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EFFECT OF FINE FRACTIONS ON ENGINEERING PROPERTIES OF SANDY SOILS IN SOUTHERN ETHIOPIA'S GAMO ZONE

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Abstract

This study investigates the influence of fine content on the engineering properties of sandy soil. The objective is to determine the effect of fine fractions on the engineering properties of sandy soil. Sand samples were collected from the Kulfo riverside and Hamasa, Mirab Abaya. The sand samples were classified as medium and fine sand in the laboratory, based on sieve sizes of 2 mm to 0.425 mm and 0.425 mm to 0.075 mm, respectively. Fine fractions were obtained by sieving through a 75 µm sieve. Laboratory tests were conducted on reconstituted sandy soil samples with varying fine content (0%, 5%, 12%, 20%, and 30% by weight). The plasticity of the reconstituted sandy soil samples was zero for both medium and fine sand with fine contents up to 12%. Plasticity began to develop at 20% fine content and increased with further increases in fine content. The average plasticity index for medium and fine sand was 5.88% and 8.46%, respectively, as the fine content increased. As the fine fraction increased, the average Maximum Dry Density for medium and fine sand increased from 1.79 g/cm³ to 1.95 g/cm³, and the Optimum Moisture Content increased from 10.64% to 13.9%. The increase in fine fractions led to increased particle interlocking, significantly impacting the Maximum Dry Density. The average California Bearing Ratio (CBR) value for medium sand decreased from 32.60% to 13.14%, and for fine sand decreased from 24.78% to 11.80% with increasing fine content. The results showed that the compression index increased with increasing fine content, reaching 0.03368 for fine sand and 0.03059 for medium sand at Mirab Abaya with a 30% fine content. The maximum permeability value for medium sand at Mirab Abaya was 2.18×10^{-2} cm/sec, while the values for medium and fine sand at the Kulfo riverside were 1.57×10^{-2} cm/sec and 7.22×10^{-2} cm/sec, respectively. The direct shear test results for medium and fine sand from the Kulfo riverside ranged from 16.6° to 0° and 10.4° to 0°, respectively. For fine sand, the range was 10.4° to 0°. Increasing fine fractions in sandy soil generally affects the engineering characteristics of fine and medium sandy soils.

Keywords: ***California Bearing Ratio, Fine Fraction Content, Fine Sand, Medium Sand***

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I. INTRODUCTION

As sand is an important construction material, it is always desirable to use good-quality sand. To judge the quality of the available sand, one must know the properties of good sand. Before using sand in a project, these desirable properties must be ensured. Natural sand commonly consists of fines and sand particles with different proportions, and the fines content significantly affects the engineering properties of sandy soil. Sand is known as the main material in land reclamation works to develop and widen an area. The Geotechnical Engineer should ensure that the sand used can withstand the load imposed by the structures that can be built on it [1]. The most common type of soil that influences a sandy soil's engineering properties seems to be fine-grained soil. The fine fraction has a large influence on soil behavior. Sandy soils are typically believed to behave with easily defined physical properties, such as a lack of structure or no structure, poor water retention properties, permeability, and high sensitivity to compaction. The most common types of sand are concrete sand, pit sand, naturally occurring or river sand, manufactured sand, utility sand, and quarry fill sand. These sands have unique engineering characteristics that make them suitable for various engineering applications. With fines contents of 18% in the sand fines mixture, the maximum and minimum void ratios reached minimum values. All parameters of deviator stress, volumetric strain, shear stress, internal friction angle, and cohesion increased as the fines content increased in the consolidated drained shear test. For constant-void-ratio and steady specimens, the critical state parameter (M) decreased and seemed to be stable for same-peak-deviator-stress specimens. Furthermore, as the fines content increased, so did the cohesion, internal friction angle, and critical state in the consolidated undrained test [2].

The impact of fines content and type can be determined using an odometer test and the intergranular void ratio [3]. At a fine content of approximately 30%, the shear strength and stress-strain characteristics of the mixture exhibit significant changes. As fine content increases, the drained angle of friction decreases, leading to a decrease in drained shear strength [4]. The angle of internal friction (Ø) decreases with the increasing fineness modulus up to 1.50, and the variation can be expressed by the linear equation Ø° = 37 - 0.245. The angle of internal friction becomes almost constant for all fine contents as the mm sieve (FM=1.70) of sand increases, with such a value estimated at 35.6° [5].

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Up until the critical fine content, the addition of finer particles leads to a decrease in the void ratio. However, after this critical point, the coefficient of volume compressibility increases from 0% to 15% as more fine particles are incorporated into the specimens.

Increases in dry density are noticed as fine content increases [6]. The angle of internal friction of the examined soil samples decreased with increasing fines content; the polynomial expression: = -0.000f^2 - 0.456f + 47.16; = -0.002f^2 - 0.19f + 43.06; = 0.001f^2 - 0.571f + 41.4 provided the best fit between fines content and soil sample cohesiveness, where f is the fines content in percent and Φ is the angle of internal friction in degrees [7].

The threshold fine content, t*1, marks a significant behavioral change as determined by consolidation loading and consistency measurements using a fall cone instrument. This transition corresponds to a shift towards a percolation regime involving both fine and coarse particles.

A second behavioral threshold, t*2, is evident from hydraulic conductivity measurements using oedometric loading, thermal conductivity measurements using a needle probe, and critical state strength determined by undrained triaxial loading. This threshold coincides with a transition from a state dominated by system-wide coarse particle clusters to a state without such clusters [8].

II. MATERIALS AND METHODS

Sandy soil is a granular material made up of finely divided rock and mineral particles that occur naturally. This study will conduct an intensive laboratory study of sandy soil with mixed ratios of investigated fine fractions around study areas to use a series of index and engineering laboratory tests. Sandy soil samples from various locations were designed (separated) in the laboratory based on their grain sizes using sieve sizes, and fine soil samples were collected from different locations and mixed with ratios of fine fractions using a series of index and selected engineering laboratory tests for this study. Soils can be submitted to a variety of laboratory tests to determine a variety of soil characteristics.

Most laboratory testing methods employed in this study followed the standards established by the American Society for Testing and Materials (ASTM). The California Bearing Ratio (CBR) test, specifically, was conducted following the guidelines outlined in both British Standard and American Association of State Highway and Transportation Officials (AASHTO) standards.

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The sand and Fine Fraction samples used in the test were collected from the Gamo Zone in Southern Ethiopia. Shear Strength, CBR, Consolidation, Compaction, Permeability, and Plasticity tests were performed on two kinds of sandy materials containing various percentages of fines, i.e. 0, 5, 12, 20, and 30%. In this paper, fines content is stated as a percent of soil mass passing through a 0.075 mm sieve (No. 200 according to ASTM).

A. Sandy Soils

To start, Medium Sand samples were sieved through a stack of ASTM Sieve No.10 – No.40 (2mm – 425mic) sieves, and Fine Sand samples were sieved through a stack of ASTM Sieve No.40 – No.200 (425mic – 75mic) sieves. For testing purposes, medium sand samples that passed sieve No.10 were retained on No.40, and fine sand samples that passed sieve No.40 were retained on No.200.

A **B** **C**

Fig.1: A), Fine sand of site one, B) fine sand of site two, and C) Medium sand of site three

III. RESULTS AND DISCUSSION

This section contains the results of the many tests carried out in this study. The fluctuation of several test parameters was examined, and conclusions were drawn from the detailed examinations.

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A. Soil Classification as per Unified Soil Classification System and Plasticity Chart

Table 1:Soil classification for fine-grained soil as per AASHTO and USCS

Tests	Test Pits	TP-One	TP-Two	TP-Three	TP-Four
Percentage Pass	#10	99.9	99.8	99.6	99.4
	#40	99.5	99.2	98.6	98.4
	#200	97.9	97.4	96.8	96.3
Atterberg Limit	LL	53.82	55.47	53.92	52.56
	PL	37.06	37.84	36.16	37.53
	PI	16.75	17.63	17.76	15.03
Compactions	MDD	1.488	1.51	1.53	1.444
	OMC	29	28	27	31.5
Specific Gravity	Gs	2.65	2.66	2.65	2.67
PI plots	Below A-line	Below A-line	Below A-line	Below A-line	Below A-line
Soil Classification	USCS	MH (elastic silt)	MH (elastic silt)	MH (elastic silt)	MH (elastic silt)
	AASHTO	A-7-5	A-7-5	A-7-5	A-7-5

Test Pit-one was selected as the fine fraction for examination from the four test pits described above in Table 1 based on their Percentage pass on sieve number 200 as per ASTM standard.

B. Atterberg Limit

The Atterberg limits of the samples increased significantly as the fines content increased. This trend suggests that as the number of particles increased, the material's specific surface area and activity also increased, leading to higher Atterberg limit values.

The liquid limit and plastic limit are the most useful parameters for identifying and classifying fine-grained cohesive soils. Soils with a high liquid limit often exhibit poor hydraulic conductivity. For applications such as landfill liners, soils with a higher liquid limit are preferred due to their lower hydraulic conductivity.

Table 2:Classification of sandy soil for different fine content based on plasticity chart

Sites	% Fine	Medium sand			Fine sand			Soil type
		LL	PL	PI	LL	PL	PI	
Site-1	0	-	-	NP	-	-	-	NP
	5	-	-	NP	-	-	-	NP
	12	-	-	NP	-	-	-	NP
	20	20.49	15.84	4.65	22.25	16.35	5.89	CL (lean clay)
	30	25.40	19.06	6.34	25.17	18.00	7.17	CL (lean clay)

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Site-2	0	-	-	NP	-	-		NP
	5	-	-	NP	-	-		NP
	12	-	-	NP	-	-		NP
	20	17.98	12.55	5.43	19.36	12.87	6.48	CL (lean clay)
	30	23.33	16.01	7.32	24.38	14.79	9.59	CL (lean clay)
Site-3	0	-	-	NP	-	-	-	NP
	5	-	-	NP	-	-	-	NP
	12	-	-	NP	-	-	-	NP
	20	19.50	13.09	6.40	18.26	12.99	5.27	CL (lean clay)
	30	24.06	16.43	7.63	25.49	16.87	8.62	CL (lean clay)

Table 2 illustrates that the reconstituted sandy soil samples, composed of both medium and fine sand, exhibited non-plastic behavior (plasticity index = 0%) for fine contents up to 12%. However, as the fine content increased beyond 20%, plastic behavior emerged. The average plasticity index for medium and fine sand was found to be 5.88% and 8.46%, respectively, with increasing fine content.

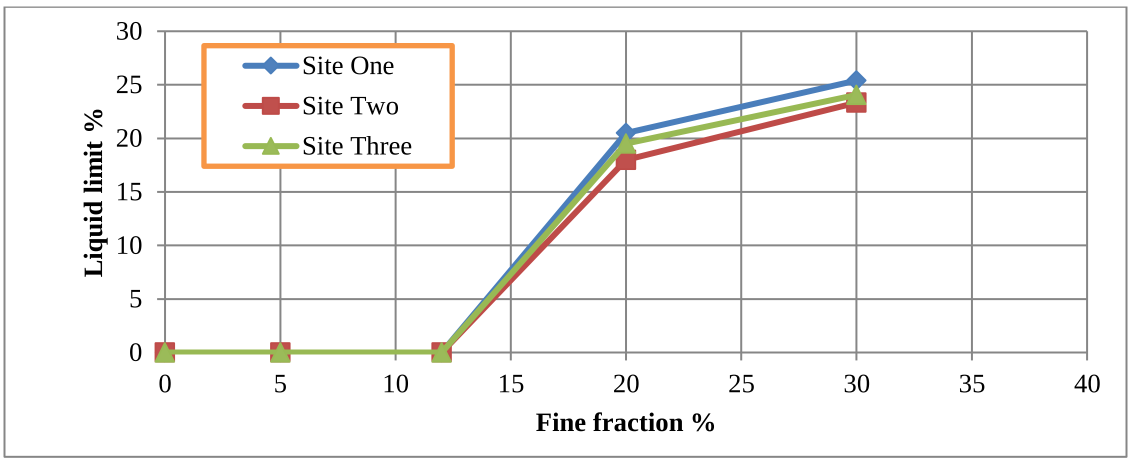

Fig. 2.: Variation in LL, with an increase in fines content of medium sand for all sites

The link between fine content and liquid limit, plastic limit, and plastic index is depicted in Fig. 2. The LL, PL, and PI all increase as the fine material increases in this graph.

C. Compaction Characteristics

Compaction curves can reveal a lot about a material's behavior during a test. It is obvious that as the fine fractions rise, the dry density increases. The finer particles occupy the vacuum spaces between the sand particles, causing an increase in M.D.D. However, particles of more than 30% may have influenced the gradation of sand soil to poor gradation, resulting in a fall in M.D.D. Furthermore, because of cohesion, the relative ease with which particles can move under

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compaction effort decreases with increased fines content, resulting in a lower maximum dry density.

The increase in fine fractions owing to particle interlocking has a major impact on maximum dry density. Because small particles interlock the spaces between large particles, the M.D.D rises as the percentage of fines increases. The amount of water in M.D.D. is another aspect that influences its worth. In general, the O.M.C of the soil rises as the clay percentage rises, owing to the fine content' increased specific surface area.

Table 3: Summary of Modified Compaction Test of Specified Soil Mixtures for All Sites

Sands	% Fines	MDD (g/cm^3)			OMC (%)		
		Site One	Site Two	Site Three	Site one	Site two	Site three
Medium Sand	0	1.86	1.81	1.77	8.53	9.80	9.60
	5	1.89	1.84	1.80	11.19	10.20	10.00
	12	1.94	1.87	1.84	11.48	11.20	11.20
	20	1.96	1.92	1.90	11.60	12.00	12.80
	30	1.98	1.94	1.97	12.74	13.52	14.16
Fine Sand	0	1.76	1.77	1.79	11.96	12.00	11.97
	5	1.83	1.78	1.82	12.60	12.82	12.40
	12	1.87	1.88	1.88	12.64	13.08	13.71
	20	1.90	1.93	1.94	12.70	13.90	14.04
	30	1.92	1.97	1.98	13.35	14.64	15.00

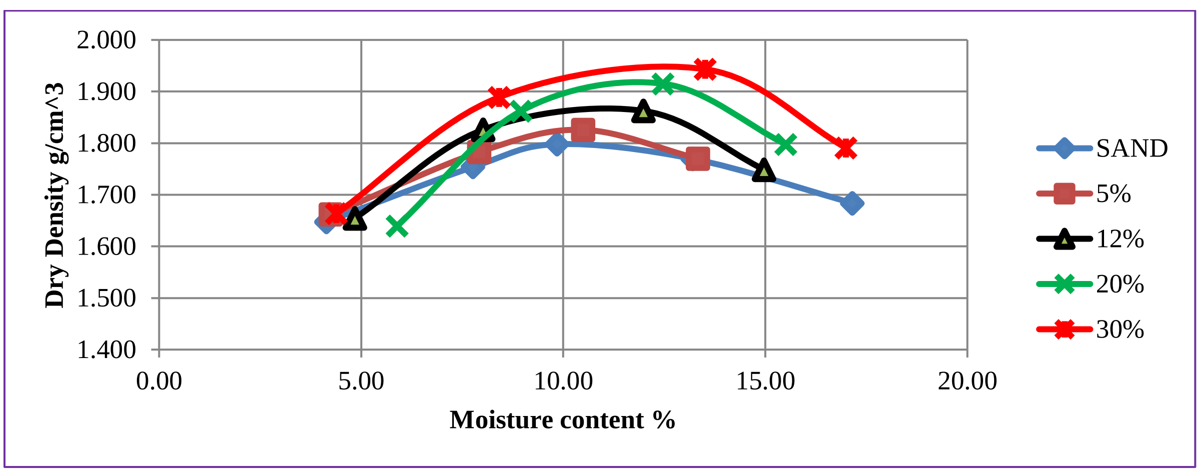

Fig. 3: Combined compaction curve for medium sand of site one.

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The relationship between fine fraction with dry density and OMC of reconstituted soil samples increases in Fig. 3 and the combined compaction curve crosses each other as a result. Several studies indicated that for fine fraction content of 50% and greater in reconstituted sandy soil, the MDD decreases and OMC increases because of the higher water-holding capacity of fine fractions. In addition, MDD and OMC decrease at 40% of fine fractions.

D. California Bearing Ratio

The CBR of sand falls as the fine content increases until it reaches 30%, indicating that an increase in fines reduces the CBR of sand for both medium and fine sand of all sites. As a result, the CBR's optimal fine content value is 30%.

Table 4: Summary of CBR and moisture content test results of specified soil mixtures for all sites of medium and fine sands

Sands	% Fine	CBR					
		Site One		Site Two		Site Three	
		Moisture Content (%)	CBR (%)	Moisture Content (%)	CBR (%)	Moisture Content (%)	CBR (%)
Medium Sand	0	12.82	26.91	11.04	30.75	10.21	40.09
	5	13.70	25.15	12.87	29.76	11.52	38.22
	12	15.51	23.61	14.77	26.69	13.30	34.05
	20	17.14	10.54	16.72	20.87	15.76	29.12
	30	18.82	4.94	18.07	16.26	17.93	18.23
Fine Sand	0	14.65	18.12	13.09	23.72	12.06	32.51
	5	15.78	17.13	14.35	22.63	13.23	31.63
	12	17.34	14.17	16.31	20.87	15.47	28.12
	20	19.03	8.35	18.56	18.45	17.02	20.87
	30	21.91	4.61	20.02	14.94	19.25	15.87

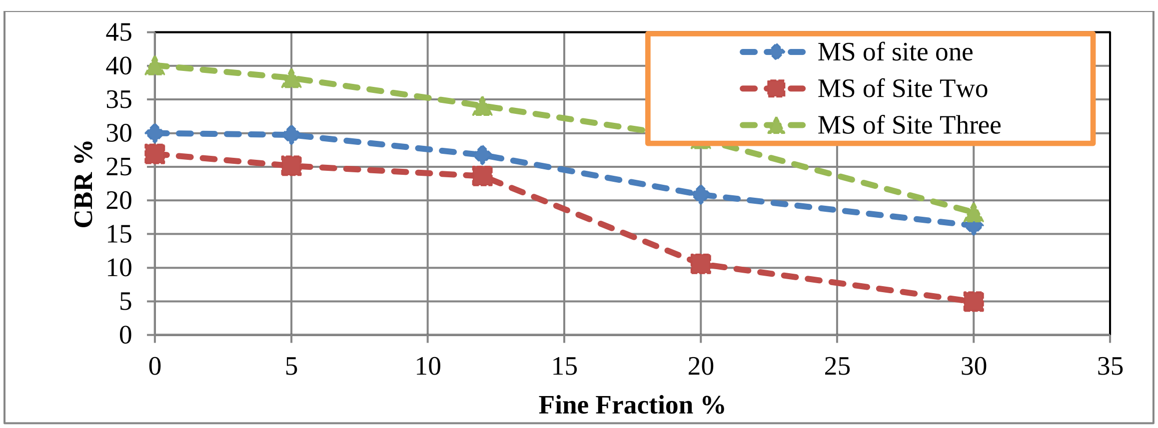

Fig. 4.: Combined Effect of fine fraction on CBR for medium sands of all sites.

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The CBR of reconstituted sandy soil reduces steadily up to 12% and then drops significantly from 12% to 30% as fine fraction content increases for both medium and fine sands. For all sites of medium and fine sands, the fine content of the reconstituted sandy soil increases while the strength of the subgrade material decreases, as shown in Fig. 4.

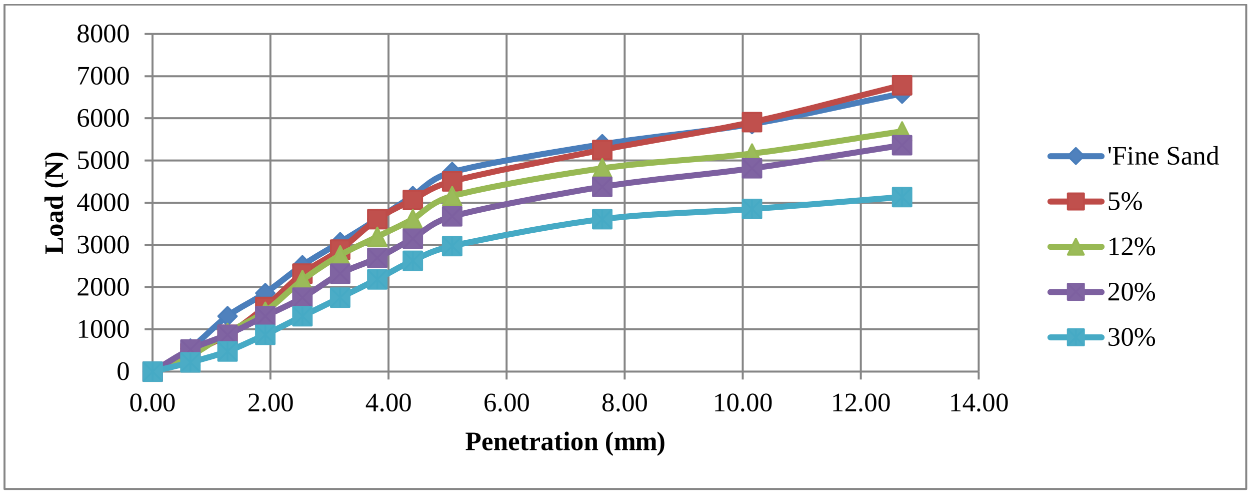

Fig. 5.: Combined CBR Curve for Fine Sand of Site One.

Penetration versus load graph shows above in Fig. 5 that the California bearing ratio for both medium and fine sand decreases as fine fraction content increases from 0% to 30% of all sites. The average CBR value for medium sand decreases from 32.60% to 13.14% and fine sand decreases from 24.785 to 11.80% as fine content increases.

E. Permeability

The soil permeability determines the amount of extra pore water pressure generated in the embankment or cuttings during the consolidation process when the embankment is pounded by water. The increased pore water pressure affects embankment stability significantly.

The image Fig. 5. depicts how the permeability of all three sand locations diminishes as the fine content increases. The maximum permeability value for medium sand at site three was $2.18*10^{-2}$cm/sec, while the values for medium sand and fine sand at site three were 1.57×10^{-2}cm/sec and $7.22*10^{-3}$cm/sec, respectively.

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Table 5: Summary of permeability test results of specified soil mixtures for site one

Sands	% Fine	Coefficient of Permeability		
		Site One	Site Two	Site Three
		K_T (cm/sec)	K_T (cm/sec)	K_T (cm/sec)
Medium Sand	0	1.6×10^{-2}	1.96×10^{-2}	2.18×10^{-2}
	5	9.5×10^{-3}	1.01×10^{-2}	1.21×10^{-2}
	12	7.9×10^{-3}	8.25×10^{-3}	8.99×10^{-3}
	20	6.13×10^{-3}	5.93×10^{-3}	6.11×10^{-3}
	30	2.24×10^{-3}	1.63×10^{-3}	2.17×10^{-3}
Fine Sand	0	7.22×10^{-3}	9.39×10^{-3}	1.57×10^{-2}
	5	5.82×10^{-3}	6.68×10^{-3}	1.05×10^{-2}
	12	4.12×10^{-3}	4.64×10^{-3}	6.81×10^{-3}
	20	3.266×10^{-3}	3.2×10^{-3}	5.21×10^{-3}
	30	9.05×10^{-4}	1.28×10^{-3}	1.28×10^{-3}

The hydraulic conductivity of sandy soil at specific time intervals for both medium and fine sand soil decreases as fine fraction content increases, as shown in Table 6. The coefficient of hydraulic conductivity of reconstituted sandy soil was extremely high from 0% to 5%, and it decreased dramatically from 20% to 30%.

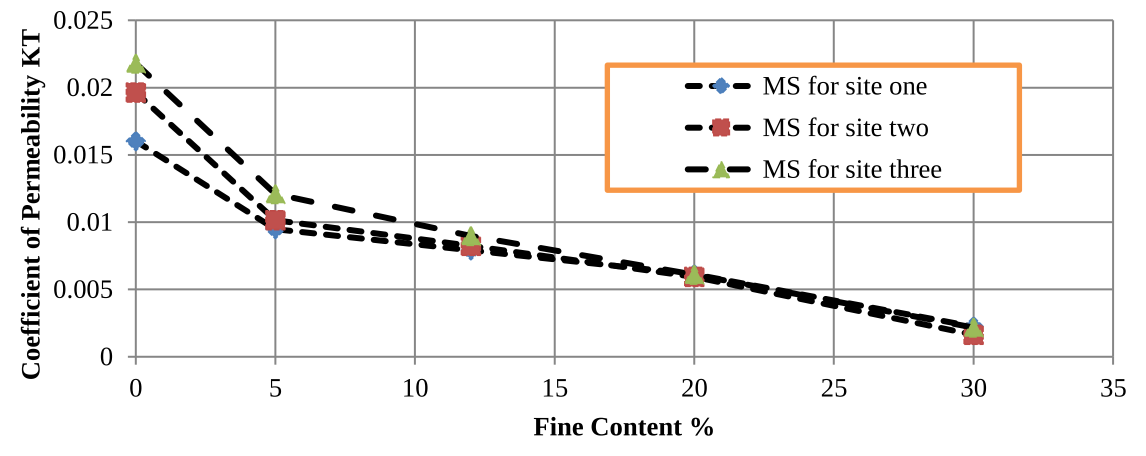

Fig. 6.: Effect of fine content on combined hydraulic conductivity of medium sand for all sites

The coefficient of hydraulic conductivity of medium sands of all sites of sandy soil drops at 5% of fine fraction and goes smoothly up to 30% while fine sands decrease smoothly from the start to

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30% of fine fraction. The combined graphs show that the permeable capacity of soil is nearly the same after 20% to 30%, as shown in Fig. 6.

F. Consolidation

Consolidation curves for dense and very loose material were examined to highlight the influence of fines content on the initial void ratio & final void ratio. The curves of consolidation for each loading phase are displayed below.

Table 6: Initial and final void ratio of all sites for medium sands

Fine Content (%)	Void Ratio e_o					
	Medium Sand					
	Site One		Site Two		Site Three	
	Initial e_o	Final e_o	Initial e_o	Final e_o	Initial e_o	Final e_o
0% Fines	0.82	0.71	0.8	0.7	0.71	0.65
5% Fines	0.62	0.54	0.76	0.69	0.7	0.61
12% Fines	0.56	0.49	0.66	0.59	0.63	0.54
20% Fines	0.50	0.41	0.58	0.52	0.61	0.53
30% Fines	0.46	0.39	0.53	0.47	0.57	0.51

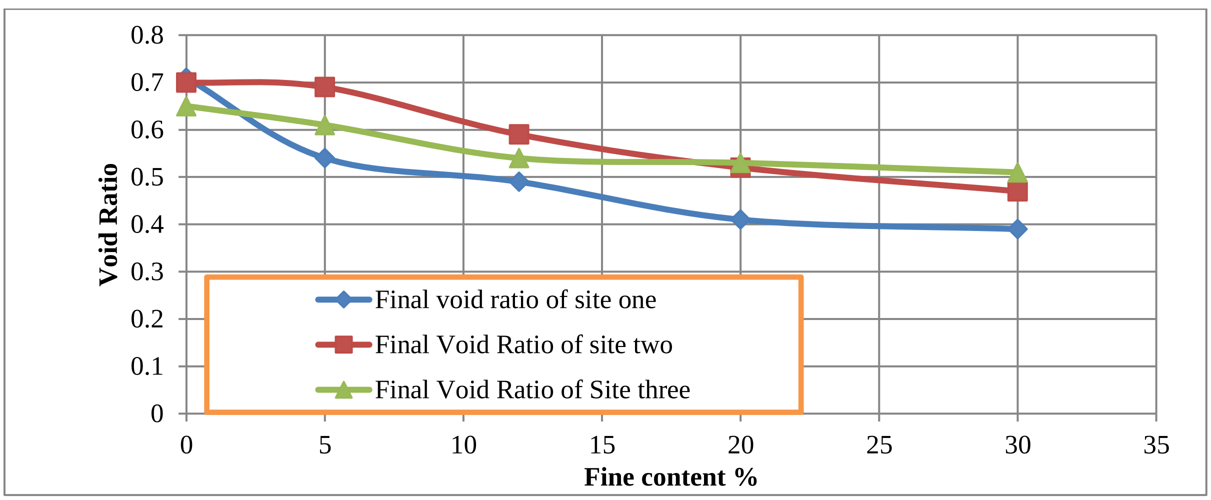

Fig. 7.: Final void ratio versus fine content relationship for medium sands of all sites

Fig. 7 shows that for medium and fine sand materials of reconstituted soil samples of all sites, the value of the initial and final void ratio decreases as fine content increases.

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G. Compressibility Characteristics

To obtain the compressibility of the reconstituted soil sample and its variation with different fines content, a series of 1D – compression tests were preferred on both the fine and medium sands of all sites.

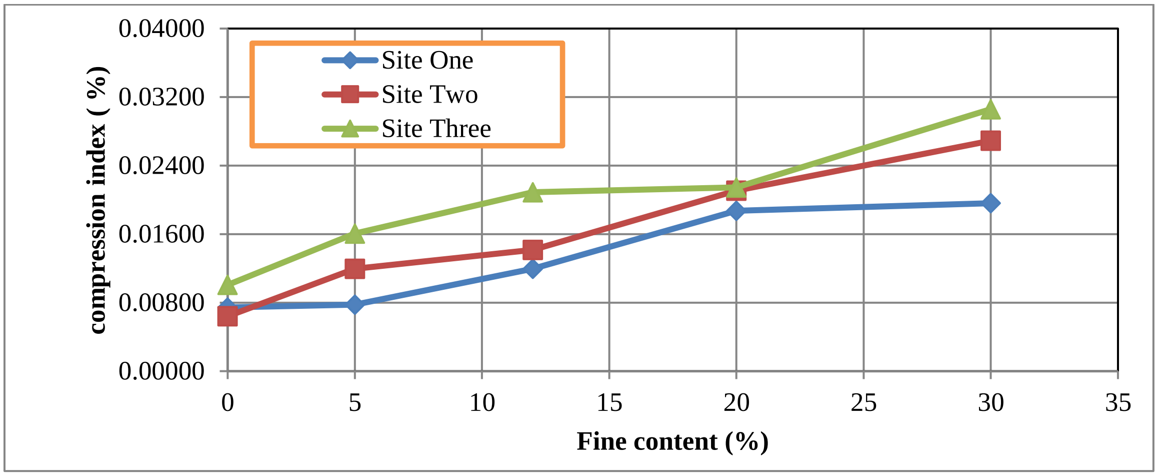

Fig. 8: Compressibility curves with various fines content for medium sand of all sites

Fig. 8 indicates that the compression index of the sand increases as the fine contents are raised to 30 percent and the increment in fines increases the compression index of reconstituted sand soil. The result in Fig. 8 showed that when the fines content grows, Cc rises to a compression index of 0.03368 of fine sand and 0.03059 of medium sand for site three linked with a fines content of 30%.

H. Direct Shear Tests

Sand samples with various fine contents were subjected to direct shear tests (0%, 5%, 12%, 20%, and 30%). As a result, 30 direct shear tests were carried out, each with three normal loads. Table 7 shows the maximum shear stresses obtained against each normal load (stress).

Table 7: Direct shear data obtained for medium sand samples of all sites

Fine Content (%)	Applied normal load, kPa	Site One	Site Two	Site Three
		The angle of internal friction, φ°		
0	9.6	14.8	16.6	15.4
	19.2			
	28.8			

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5	9.6	13.6	15.7	13.9
	19.2			
	28.8			
12	9.6	12.3	11.3	11.4
	19.2			
	28.8			
20	9.6	9.7	9.3	9.4
	19.2			
	28.8			
30	9.6	7.8	5.78	7.4
	19.2			
	28.8			

The angle of internal friction of medium and fine sand decreased by 17.73% and 11.41% respectively, as shown in Table 7. In comparison to the prior study [5], the present study's angle of internal friction was reduced by 57.37% because the prior study's normal load was 77.4kPa, 154.8kPa and 309.6kPa while the current study's normal load is 9.6kPa, 19.2kPa and 28.8kPa. Also angle of internal friction results are compared in the above table.

When the fines content increases, the angle of internal friction (Ø) decreases. The values of shear strength parameters (c and Ø) at varying fines content of the soil samples are summarized in Table 7. The angle of internal friction value for medium sand from Site One ranges from 16.6° to 0°. This is a decrease of 16.6 %. The angle of internal friction values for fine sand ranges from 10.4° to 0°. This equates to a 10.4°. As the fine content of the samples increases, the angle of internal values decreases.

IV. CONCLUSION

The findings of this study indicate that the fine fraction of sandy soil affects the CBR, Permeability, Shear Strength, Plasticity, Compressibility, and MDD values of sandy soils Permeability and CBR values of the soil decrease as the fine fractions increase, and also the angle of internal friction (Ø) of the soil decreases. Furthermore, as the fine fraction of the material rises, the optimum moisture content, MDD, and plasticity increase.

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- Plasticity has a stronger influence on fine fractions. As the fines content increases, the Plasticity Index rises, while the Shear Strength at Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) continue to decrease.
- Due to particle interlocking, an increase in dry density significantly impacts the California Bearing Ratio (CBR). The highest CBR value is achieved at the optimum water content.
- Mixtures with fines content ranging from 5% to 30% exhibit a lower ultimate void ratio as the fines content increases.
- Permeability parameters are closely linked to consolidation characteristics. As the fine content increases, the final void ratio and permeability of sandy soil decrease.
- The coefficient of compressibility, obtained from the 1D Consolidation test, decreases for each specimen as the fines content increases from 0% to 30%.
- The internal friction angle (φ) of sandy soil steadily decreases as the fines content increases from 0% to 30%. Further increases in fines content can lead to a reduction of φ to zero.

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