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Behaviour of Dune Sand and its Stabilization Techniques

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Abstract – *Thar Desert of Rajasthan, a state of India, covering approximately five Laces sq km area, consists of desert soils, which are windblown deposits of fine sand called sand dunes. The sand dunes have an average height of about fourteen to fifteen meter. They are formed under highly arid conditions. Dune sand is uniformly graded non-plastic fine sand. It causes many geotechnical and structural problems. They are considered inferior foundation material due to their low supporting power and less stability. The study presents the characteristics of dune sand and problems related to these soils, including the methods to improve its geotechnical properties. Issues related with these soils are, soil stabilisation for highways and airfields, minimizing foundation settlement under loads and reducing its permeability to make them suitable for storage and transport of water through canal systems. The various methods to improve the Thar Desert soils are mixing guar gum and bentonite for reducing permeability, introduction of lime, cement and randomly distributed fibres in the dune sand to improve the desirable geotechnical properties.*

Keywords: Dune Sand, Field Investigation, Laboratory Investigation

1.0 INTRODUCTION

Desert/Dune soils are mainly found in Barmer, Jaisalmer, Phalodi, Bikaner, Jalore, Churu, Nagaur, Jodhpur and Ganganagar district of Rajasthan, India. It is a collapsible soil, which goes through a radical rearrangement of particles and loss in volume upon wetting with or without load. The allowable bearing pressure of these soils is low, ranging from 5 to 12 t/m^2 as reported by many researchers [1, 2] and considered poor for construction practices. The only solution of the problem is to enhance the geotechnical properties of dune sand, so that these poor soils can also be used for construction purposes.

2.0 PHYSICAL AND MINERALOGICAL CHARACTERISTICS OF DUNE SAND

2.1 Gradation Analysis of Desert Soil

The soil samples were procured from Jaisalmer, Rajasthan. Gradation analysis was carried out as per IS 2720 (IV): 1985 [3]. The soil was classified as poorly/ uniformly graded sand as per Indian Standard Soil Classification system [4] as shown in Figure 1. It had a specific gravity of 2.66.

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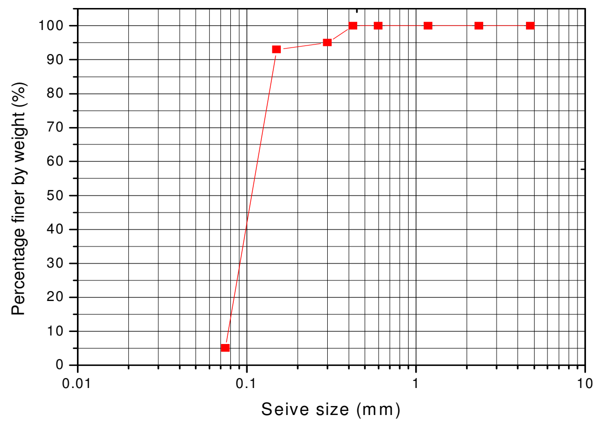

Figure 1: Gradation curve of dune sand

2.2 Moisture Content and Dry Density Relationship

Compaction characteristics of the soils have been determined by using standard Proctor's test according to the procedure laid down in IS 2720 (VII): 1980 [5]. The maximum dry unit weight varies from 15.6 kN/m^3 –16.5 kN/m^3 at a water content from 11.5 –13.5%. Figure 2 shows a typical pattern of water content–dry unit weight relationship. The initial decrease of dry unit weight from 15.90 to 15.69 kN/m^3 has been observed with the addition of water from 0 to 6%. The reason for the decrease in dry unit weight may be the development of capillary phenomenon. The capillary tension induced is not counterbalanced by the compaction energy. Soil grains remain in a loose state as they are in the state of tension. The dry unit weight further increases to 16.3 kN/m^3 at 11.5% of moisture content and decreases with further increase in moisture content. The attainment of maximum density may be due to the lubrication action of water between the soil particles causing the closest packing.

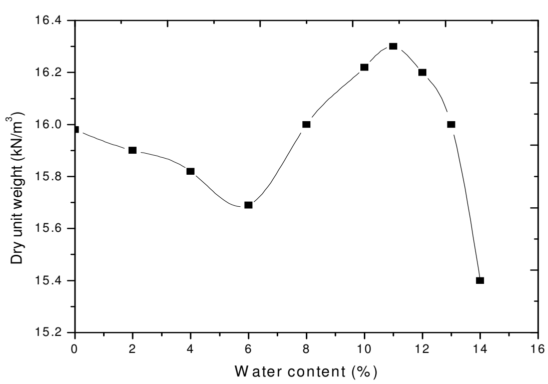

Figure 2: Moisture Content -Dry unit weight relationship

2.3 Shear Strength Parameters

Direct shear box test apparatus with shear box size 60 mm x 60 mm x 50 mm was used to perform shear strength test on samples of dry dune sand at different densities according to IS 2720 (XIII): 1986 [6]. The test results in terms of angle of shear resistance (ϕ) at different unit weight are presented in Table 1.

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Table 1: Values of angle of internal friction

Dry Unit Weight (kN/m^3)	13.74 to 15.21	15.22 to 15.72	15.72 to 16.29
Angle of internal friction (degrees)	26-29	29-31	31-33

The peak angle of shear resistance depends upon the initial voids ratio of the samples. The average value of angle of shear resistance may be taken from 31^0 to 34^0 at a rate of variation of 3^0 per 10% change in voids ratio. Submergence reduces the friction angle by approximately $2\ ^0$. The average ultimate friction angle is about 29^0. The theoretical void ratio is found to decrease with increasing normal stress and water content e.g. its value ranges from 83% to 71.5% of dry dune sand as the normal stress is varied from 20 to 500 kN/m^2. Similarly, the critical void ratio in a submerged state decreases from 75% to 68% under the same stress range.

2.4 Chemical Characteristics

The chemical analyses of dune sand were carried out following the guidelines given in IS 2720 (XXVI): 1987 [7]. It consists P_2O_5 ranging from 0.5% - 1.0% in most of the desert soil samples. The total nitrogen varies from 0.02% -0.07%, which is low. The pH of dune sand was found to be in the range of 7.2- 9.4. The soluble salt contents vary between 0.05% - 0.25% in the surface, which is not in toxic doses. Thus, the soils of the Rajasthan desert contain high amount of available boron in comparison to that of desert soil in other parts of the world, which may be toxic [8].

2.5 X -Ray Diffraction Analysis and Scanning Electron Micrographs of Dune Sand

Figure 3 illustrates the mineralogical characterization of Dune sand using the X –ray diffraction technique. The most intense peak near $2\theta = 26.652$ is for quartz, the primary mineral present in the dune sand. The other minerals present in the dune sand samples is Calcite, Dolomite, Microcline, Lead Oxide, Chromium, Cummingtonite, which occur in the crystalline form are represented by the peak characteristic as shown in Fig. 3.

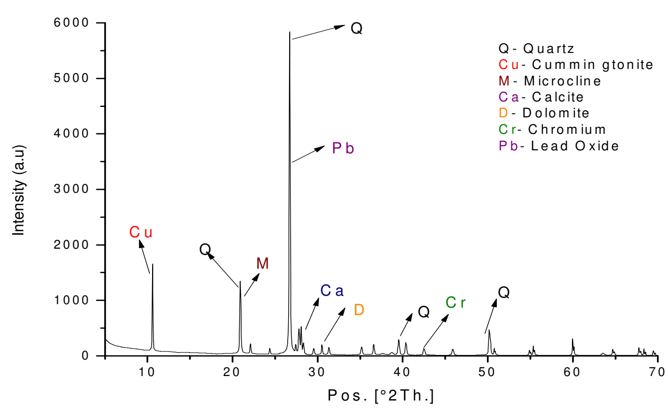

Figure 3: The X -ray diffraction analysis of dune sand

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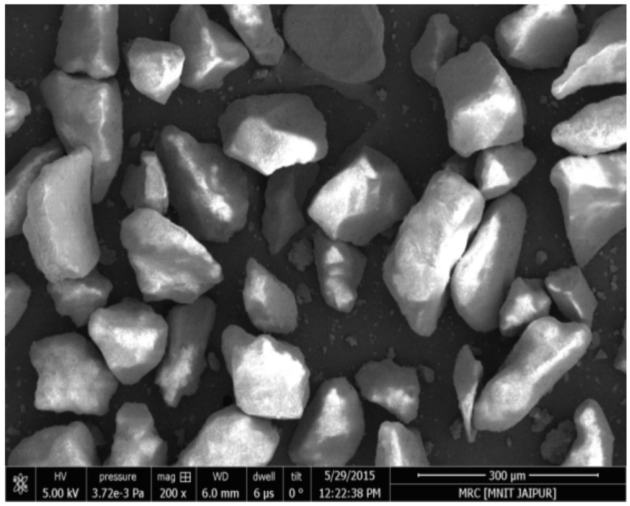

Figure 4: Scanning electron micrograph image of Dune sand at 200 magnifications

The particle morphology of dune sand is analysed from micrograph obtained with the help of scanning electron microscope, Nova Nano FE-SEM 450 (FEI). The scanning electron micrograph of dune sand at 200 magnifications is shown in Figure 4, which reveals that the dune sand particles are edged with a flat surface, angular, elongated and flaky in shape and size.

3.0 FIELD INVESTIGATION OF DUNE SAND

The authors had carried out many in situ field tests for geotechnical investigation for estimating foundation design parameters for various structures for overhead water tanks for water supply projects, buildings, roads, bridges etc in Jaisalmer city. Plate load tests (PLT) and standard penetration tests (SPT) were carried out at various locations during consultation works assigned by various engineering departments, particularly Public Health Engineering Department, Water Resources Engineering Department, Rajasthan Housing Board, and private organizations etc.

3.1 Investigations based on Plate Load Tests (PLT)

The low bearing capacity and high settlement are well known facts of the dune sand. Plate load tests were carried out at many locations in Jaisalmer during consultation works for determination of ultimate bearing capacity, modulus of subgrade reaction etc. of soil in place. For obtaining dependable and reproducible results, the tests were conducted following the procedure described by IS 1888:1982 [9].

The inclusion of all test results in this paper is cumbersome and makes the paper long. Only one of them is presented here. Figure 5 illustrates two average load- settlement curves obtained from field tests performed on 75 cm x 75 cm plate size in Jaisalmer city**.** The ultimate bearing capacity was found in the range of 30 kPa (for stable dune sand) to 18 kPa (for weak dune sand).

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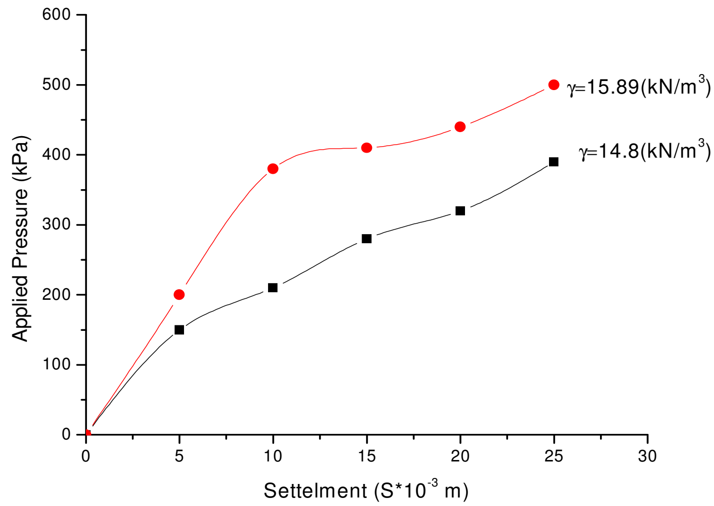

Figure 5: Applied Pressure and corresponding Settlement curve

3.2 Investigations based on Standard Penetration Test (SPT)

Standard penetration tests were conducted following the procedure described by IS 2131:1981 [10]. Methods of calculation of bearing capacity of soils based on N values were adopted as per IS 6403:1981. Table 2 gives the average variation of N- values for stable and unstable dunes for dry and submerged dune sand for various locations in Jaisalmer city.

Table 2: SPT (N) values for stable and unstable dunes

Depth (m)	Soil	N values	
		Stable dune	Unstable dune
1.0	Dry	9-13	4-7
2.0	Dry	10-18	7-12
3.0	Dry	13-26	10-15
4.0	Dry	17-36	13-26
1.0	Submerged	-	1-3
2.0	Submerged	-	3-5

4.0 GEOTECHNICAL PROBLEMS ASSOCIATED WITH DUNE SAND AND GAP AREAS IDENTIFIED

Dune sand being in the category of collapsible soil that goes through a radical rearrangement of particles. Due to this, they are susceptible to change in volume when subjected to wetting. The safe bearing capacity is low to support the structural loads. Construction of highways in the Thar region has its own problems due to the vast expansion of fine sand and compaction up to desirable degree is difficult. The conventional road construction materials are not available in this region. The only solution of these problems is to enhance the geotechnical properties of dune sand, so that these poor soils can also be used for construction purposes.

The problems associated with dune sands have been discussed. Many cases of structural failure, particularly the foundations of overhead water tanks, problem of erosion of earthen embankments, settlement of roads and buildings in Thar areas are reported in local newspapers

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frequently. These current problems led authors to think and investigate the innovative methods to improve the strength characteristics of the dune sand, which is a challenge for engineers dealing with these soils. Few studies have been reported in the literature available on the stabilization of these problematic dune sands. These studies have been referred and included in the paper.

5.0 REMEDIES OF THE PROBLEMS ASSOCIATED WITH DUNE SAND

The dune sand samples from the area near Jaisalmer city were taken in the investigation. The physical and mineralogical properties of dune sand are already discussed in the previous sections.

5.1 Permeability

For developing a suitable impermeable material for dune sand, a few permeability studies have been conducted with the addition of guar-gum and bentonite with dune sand in permeameter. Guar gum (galactomannan), a product of Indian desert, appears promising for short duration field applications and in exigencies. It is a pure natural and environmental friendly material. The powdered gum and its derivatives are commonly used in the oil and gas, food, paper, textile, explosive and mining industries at concentration below one per cent. The properties of Guar gum used for present investigation are listed in Table 3. Sodium bentonite being fine clay of low permeability can be used for reducing the permeability of dune sand. Bentonite fills the pore spaces of dune sand particles. In the presence of water, it hydrates and swells, pressing the sand particles causing a decrease in permeability. The bentonite used for present investigation is high swell sodium bentonite containing sodium montmorillonite and its properties are listed in Table 4.

Table 3: Physico-chemical characteristics of Guar-gum

Property	Value
Physical appearance	White with pale yellow tinge; IS sieve 75-micron, 98%
Moisture (%)	10.28
Solubility	Soluble in water
Ash:	
a) Acid insoluble (%)	0.72
b) Minerals after combustion (%)	0.85
pH (1 %)solution)	6.3

Table 4: Properties of bentonite

Property	Value
Specific gravity	2.24
Liquid Limit	250 %
Plastic Limit	47 %
Plasticity Index	203%
Maximum Dry Density	1.17 g/cm^3
Optimum Moisture Content	46.70 %
Swelling water absorbed per gm of oven dried bentonite in cubic cm	7 to 8 times

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Table 5 presents the results showing relationship between dry density and coefficient of permeability for the addition of various percentages of gaur-gum and bentonite

Table 5: Effect of gaur-gum and bentonite on the Coefficient of Permeability of dune sand

Dry Density (kN/m^3)	Coefficient of Permeability(m/s)								
	DS alone	DS+1% GG	DS+2% GG	DS+4% GG	DS+6% GG	DS+8% GG	DS+2% BT	DS+4% BT	DS+6% BT
15.0	0.1*10^{-5}	0.1*10^{-8}	0.7*10^{-5}	0.5*10^{-6}	0.8*10^{-7}	9*10^{-7}	0.9*10^{-6}	0.5*10^{-7}	0.7*10^{-7}
15.2	0.3*10^{-5}	0.9*10^{-8}	0.8*10^{-5}	0.8*10^{-6}	0.9*10^{-7}	0.1*10^{-8}	0.95*10^{-6}	0.5*10^{-7}	0.9*10^{-7}
15.7	0.7*10^{-5}	0.5*10^{-10}	0.5*10^{-6}	0.5*10^{-7}	0.3*10^{-8}	0.8*10^{-8}	0.5*10^{-7}	0.9*10^{-7}	0.95*10^{-7}

*DS-Dune Sand, GG- Guar gum, BT- Bentonite

It is estimated from the tests that the permeability decrease by eight times by the addition of 2% bentonite to dune sand and that 4% and 6% bentonite reduces permeability approximately to 25 times and 51 times respectively. Gaur-gum gives much better results in comparison to bentonite. It does not require any curing and need of a skilled labour. It can be however recommended, for impermeabilization of dune sand in short term water storage works, stabilisation of bunds of dune sand.

5.2 Stabilization using lime and cement

In the present investigation, an attempt has been made to stabilise dune sand using lime and cement. Unconfined compressive strength was conducted for assessing the suitability of lime and cement mix with dune sand. The test samples were prepared by mixing dune sand, lime, cement and water in various proportions. The various mixes, prepared were by using cement in 8%, 10%, 12%, 14%, 16% and lime in 4%, 6% and 8%. The lime used in this study for stabilisation was hydrated lime passed through 425 micron IS sieve. Potable water is available in the supply through taps. Its *pH* value was 7.45 as used for the study. Ordinary Portland cement (OPC 43 grade) has been used in the present investigation.

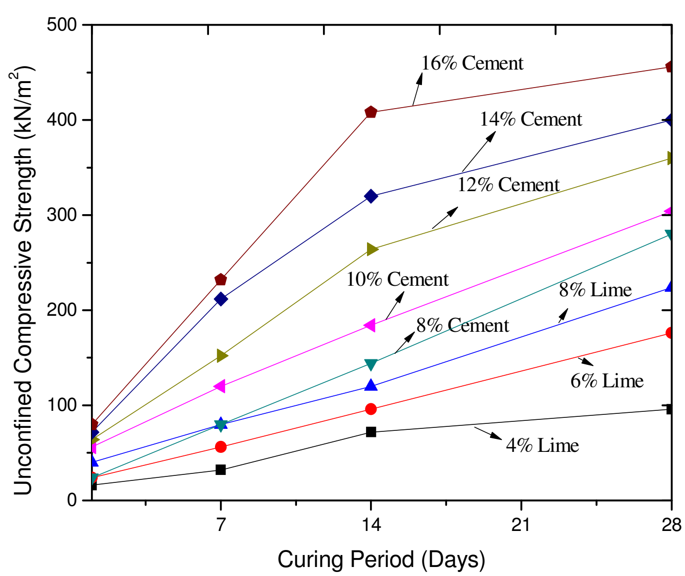

Figure 6: Unconfined Compressive Strength versus Curing Period

The specimen's samples of cement-sand having 38 mm diameter and length of 76 mm were subjected to curing. These samples were prepared for an age of 1, 7, 14 and 28 days. The sample's top and bottom surface were well prepared with the help of a knife and sandpaper. The length and height ratio was kept as 2:1.

These specimens were tested for unconfined compressive strength at one constant strain rate of 1.25 mm/min, with the major principal stress direction concluding with the direction of sampling at constant strain rate. Any possibility of development of eccentricity of loading was being strictly avoided.

The typical unconfined compressive strength versus curing period curves for various proportions of lime and cement are presented in Fig. 6. The unconfined compressive strength increases gradually with age of curing as evident from this figure.

5.3 Stabilization Using Randomly Distributed Fibres

Fibre reinforcement is one of major ground improvement techniques for enhancing the engineering properties of these soils. Experimental work done by various investigators for last many years has established beyond doubt that the addition of fibre in the soil improves the overall engine performance of soil. Among the notable properties that improve, are greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness.

Thus, RDFS has been used for stabilization of dune sand in the present research work. A number of studies have been conducted recently to investigate the influence of randomly oriented fibres on the geotechnical behaviour of coarse grained and fine-grained soils. Polypropylene, polyester and glass fibres have been commonly used for reinforcing soils because they are easily available.

The triaxial and direct shear tests were carried out on soils in which the fibres were oriented in particular directions or randomly distributed [11-22]. Investigations reported that reinforced soils using randomly distributed fibres have greater ductility and improved toughness. The toughness and ductility of the fibre-reinforced soils are beneficial for anti-earthquake geo-structures. However, information regarding the effect of fibre reinforcement on the geotechnical behaviour of dune sand is scarce.

No previous studies have comprehended the effect of inclusion of randomly distributed polyester fibres on strength and mechanical behaviour of dune sand covering a large portion of Rajasthan, the Thar Desert. Hence, rigorous research and investigation is required to predict the effect of reinforcement on shear strength characteristic of dune sand. Improvement in shear strength will enhance the desirable soil properties as foundation material. To accomplish the objectives a series of triaxial tests were carried out at different fibre content (0.5%, 1%, 2%, and 3 % by dry weight of dune sand) and under different confining pressures of 50 kPa, 100 kPa, 200 kPa and 300 kPa respectively.

5.3.1 Fibres

The synthetic fibres used in the present investigation are polyester fibres manufactured from high-density polyester and polyethylene. It is very resistant to seawater, acids, alkalies and chemicals. It has a high breaking strength and high abrasion resistance as it is less prone to wear and tear. Table 6 shows its characteristics as provided by the supplier.

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Table 6: Fibre characteristics

Fibre type	Diameter, d (mm)	Aspect ratio, *l/d*	Specific gravity, G_f	Tensile strength, kPa	Tensile modulus, kPa	Coefficient of friction
Polyester	0.3	50, 75, 100, 125	0.92	1.50×10^5	3.0×10^6	0.41

5.3.2 Methodology

To examine the probability of enhancing the engineering characteristics of dune sand, using fibres an experimental investigation were carried out. A series of triaxial tests were performed on fibre reinforced dune sand at different fibre contents (0.5%, 1%, 2%, and 3 % by dry weight of dune sand) and under different confining pressures of 50 kPa, 100 kPa, 200 kPa and 300 kPa respectively.

A split metal mould of about 100mm internal diameter and 200 mm height was used for the preparation of the samples. A coarse porous stone was placed on the top of the pedestal of the triaxial base and pressure connection was attached to a burette. One end of a membrane was sealed to the pedestal o-rings. The metal former was clamped to the base. The upper metal ring of the former was kept inside the top end of the rubber membranes and was held with the help of a clamp before placing the funnel and the rubber bung in position. The sample was levelled and a porous stone was placed on its top. The loading cap was placed gently on the top porous stone. The standard procedure was followed according to IS: 2720(Part 10)-1973 for carrying out the test. In the first stage of the test, the specimen was subjected to an all-around confining pressure (σ_c) on the sides and at the top and the bottom. In the second stage of the test, deviator stress (σ_d) is applied on the top of the specimen through a ram. Thus, the total stress in the axial direction at the time of shearing is equal to $\sigma_c + \sigma_d$.

6.0 RESULTS AND DISCUSSION

To evaluate and understand the influence of reinforcing the dune sand by fibres a series of exhaustive experimental investigation are carried out and presented in the section to follow.

A glance of the figures indicates that for a constant confining pressure of 50 kPa, the deviator stress increases with an increase in axial strain. At low values of axial strain, the deviator increases almost linearly with axial strain. This then changes into a curvilinear fashion and again varies almost linearly with increase in axial strain, though at a much slower rate. Further, it may be noted stress-strain curve does not show peak stress, even up to 20% axial strain, exhibiting a ductile behaviour of the composite. Similar trends in stress-strain curves is observed for other confining pressures of 100, 200, and 300 kPa, though the deviator stress values at a particular axial strain are higher for higher values of confining pressure. Fig. 7(a) shows the plots of deviator stress-axial strain from triaxial tests under confining pressure of 50 kPa on polyester fibre reinforced dune sand at an aspect ratio of 75 and at different fibre weight fractions ranging from 0.5% to 3.0%. For the sake of comparison, test results of unreinforced dune sand have also been plotted. Similar curves under confining pressures, σ_3 of 100, 200, and 300 kPa have been plotted in the Fig.7 (b) to Fig.7 (d) respectively. Fig. 7(a) indicates that the deviator stress-axial strain plots of fibre reinforced dune sand do not exhibit any peak stress. In addition, the deviator stress-axial strain curves of fibre reinforced dune sand do not indicate the decreasing trend for any value of fibre content and confining pressure. The deviator stress continuously increases with increase in axial strain. In general, the increasing trend of the

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curves is more pronounced at fibre content ≥ 1percentage (Fig. 7(a) to Fig. 7(d)). Further, the increasing trend of the stress-strain curves is less significant in case of lower fibre content, w_f < 1% and lower confining pressures, $\sigma_3 \leq 100$ kPa as compared to the higher fibre concentration and higher confining pressure (Fig. 7 (a) to Fig.7 (d))respectively. The stress-strain behaviour of fibre reinforced dune sand is observed to be similar to that of reinforced sand investigated by other researchers [11, 13-15].

Figure 7 indicates that the deviator stress-axial strain behaviour of dune sands reinforced with polyester fibre is very much different from that of unreinforced dune sand. Unreinforced dune sands attain a peak stress at around 10% axial strain which then remain practically constant or indicate a slightly decreasing trend, whereas fibre reinforced dune sands exhibit neither any peak value nor a decreasing trend. The deviator stress-axial strain curves of reinforced dune sands indicate an increasing trend even at higher axial strains, as high as up to 20%. Further, with the increase in fibre content keeping other parameters constant, the slope of deviator stress-axial strain curves becomes steeper [Figs.7 (a, b, c, d) indicating that fibre reinforced dune sands exhibit low modulus, high strain(i.e. the greater ductility of the composite material) as compared to unreinforced dune sands.

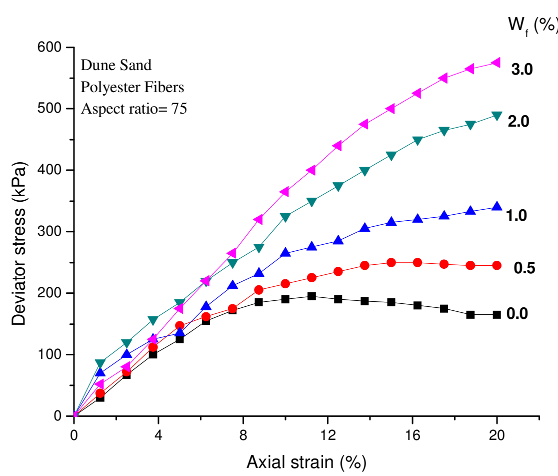

Figure 7: **(a)** Typical Deviator Stress-Axial Strain plots of Polyester Fibre-Reinforced Dune Sand at σ_3 = 50 kPa and *l/d* = 75

This difference in deviator stress-axial strain behaviour of fibre reinforced dune sand as compared to unreinforced dune sand needs to be examined. The behaviour of fibres in the composite is controlled by the deformation in the surrounding dune sand. As the fibre-reinforced sample is subjected to strain, friction between dune sand and fibres comes into play resulting into development of tensile stress in the fibre. The surface friction and the tensile stress developed in the fibres are responsible for enhanced stress in fibre reinforced dune sand. Since the fibres are capable of resisting large tensile stress, the fibre-reinforced soils tend to gain the strength even at large deformations. It can be seen from Figs.4, wherein the unreinforced dune sand may be losing the strength after attaining a peak value, but the fibre reinforced dune sands gain strength continuously. However, at low confining pressure, the friction between dune sand-fibre surfaces may not have fully mobilized. In such cases, the enhancement in stress is governed by the amount of surface friction mobilized. Thus, the dune sand fibre composite exhibits overall lesser deformations under any particular load or large load carrying capacity at a given deformation in comparison of unreinforced dune sand.

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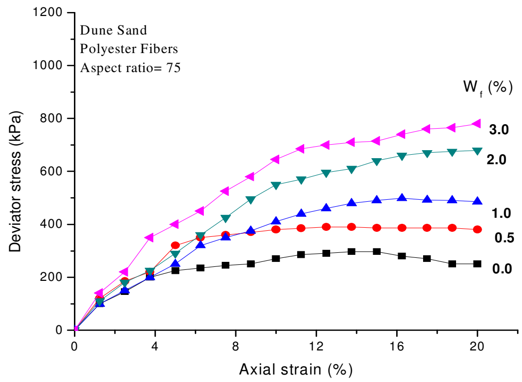

Figure 7: (b) Typical Deviator Stress-Axial Strain plots of Polyester Fibre-Reinforced Dune Sand at σ_3 = 100 kPa and *l/d* = 75

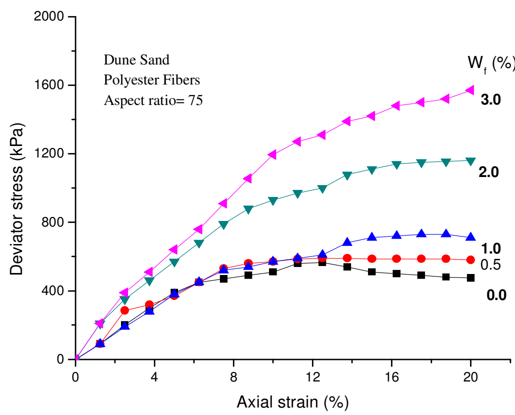

Figure 7: (c) Typical Deviator Stress-Axial Strain plots of Polyester Fibre-Reinforced Dune Sand at σ_3 = 200 kPa and *l/d* = 75

Figure 8 shows the deviator stress-axial strain plots for dune sand reinforced with polyester fibres, of weight fraction, 1% and aspect ratio 100, under confining pressure of 50, 100, 200, and 300 kPa. Similar trends in stress-strain curves are observed for reinforced dune sand at an aspect ratio of 100 and at different fibre weight fractions ranging from 0.5% to 3.0% under different confining pressures. Table 7 shows the increase in the strength of fibre reinforced dune sand over unreinforced dune sand at an aspect ratio of 100. As the fibre content and confining pressure goes on increasing, the relative strength of the reinforced composite over unreinforced composite decreases. At aspect ratio 100, there is increase in deviator stress as compared to aspect ratio 75. This is perhaps due to the development of larger friction between the particles of composite and fibre, which make it difficult for the particles that nearby fibres to change its position from one point to another, which leads to the improvement in the frictional resistance to the force applied.

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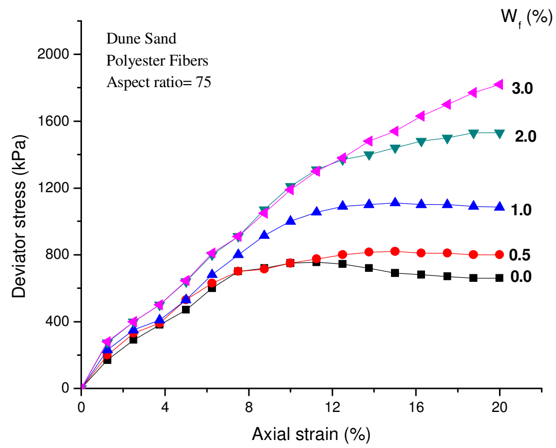

Figure 7: (d) Typical Deviator Stress-Axial Strain plots of Polyester Fibre-Reinforced Dune Sand at σ_3 = 300 kPa and *l/d* = 75

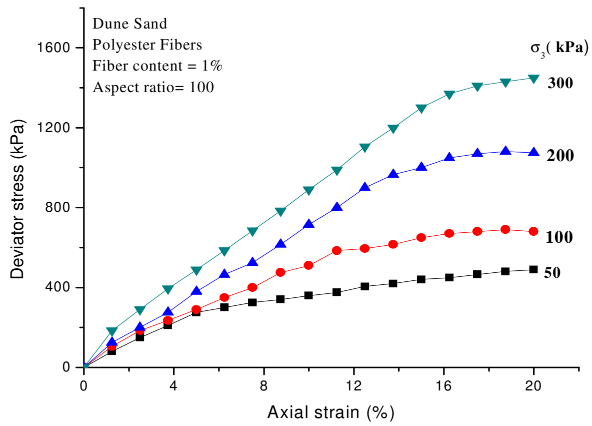

Figure 8: Typical deviator stress-axial strain plots for dune sand reinforced with polyester fibres at 1% fibre content and *l/d* = 100, under confining pressures.

Table 7: Increase in strength of fibre reinforced dune sand over unreinforced dune sand (Polyester fibres; *l/d* = 100)

Fibre content w_f(%)	Increase in strength due to fibre inclusions, (%) Confining pressure, σ_3 (kPa) Strain = 20%			
	50	100	200	300
0.5	58.4	53.2	52.1	51.4
1.0	77.6	67.3	66.5	67.9
2.0	196.9	179.5	144.2	131.5
3.0	248.4	225.1	195.5	154.9

7.0 CONCLUSIONS

Geotechnical engineering problems posed by the dune sand are numerous. An experimental investigation was carried out to study the engineering properties of dune sand and methods to improve its engineering properties using gaur-gum, bentonite, lime, cement and RDFS. The following conclusions are drawn from this investigation:

1. The maximum dry unit weight of dune sand ranges from 15.69-16.3 kN/m^3 at a moisture content from 11.5 -13.5%.
2. The value of the angle of shear resistance of dune sands may be adopted in the range of 31^0 to 34^0 at a rate of variation of 3^0 per 10% change in voids ratio for the design purposes. The average ultimate friction angle is about 29^0.
3. The ultimate bearing capacity obtained by the plate load tests is 30 kPa and 18 kPa for stable and comparatively weak dune sand respectively.
4. From the standard penetration test data, it has been observed that the penetration resistance decreases considerably in the submerged dune sand.
5. The permeability of the dune sand decreased by eight times by the addition of 2% bentonite to dune sand and that 4% and 6% bentonite reduces permeability to 25 times and 51 times respectively. Guar -gum gives much better results in comparison to bentonite. It does not require any curing and need of a skilled labour. It is recommended to use the Guar-gum for impermeabilization for water storage works and stabilizations of bunds of dune sand.
6. The introduction of lime and cement in dune sand increases its unconfined compressive strength significantly. The unconfined compressive strength values of cement treated dune sand samples are found to be much higher than that of lime treated dune sands. The strength depends upon doses of lime, cement and age of curing.
7. The stress-strain curves obtained from Triaxial tests on samples of dune sand reinforced with randomly distributed polyester fibres does not show peak stress, even up to 20% axial strain, exhibiting a ductile behaviour of the composite material at various percentages of polyester fibre having different aspect ratios under various confining pressures. The unreinforced sample obtains peak stress at about 10 % axial strain. The ductile behaviour is much pronounced at fibre content more than 1%. The toughness and ductility of the fibre-reinforced soils are beneficial for anti-earthquake geo-structures.

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REFERENCES

[1] Ohri, M.L., A. Singh, and D.G. Purohit. "Ultimate bearing capacity of footings on dune sand overlaying dense sand." Proc. IGC-84, Calcutta, India, (1984).

[2] Chowdhary, G.R. "Behaviour of ring footings on dune sand." Dissertation, Department Of Civil Engineering, University of Jodhpur, India (1983).

[3] Indian Standard. "Methods of test for soils: Grain size analysis (IS: 2720, Part IV)." Bureau of Indian Standards, (1985).

[4] Indian Standard. "Classification and identification of soils for general engineering purposes (IS: 1498)." Bureau of Indian Standards, (1972).

[5] Indian Standard. "Methods of Test for Soils: Determination of moisture content dry density relation using light compaction (IS: 2720, Part VII)." Bureau of Indian Standards, (1980).

[6] Indian Standard. "Methods of Test for Soils: Direct shear test (IS: 2720, Part XIII)." Bureau of Indian Standards, (1986).

[7] Indian Standard. "Methods of test for soils: determination of pH value of soil samples (IS: 2720, Part XXVI)." Bureau of Indian Standards, (1987).

[8] CWPC. "Dynamics of Shifting Sand Dunes in Western Rajasthan and its Stabilization" Government of India, New Delhi, (1971).

[9] Indian Standard. "Method of load test on soils (IS: I888)." Bureau of Indian Standards, (1981).

[10] Indian Standard. "Method for standard penetration test for soils (IS: 2131)" Bureau of Indian Standards, (1981).

[11] Ranjan, Gopal, and H. D. Charan. "Randomly Distributed Fibre-reinforced Soil-the State-of-the Art." JOURNAL-INSTITUTION OF ENGINEERS INDIA PART CV CIVIL ENGINEERING DIVISION 79 (1998): 91-100.

[12] Consoli, Nilo C., Pedro DM Prietto, and Luciane A. Ulbrich. "Influence of fiber and cement addition on behavior of sandy soil." Journal of Geotechnical and Geoenvironmental Engineering 124, no. 12 (1998): 1211-1214.

[13] Gray, Donald H., and Harukazu Ohashi. "Mechanics of fiber reinforcement in sand." Journal of Geotechnical Engineering 109, no. 3 (1983): 335-353.

[14] Gupta, P.K. "Behavior of Fiber Reinforced Sand." Indian Geotechnical Journal, (2004).

[15] Jiang, Hongtao, Yi Cai, and Jin Liu. "Engineering properties of soils reinforced by short discrete polypropylene fiber." Journal of Materials in civil Engineering 22, no. 12 (2010): 1315-1322.

[16] Makiuchi, Katshuhiko, and Kunio Minegishi. "Strain-induced toughness and shearing characteristics of short-fiber reinforced soils." In Landmarks in Earth Reinforcement: Proceedings of the International Symposium on Earth Reinforcement: Fukuoka, Kyushu, Japan, 14-16 November, 2001, vol. 1, p. 83. Taylor & Francis US, 2001.

[17] Michalowski, Radoslaw L., and Aigen Zhao. "Failure of fiber-reinforced granular soils." Journal of Geotechnical Engineering 122, no. 3 (1996): 226-234.

[18] Ranjan, Gopal, R. M. Vasan, and H. D. Charan. "Probabilistic analysis of randomly distributed fiber-reinforced soil." Journal of Geotechnical Engineering 122, no. 6 (1996): 419-426.

[19] Sadek, Salah, Shadi S. Najjar, and Fadi Freiha. "Shear strength of fiber-reinforced sands." Journal of geotechnical and geoenvironmental engineering136, no. 3 (2010): 490-499.

[20] Shewbridge, Scott E., and Nicholas Sitar. "Deformation characteristics of reinforced sand in direct shear." Journal of geotechnical engineering 115, no. 8 (1989): 1134-1147.

[21] Correia, António AS, Paulo J. Venda Oliveira, and Dione G. Custódio. "Effect of polypropylene fibres on the compressive and tensile strength of a soft soil, artificially stabilised with binders." Geotextiles and Geomembranes43, no. 2 (2015): 97-106.

[22] Hamidi, Amir, and Mahdi Hooresfand. "Effect of fiber reinforcement on triaxial shear behavior of cement treated sand." Geotextiles and Geomembranes 36 (2013): 1-9.