means that the displacement at failure tends to be smaller at higher normal pressure. Therefore, at higher normal pressure, the specimen tends to fail by tensile rupture. It was also observed that pullout resistance is equal to friction plus the elongation of the specimen before tending to fail by pullout failure or tensile rupture. Therefore, the applied normal pressures affect both the magnitude and type of pullout failure.

The pullout tests indicate that the pullout interaction coefficient Ci of the sandy backfill and the Coconet 700 ranges from 0.87 to 1.24, the Coconet 500 ranges from 0.79 to 1.18, and the Coconet 400 ranges from 0.71 to 1.06. Moreover, these obtained Ci values are comparable with those from other investigators using woven, non-woven geotextile, and natural fiber materials. The effect of specimen length was only pronounced at lower normal pressures. The pullout resistance increases with increasing specimen length, especially at lower normal pressures. Furthermore, the pullout displacement at failure tends to be smaller at longer specimen lengths. This result indicates that at a longer length, the coconet specimen tends to fail by tensile rupture. The values of Ci decrease slightly with increasing specimen length. Furthermore, Ci values are slightly affected by the specimen length and the type of coconets, but are dominantly affected by the applied normal pressure.

5.3. Analysis of Pullout Behavior of Coconet Reinforcement

The laboratory pullout tests show that machine-twine coconets interact effectively with sandy backfill and exhibit reinforcement behavior comparable to conventional geosynthetics used in MSE systems. Pullout resistance increases with applied normal pressure due to enhanced interface friction and soil-reinforcement interlocking, consistent with soil-reinforcement interaction theory. The pullout resistance-displacement response demonstrates progressive mobilization and ductile behavior, which is advantageous for stress redistribution and provides warning deformations prior to failure.

Coconet stiffness significantly affects performance. The stiffer coconet 700 developed higher pullout resistance but required longer embedment lengths to fully mobilize its tensile capacity, while the less stiff coconet 400 achieved nearly uniform pullout resistance at shorter lengths, indicating dominance of interface friction. Overall, the results confirm that machine-twine coconets can provide adequate pullout resistance in sandy backfill, supporting their use as environmentally friendly reinforcement materials for low- to medium-height MSE walls, slope stabilization, and temporary earth-retaining structures.

5.4. Ci Modeling and Interpretation

The pullout interaction coefficient (C_i) is a key design parameter in MSE systems, reflecting the efficiency of stress transfer between soil and reinforcement. Experimental results show that C_i is primarily influenced by applied normal pressure, exhibiting a decreasing trend as σ_n increases. Average C_i values dropped from about 1.3 at 10 kPa to around 0.80 at 30 kPa, indicating that although higher normal pressures increase absolute pullout resistance, the proportional interface efficiency is reduced.

This behavior is attributed to soil crushing, fiber compression, and diminishing frictional gains under higher confining stresses, consistent with findings from soil-geosynthetic interface studies. Specimen length had a minor but consistent effect on C_i, with slight reductions observed at longer embedment lengths due to non-uniform stress distribution and the concept of effective anchorage length. Material stiffness also influenced interaction efficiency, as the stiffer coconet 700 exhibited slightly higher C_i values than coconet 400, indicating better load transfer and reduced deformation. An empirical model relating C_i to normal pressure was developed, capturing its nonlinear reduction and improving pullout resistance predictions. Overall, the results show that coconets-particularly stiffer types-exhibit interaction coefficients comparable to some polymeric geosynthetics, supporting their use as sustainable and cost-effective reinforcement materials in MSE applications.

6. Conclusion and Future Work

A pullout box machine was successfully fabricated, tested, and used to conduct laboratory simulations of the pullout behavior of coconets. Of the three types of locally available coconets being investigated, the Coconet 700 can be utilized as a suitable and cheaper alternative reinforcement material for Mechanically Stabilized Earth (MSE) structure applications, such as MSE walls, slopes, and embankments. An empirical relationship of the pullout interaction coefficient (C_i) is proposed for use in the design of MSE structures utilizing coconet reinforcement. Full-scale pullout tests and analysis should be conducted using a prototype MSE wall with coconet reinforcement to verify and validate the potential application of coconet as soil reinforcement, as concluded in this present study.

Future research work can be extended by considering more varieties of coconets and types of soil to evaluate the factors affecting the pullout resistance and to expand the application of this type of reinforced earth application. Conduct studies related to degradation aspects and their effects in using this type of reinforcing material for MSE wall applications. Coating of coir fiber can be done to increase the life of the fiber.

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