Effect of Soil Gradation and Particle Size on Correlation between Relative Density and Shear Strength of Middle Gujarat Sand and its Well-graded Combinations

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Abstract: Shear strength is a crucial parameter in geotechnical engineering, influencing the stability of foundations, slopes, and other structures. This research work explores the relationship between shear strength and relative density of sands prevalent in middle Gujarat, India. We collected sand samples from various locations across the region viz., Khanpur, Sevaliya and Ahmedabad. Unconsolidated-Undrained direct shear tests in the laboratory were performed on these samples under controlled conditions to determine their shear strength at different relative densities of 30%, 50%, 65%, and 75%. To understand the effect of gradation, collected samples were mixed in different proportions to get three different well graded samples and the same study was carried out. The results are analyzed to establish a correlation between these two critical soil properties. Strength properties of soil in dry as well as wet condition is also studied to understand effect of drainage on soil strength.

Keywords: Sand, Direct Shear Test, Relative Density, Gradation, Grain Size

I. INTRODUCTION

Sand is needed for a variety of tasks, such as foundation trench backfill, earth retaining structure backfill, building road embankments and reclaiming low-lying areas, etc. It is important to guarantee proper fill compaction in all these scenarios to prevent future liquefaction, foundation failure, and subsidence.

The best indicator for managing sand compaction is relative density [1]. The state condition of cohesion-less soils is described by the term relative density(D_R), which is used to represent the strength qualities in a qualitative manner. Considering this, relative density is a crucial indicator for sandy soils. Granular soil has a different density depending on the size, shape, and compaction technique of the grains as well as the mass's gradation. Relative density of cohesion-less soil can be determined from IS2720 (Part-14):1983. However, comprehensive data regarding sand behavior has been determined by laboratory experiments on reconstituted and samples that are not altered. The relative density is well recognized as a primary component determining the strength and deformation characteristics of sands in these laboratory investigations[2],[3].

The relationship between relative density and shear strength is a fundamental principle in geotechnical engineering. It allows engineers to design safe and stable structures, optimize foundation and retaining wall designs, and make informed decisions regarding soil improvement techniques. This knowledge also contributes to mitigating risks associated with natural disasters like earthquakes and liquefaction.

Relative density, a crucial parameter reflecting the compactness of soil particles within a given volume, holds profound significance in a myriad of geotechnical applications, ranging from foundation design to slope stability analysis[4].Relative density for this research study was chosen in such a way that it covers all states of compactnesse.g.,loosestform to densest state.

Along with other types of construction projects, shear strength plays an important role in the design of road subgrade layer[5].High shear strength ensures the subgrade can support the weight of traffic without excessive deformation or sinking. Weak subgrades with low shear strength are prone to cracking under traffic loads, which can damage the road surface. Adequate shear strength helps the subgrade resist lateral movement, preventing rutting and potholes that compromise the road's geometry. For the entire roadway section, different types of soils are met, whose compaction

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properties and strength properties need to be determined meticulously. Relative density being an important property for measuring degree of compactness, it will give better insight about strength of subgrade layer, if we have correlation between these two important soil properties.

In the past many researchers have tried to correlate these properties [6]. But much emphasis was not provided to importance of grain size, gradation, and wetting effect of soil on derived relations. Some researchers have studied these relationships for sand with varying amount of fines[7]. Sand, being dominating material in fill, property of it govern by its proportion, grain size and gradation.

Grain size and gradation, the distribution of different particle sizes within a soil, play a fundamental role in determining its overall properties. Soils with a mix of large and small particles (well-graded) tend to be denser and more stable due to better packing. This translates to improved drainage as water can flow through the larger voids, while the smaller particles fill the gaps, reducing erosion. Conversely, poorly graded soils with uniform particle sizes can have large empty spaces, leading to waterlogging or poor drainage[8]. Additionally, grain size affects a soil's strength and susceptibility to erosion. Larger particles generally offer higher shear strength for structures built on the soil, while finer particles are more prone to erosion by wind or water. Understanding grain size and gradation is crucial for selecting suitable soil types for various applications in engineeringprojects.

II. EXPERIMENTAL SET-UPAND TEST RESULTS

A. Soil Sample – collection and preparation of well graded samples

Three different kinds of sand samples are collected from different locations of Gujarat viz., Khanpur, Sevaliya, and Ahmedabad, considering the requirement of sample throughout research work. The selection of Sevaliya, Khanpur, and Ahmedabad as study areas for soil sampling is driven by a strategic amalgamation of geographical diversity and contextual relevance.

Sevaliya, nestled amidst the verdant landscapes of rural Gujarat, offers a glimpse into the agricultural heartland, where soil composition plays a pivotal role in crop yield and land productivity. Khanpur, with its proximity to riverine systems and potential for floodplain dynamics, presents a unique opportunity to explore the interplay between soil characteristics and hydraulic forces. Meanwhile, Ahmedabad, as an urban hub pulsating with human activity and infrastructural development, provides insights into the complex interactions between soil mechanics and anthropogenic influences. By encompassing these distinct environments, our study endeavors to capture a holistic understanding of soil behavior, encompassing rural, transitional, and urban contexts, thereby enriching the broader discourse on geotechnical engineering and environmental sustainability. The approximate weight of samples collected during the research work is 500 kg each, and samples are collected according to it.

Grain size being very important property for this research, grain size analysis of the collected soil samples is carried out by IS 2720 (Part-4) and mentioned in below figure1.Grain size analysis was restricted to sieve analysis only as sand was found to have very least amount of fines which is negligible.

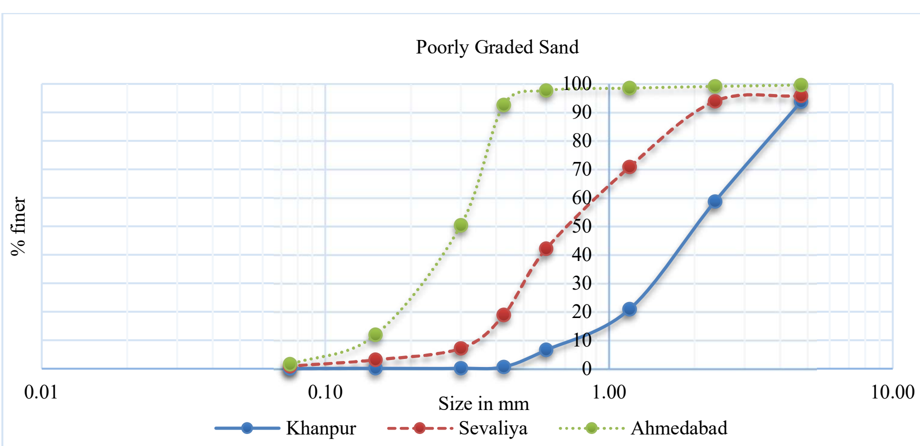

Fig. 1 Grain Size Distribution of Poorly Graded Sa

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Along with sieve analysis, other important soil tests like specific gravity and relative density test were performed according to IS 2720 (Part-3) and IS 2720 (Part-14) respectively. Properties of Khanpur, Sevaliya and Ahmedabad sand are tabulated below. Based on the elementary physical properties of sand, it was noted that Khanpur sand has more coarser particles than Sevaliya Sand and Ahmedabad Sand.

TABLE I

VARIOUS PROPERTIES OF KHANPUR. SEVALIYA, AND AHMEDABAD SAND

Properties	% Gravel	% Coarse Sand	% Medium Sand	% Fine sand	% Silt And Clay	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	C_u	C_c	Specific Gravity G	γ_{max} (gm/cc)	e_{min}	γ_{min} (gm/cc)	e_{max}
Ahmedabad Sand	-	0.47	6.5	88.4	4.63	0.33	0.23	0.15	2.2	1.1	2.59	1.66	0.56	1.47	0.71
Khanpur Sand	6.28	35.04	58	0.68	-	2.5	1.5	0.75	3.3	1.2	2.7	1.94	0.39	1.69	0.6
Sevaliya Sand	4.2	1.9	75	15.92	2.98	0.9	0.5	0.35	2.6	0.8	2.6	1.81	0.38	1.53	0.63

Minimum density (gmin) and maximum density (gmax)of collected samples are derived by carrying out relative density tests according to IS 2720 Part –14.Different combinations of well graded samples of sand are prepared by mixing raw sand samples from different sources in below given proportions:

- Combination 1 (250, 100, 50): The combination comprises of 250 kg sand sourced from Khanpur, 100 kg sand sourced fromSevaliya, and 50 kg sand sourced from Ahmedabad.
- Combination 2 (137, 168, 95): The combination comprises of137 kg sand sourced from Khanpur, 168 kg sand sourced fromSevaliya, and 95 kg sand sourced from Ahmedabad.
- Combination 3 (180, 143, 77): The combination comprises of180 kg sand sourced from Khanpur, 143 kg sand sourced fromSevaliya, and 77 kg sand sourced from Ahmedabad.

The raw sample of sand are properly mixed with proper tools and sufficient time to get uniform distribution of sand.To ensure uniform mixing, multiple times grain size analysis were performed on prepared samples. A summary of grain size analysis of these combinations is carried out as per IS 2720 (Part -4) and mentioned in below figure2.

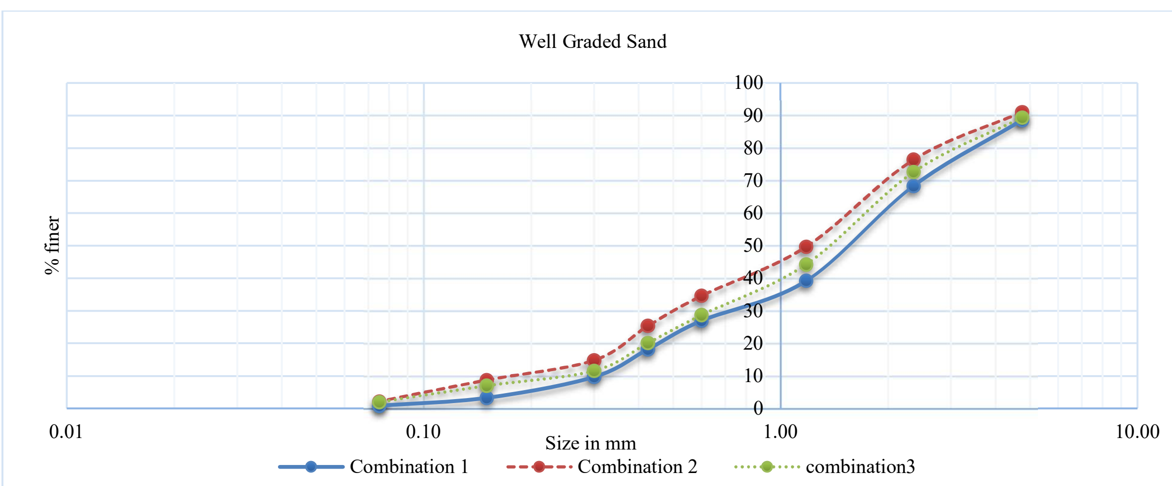

Fig. 2 Grain Size Distribution of Well Graded Sand

Soil properties of above combinations of well graded sand are tabulated below. As all the prepared sand samples are well graded, it was observed that its properties are not deviating much from each other. Improvement in minimum and maximum density of sand is observed due to close packing of particles in well graded samples compared to poorly graded samples.

TABLE II

VARIOUS PROPERTIES OF WELL GRADED SAND

Properties	% Gravel	% Coarse Sand	% Medium Sand	% Fine sand	% Silt And Clay	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	C_u	C_c	Specific Gravity G	γ_{max} (gm/cc)	e_{min}	γ_{min} (gm/cc)	e_{max}
Combination 1	1.38	20.28	50.2	17.35	-	1.9	0.75	0.31	6.1	1	2.63	2.16	0.22	1.72	0.48
Combination 2	8.93	14.65	51.08	22.36	2.98	1.6	0.51	0.17	9.4	1	2.6	2.16	0.2	1.72	0.51
Combination 3	10.6	16.76	52.53	18.15	1.96	1.7	0.65	0.26	6.5	1	2.6	2.23	0.17	1.77	0.47

B. Direct Shear Test

Unconsolidated Undrained direct shear tests as per IS 2720 part – 13 have been performed on each of the three poorly graded sand in dry and submerged conditions. The volume of the test specimen is 6 cm × 6 cm × 2.5 cm. The weight of the sample required for the test, was calculated by multiplying volume with target density. The target density was calculated from selected relative density, minimum, and maximum density.

It is clearly seen that values of angle of internal friction, ϕ is decreasing with decrease in particle size. As well as values of ϕ in dry condition is higher than submerged condition for any size of particle. Difference in values of ϕ between dry and submerged condition is 0.5° for Khanpur sand, 1.5° for Sevaliya sand and 1.0° for Ahmedabad sand.

TABLE III

DIRECT SHEAR TEST RESULTS FOR KHANPUR, SEVALIYA AND AHMEDABAD SAND

D_R (%)	Khanpur			Sevaliya			Ahmedabad		
	γ (gm/cm^3)	ϕ° (Dry)	ϕ° (Submerged)	γ (gm/cm^3)	ϕ° (Dry)	ϕ° (Submerged)	γ (gm/cm^3)	ϕ° (Dry)	ϕ° (Submerged)
30	1.76	45.45	45.05	1.61	38.29	36.85	1.52	33.86	32.77
50	1.81	48.03	47.76	1.66	39.76	38.01	1.56	35.69	34.36
65	1.84	49.61	48.78	1.70	40.9	39.15	1.59	36.5	35.28
75	1.87	50.05	49.28	1.73	42.71	40.94	1.61	37.22	36.33

Direct shear tests as per IS 2720 part – 13have been performed on each of the three well graded sand in dry and submerged conditions. It is clearly seen that values of ϕ is almost remain constant with particle size. As well as values of ϕ in dry condition is higher than submerged condition for any size of particle. Difference in values of ϕ between dry and submerged condition is almost 2.0° to 2.5° for any kind of gradation.

Direct shear tests were performed on dry samples also to understand the lubricating effect of water. It was observed that the difference in value of ϕis profound for fine grained soil. With the increase in grain size, this effect is diminished.

TABLE IV

DIRECT SHEAR TEST RESULTS FOR VARIOUS COMBINATIONS OF WELL GRADED SAND

D_R (%)	Combination-1			Combination-2			Combination-3		
	γ (gm/cm^3)	ϕ° (Dry)	ϕ° (Submerged)	γ (gm/cm^3)	ϕ° (Dry)	ϕ° (Submerged)	γ (gm/cm^3)	ϕ° (Dry)	ϕ° (Submerged)
30	1.87	42.03	40.51	1.83	40.54	38.62	1.88	41.89	40.24
50	1.95	44.86	42.7	1.91	42.82	40.5	1.97	44.71	42.11
65	2.01	46.41	43.99	1.98	45.16	43.36	2.04	46.2	43.4
75	2.05	47.69	45.21	2.03	46.43	44.43	2.09	47.46	45.19

III. INTERPRETATION OF TEST RESULTS

By performing a series of test, following correlations are made between relative density and angle of internalfriction, ϕ (dry and submerged condition)for all poorly graded sample and well graded samples.

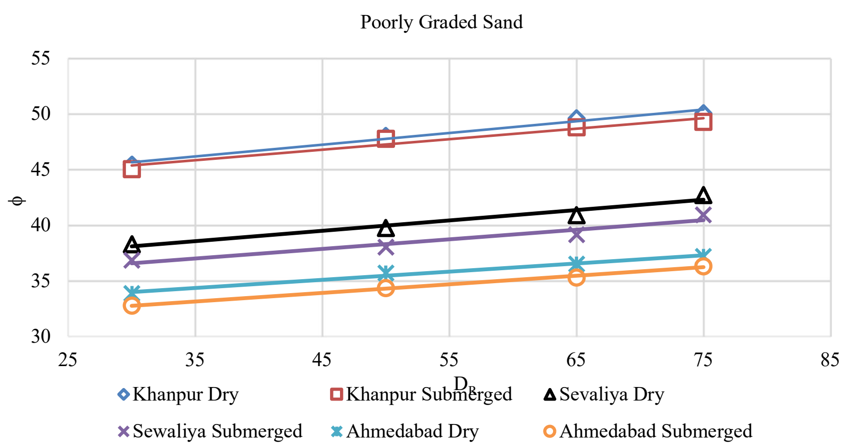

Fig. 3 Relation between ϕ (dry and submerge) and Relative Density for poorly graded sand

The above results shows that value of ϕ is low in submerged condition compared to dry conditions corresponding to each relative density. Irrespective of grain size, similar degree on increase was observed in ϕvalue with increase in relative density.

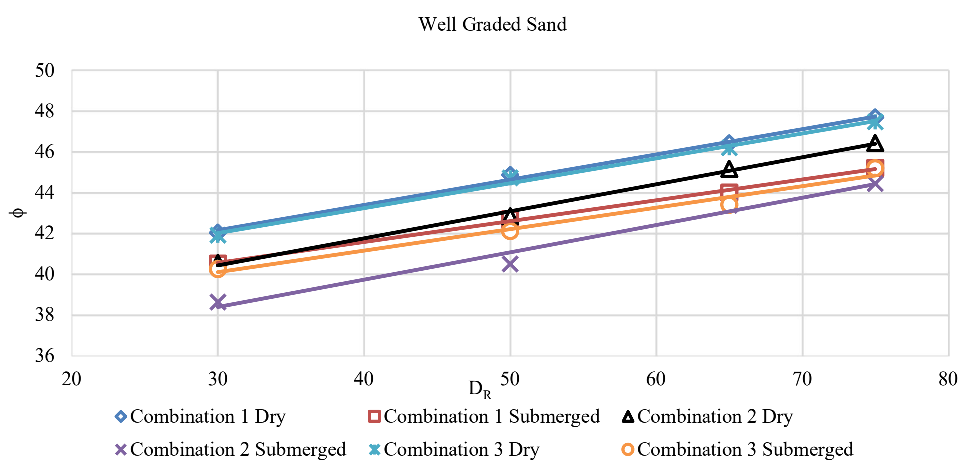

Fig. 4 Relation between ϕ (dry and submerge) and Relative Density for well graded sand

The following table gives the derived correlation between relative density and ϕ values for tested poorly graded sand.This empirical correlation unveils a fundamental link between the degree of soil densification and its capacity to resist shear stresses, offering invaluable insights into the engineering properties of granular materials. By elucidating this relationship, engineers gain a powerful tool for predicting shear strength variations in response to changes in relative density, thereby enhancing the accuracy and reliability of geotechnical analyses and design methodologies.

TABLE V

CORRELATION BETWEEN ΦAND RELATIVE DENSITY FOR POORLY GRADED SAND AND WELL GRADED SAND

Sand Type	Correlation of relative density with φ in dry condition	Correlation of relative density with φ in submerged condition
Khanpur Sand	$y = 0.105x + 42.512$, $R^2 = 0.9765$	$y = 0.0942x + 42.536$, $R^2 = 0.9552$
Sevaliya Sand	$y = 0.0932x + 35.29$, $R^2 = 0.9557$	$y = 0.0861x + 34.003$, $R^2 = 0.9352$
Ahmedabad Sand	$y = 0.0734x + 31.779$, $R^2 = 0.9874$	$y = 0.0768x + 30.46$, $R^2 = 0.9934$
Combination 1	$y = 0.1242x + 38.416$, $R^2 = 0.9958$	$y = 0.1025x + 37.466$, $R^2 = 0.9971$
Combination 2	$y = 0.1327x + 36.439$, $R^2 = 0.9956$	$y = 0.1341x + 34.353$, $R^2 = 0.9784$
Combination 3	$y = 0.1221x + 38.35$, $R^2 = 0.9948$	$y = 0.1054x + 36.936$, $R^2 = 0.977$

In the above equation, y is angle of internal friction ϕ values and x is a relative density value in percentage.

IV. CONCLUSIONS

The following conclusions are made based on the following study:

1. Values of ϕ (dry and submerged) increase linearly with increase in relative density for poorly graded as well as well graded sand.
2. Increase in values of ϕ in dry condition with increase in D_R values is almost similar to increase in values of ϕ in submerged condition with increase in D_R values for poorly graded sand as well as for well graded sand.
3. With respect to given value of D_R, ϕvalues are more in dry conditions compared to submerged condition irrespective of grain size and gradation.

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