ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 6, Issue 11, November 2021

Prediction of Shear Strength Parameters from the Compressive Strength of Grouted Sandy Soils

[1] Sekhar, A.C, [2] Santhosh Kumar, T.G, [3] Benny Mathews Abraham

[1] Research Scholar, SOE, CUSAT, Kochi, India.
[2] HOD, Civil Engineering, Government Polytechnic College, Kalamassery, India
[3] Professor and Head, AISAT & Former Professor, CUSAT, Kochi, India
Email: [1]sekharlatha@gmail.com, [2]santhoshkumartg65@gmail.com, [3]bennymabraham@gmail.com

***Abstract*--- Grouting is normally undertaken to increase the strength of loose sandy soil formations. Determination of shear strength of these grouted sandy soils is very difficult and is a time-consuming process. But on the other hand, the determination of compressive strength is comparatively easy. In this paper, an attempt has been made to correlate the compressive strength and shear strength of grouted sandy soil. Compressive strength tests and direct shear tests were conducted on a series of samples prepared at different cement contents. The correlation developed between the Shear strength and the Compressive strength will be very much useful to the researchers and the field engineers to estimate the shear strength parameters of these hard soils from the Compressive strength.**

***Index Terms*— Compressive strength, Grouting, Sandy soils, Shear strength**

I. INTRODUCTION

For the construction works to be carried out in weak ground, the bearing capacity of the ground is to be improved. Grouting is an important ground improvement technique to enhance the engineering properties of loose sandy soil. Grouts in liquid form both in suspension or solution can permeate to the voids of the soil and blind the particle together. The reduction in voids and increase in bonding between particles of the soil leads the soil formation to form a lesser compressible and stronger stratum. These characteristics give the soil higher shear strength and the shear strength is the main engineering property of sandy soil.

Determination of shear strength of these grouted foundation beds through direct shear test is a time-consuming process and also require at least three to four specimens. Further, at higher cement contents, it is very difficult to conduct the tests till the failure of the specimens with the normal test set up. But determination of compressive strength in such cases is very easy and can be done very accurately. Hence, in this paper, an attempt has been made to correlate the compressive strength with the shear strength / shear strength parameters of the cement grouted soils, which will be very much beneficial to the geotechnical engineering community.

Injection of a cementing agent into sand produces a material with two components of strength- that due to the cement itself and that due to friction. The friction angle of cemented sand is similar to that of uncemented sands. Density, grain size distribution, grain shapes and grain arrangements all have a significant effect on the behavior of cemented sand [1]. The weakly cemented sand shows a brittle failure mode at low confining pressures with a transition to ductile failure at higher confining pressures. The shear strength parameters - cohesion and angle of internal friction increase when grouted with cement. The cement-water ratio of the grout acts as key parameter in the strength gain of grouted sandy soil [2].

The gradation and type of sand influenced the compressive properties of grouted sand. The compressive strength increased with the increase of the coefficient of uniformity of the sand (better gradation) and with the increase of the particle's angularity. Generally, the strength of the soil is estimated by Mohr- Coulomb's failure criterion. It is generally accepted that grouting effectively increases the compressive strength of the sand by filling the voids and by imparting a cohesion or adhesion factor, yet the grout contribution cannot simply be added to the sand strength [3]. The penetrability of soils can be characterized by its grain size distribution and the dispersivity of the cement - water suspension [4].

Unconfined compressive strength of micro fine slag cement grouts increases with increase in curing time from 7 to 60 days and decreases in water cement ratio from 2 to 0.8 [5]. The grain size of cohesionless soils has effect on its shear strength characteristics. As the particle size increase, the angle of shearing resistance will also increase at both constant density and constant relative density. However, the increase of angle of shearing resistance for constant density

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 6, Issue 11, November 2021

is insignificant compared to that in the case of constant relative density [6].

Cement grouting can be profitably used for strengthening foundation beds. The shear strength parameters, *c* & Ø, shows phenomenal increase when grouted with cement. The cement-water ratio of the grout act as a key parameter in the control of strength gain of sandy soils. Increasing amounts of cementation in granular soils induce increasing cohesion and tensile strength as well as increasing friction angle at low confining pressures [7]. The finer the sand that is being grouted, the larger is the increase in strength and decrease in permeability [8]. The presence of admixture also affects the viscosity of cement grouts. By adding 3% of sodium silicate with cement, the viscosity increased and free flow of grout solution was obtained [9].

The cohesion intercept (apparent cohesion) is a measure of the degree of grain-to-grain bonding. Therefore, it might correlate with the uniaxial compressive strength which is also a measure of grain-to-grain bonding magnitude [10].

II. MATERIALS AND METHODS

The success of grouting depends upon the properties of grouting materials, grouting medium and the grouting technique. The mechanical permeance, penetrability and strength are the specific mechanical properties which are important for the selection of grout for a specific job [11]. The effect of particle size of cement grout and grain size of the soil medium were evaluated by Akbulut and Saglamer . The groutability and several relationships were found out, but they observed only insignificant differences in limiting grain-size distribution curves of the grouted soils [12].

In the present study, sand was used as the grouting medium and cement was used as the grouting material.

The sand from Kalady (Periyar river) was procured, dried and sieved in to different fractions -coarse (2mm-4.75mm), medium(425µm-2mm) and fine (75µm-425µm) as per ASTM (D2487-10) and BIS (1498-1970). Medium sand was used for the present study.

53 grade Ordinary Portland cement conforming to IS: 12269 was used for the preparation of the cement grout. These were stored in air tight bins. The physical properties of cement were found out in accordance with IS:269, IS:4031 and IS: 12269. The increase in cement content and curing period will increase the shear strength of cement grouted loose sandy soil [13],[14]. The diffusion radius of the cement slurry in sand has good power function relationship with grouting pressure, water-cement ratio, permeability coefficient and grouting amount [15]. Cement grouting with 4% cement is more effective than 2% and 6% cement [16].

To place the grout within the pores of the granular medium, two methods were adopted. In the first method, the grout was deposited within the pores by mixing the sand with the required quantity of the grout material (10% cement at 10% water content) and soil specimens were prepared in the moulds at density of 14.5kN/m3 and kept for curing under humid conditions for 28 days. In the second method, previously prepared sand beds of density 14.5kN/m^3 were grouted with grouting materials (10% cement) using a grout pump similar to the procedure used in the field. Hand impregnated specimens were prepared in mortar cube moulds and grouted specimens were cut in to the size from the grouted mass by diamond cutter.

The shear strength can be determined in the laboratory by direct shear box test or triaxial test. In the present study, direct shear tests were conducted for the determination of shear strength parameters. Saturated specimens of size 60mm x60mmx25 mm were made and tested in the direct shear mould. The normal stresses corresponding to the shear stress at failure were plotted and the shear strength parameters *c* and Ø were obtained from the best fit straight line through those points.

70.6mm cube specimens were prepared and the compressive strength of these specimens were determined. To obtain a correlation between the shear strength and compressive strength of the grouted soils, results obtained from the direct shear test and compressive strength tests on soil specimens having same composition were plotted.

III. RESULTS AND DISCUSSIONS

As mentioned in the earlier section, the main purpose of conducting the compressive strength tests was to try for a correlation with the shear strength/shear strength parameters of the grouted soil because of the difficulty in conducting the shear tests on these grouted soils having high strength.

To obtain a correlation between the shear strength and compressive strength of the grouted soils, results obtained from the direct shear tests and compressive strength tests on soil specimens having same composition were plotted. Such a plot is given in Fig. 1 in which the compressive strength results are plotted against the corresponding cohesion intercept obtained from the results of the direct shear tests. The plot gives an excellent straight-line relationship with a high correlation coefficient of 0.95.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 6, Issue 11, November 2021

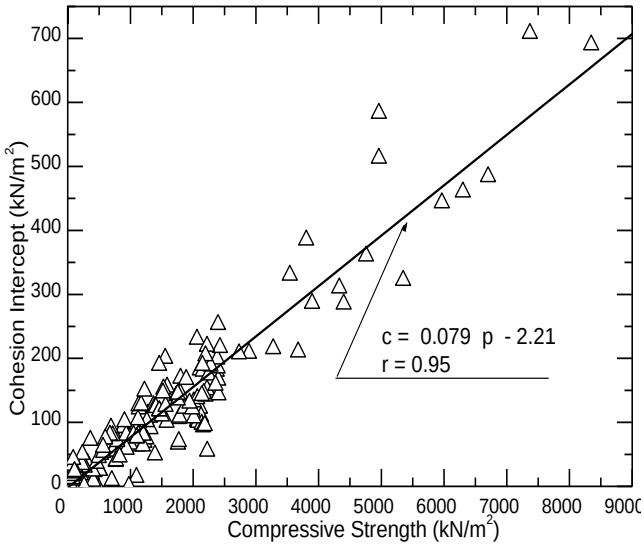

Fig. 1 Relation between compressive strength and cohesion intercept

The relationship can be expressed as;

$$c = 0.079\,p - 2.21$$

Where, c = cohesion intercept in kN/m^2

p = compressive strength in kN/m^2

Fig. 2 represents the relation between the measured and predicted cohesion intercept (from the above equation) values. It can be seen that most of the data points are located very close to the 45^0 line, as evident from a high correlation coefficient of 0.95. Similar result was obtained in the case of the plot between the measured and predicted compressive strength values shown in Fig 3.

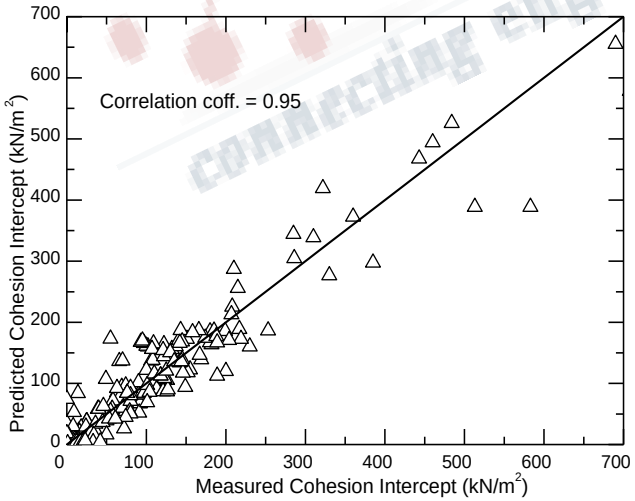

Fig. 2 Relation between measured cohesion intercept and predicted cohesion intercept

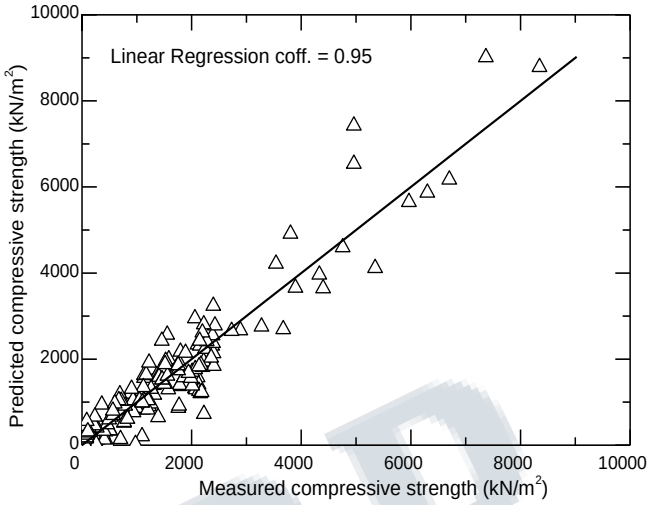

Fig 3 Relation between measured compressive strength and predicted compressive strength

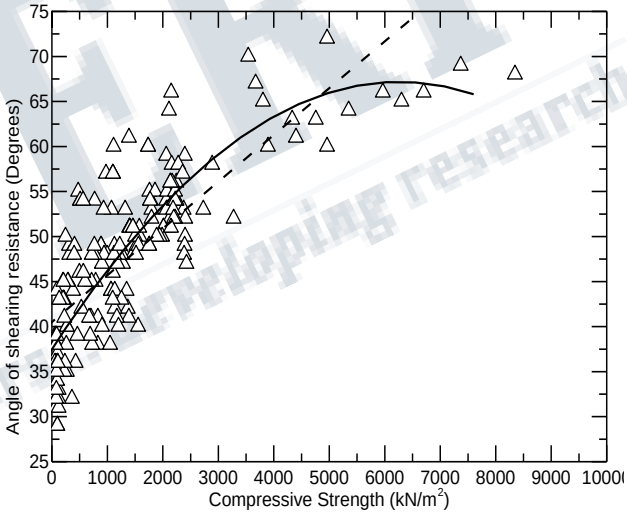

Fig. 4 Relation between compressive strength and angle of internal friction

Fig. 4 gives the relation between the compressive strength and the angle of shearing resistance (obtained from results of direct shear tests). The plot gives a non-linear relationship, the equation being,

$$Ø = 37.52 + 0.009\,p - 7.58\,E^{-7}p^2$$

and the correlation coefficient in this case is only 0.83. A linear relationship between Ø and p will yield an equation,

$$Ø = 0.005\,p - 40.50$$

with a low correlation coefficient of 0.78.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 6, Issue 11, November 2021

The main purpose of this attempt is to arrive at a reasonable relationship between the shear strength and the corresponding compressive strength of the grouted soils. Hence the values of shear strength computed from the results of direct shear tests were plotted with the compressive strength of the 199 samples and are shown in Fig 5. It can be seen that the plot gives an excellent linear relationship with a high correlation coefficient of 0.96.

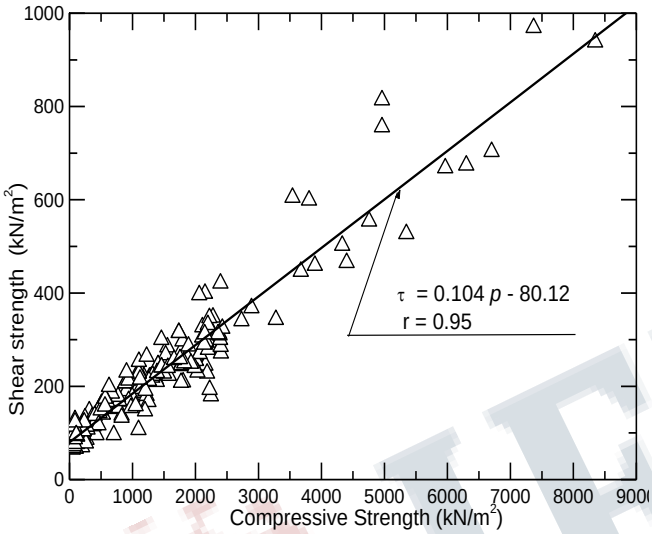

Fig 5 Relation between Compressive strength and Shear Strength of Grouted samples

The relationship between shear strength and compressive strength is given by

$$\tau = 0.104\, p - 80.12$$

Where, τ - shear strength in kN/ m^2

and p - compressive strength in kN/m^2

Fig. 6 shows the comparison between Predicted (computed from the above equation) and Measured Shear Strength of Grouted samples. It can be seen that most of the points are located close to the 45^0line, the correlation coefficient being 0.95.

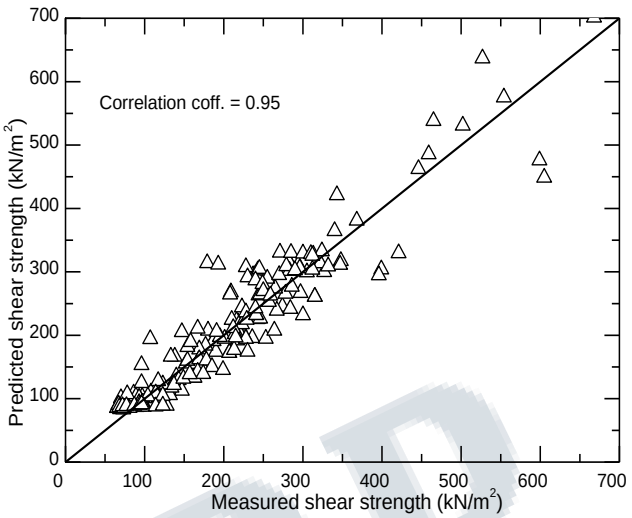

Fig. 6 Comparison between Measured and Predicted Shear Strength of Grouted samples

IV. CONCLUSIONS

The following conclusions are drawn from the results of compressive strength tests and shear strength tests conducted on sand samples prepared with cement as grouting material.

1) The relationship between cohesion intercept (c in kN/m^2) and compressive strength (p in kN/m^2) can be expressed as $c = 0.079\, p - 2.21$

2) The relationship between the compressive strength (p in kN/m^2) and the angle of shearing resistance (Ø in degree) yields a non-linear relationship $Ø = 37.52 + 0.009\, p - 7.58\, E^{-7} p^2$.

3) The relationship between the compressive strength (p in $kN/m^{2)}$ and the angle of shearing resistance (Ø in degree), considering a linear relationship gives the relation $Ø = 0.005\, p - 40.50$

4) The relationship between shear strength (τ in $kN/m^{2)}$ and compressive strength (p in $kN/m^{2)}$ can be expressed as $\tau = 0.104\, p - 80.12$

Hence a simple test such as compressive strength will be sufficient to predict the shear strength of the grouted soil. Thus, the relationship developed between the shear strength and the compressive strength can be advantageously used to estimate the strength of the grouted soil in the field.

REFERENCES

[1] G.W.Clough,N.Sitar,R.C.Bachus and N.S. Rad, "Cemented sands under static loading",Journal of Geotechnical Engineering Div., ASCE, Vol. 107,No GT6,799-817,1981.

[2] J.Glory, B.M.Abraham,B.T.Jose, and B. Paul, "Improvement of bearing capacity of sandy soils by

grouting". The New Millennium Conference IGC pp 14-16 ,2001.

[3] A.Ata and C.Vipulandan, "Factors affecting mechanical and creep properties of silicate grouted sand," J.Geotech.Geoenviron.Eng.125(10),868-876,1999.

[4] T.G.S.Kumar,B.M.Abraham,A.Sridharan and B.T.Jose, "Bearing capacity improvement of loose sandy foundation soils through grouting", International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622, Vol. 1 (3), pp 1026-1033(2011a).

[5] J.M.Sinroja,N.H.Joshi and A.V.Shroff, "Ground improvement technique using microfine slag cement grouts" IGC 2006,14-16 December 2006,Chennai,p 661-664,2006.

[6] B.C.Chattopadhya and S.Saha "Effect of grain size of cohesion less soil on its shear strength characteristics", Sym.Engrg.Behaviour of course grain soil,boulders and rocks,Geomech-81,Vol 2,291-297,1981.

[7] P.V.Lade and D.D.Overton, "Cementation effects in frictional materials", J.Geotech.Engrg., ASCE, 115(10),1373-1387,1989.

[8] K.Venkatraman,P. Dayakar and K.V.B. Raju, "Improvement of sandy soil by low pressure grouting using cement grout", Journal of Chemical and Pharmaceutical Sciences, Vol.9 Issue 2,2016.

[9] K.Venkatraman,P.Dayakar and Venkitakrishnaiah, "Study of permeation grouting in coarse grain soil with cement chemical grout (Sodium Silicates)", Intranational Journal for pure and Applied Mathematics.Vol.119 No 12 ,9289-9300,2018.

[10] M.N.J.Al-Awad, "Simple correlation to evaluate Mohr-Coulomb failure criterion using uniaxial compressive strength",j.King Saud Uni.,Vol.14 Eng.Sci.(1),pp 137-145,Riyad,2002.

[11] A.V.Shroff, and D.L.Shah, "Grouting technology in tunnelling and dam construction", Oxford and IBH publishing Company, New Delhi,1992.

[12] S.Akbulut and A.Saglamer, "Estimating the groutability of granular soils: a new approach", Jl. Tunnelling and underground space technology, Elsevier Science Ltd.17 pp 371-380 ,2002.

[13] B.M.Abraham, T.G.S.Kumar,A. Sridharan and B.T. Jose, "Strength improvement of loose sandy soils through cement grouting" Indian Geotechnical journal,44(3) 234-240,2014.

[14] T.G.S.Kumar,B.M. Abraham,A.Sridharan,and B.T.Jose,"Determination of cement content of grouted sandy soils", International Journal of Earth Sciences and Engineering, ISSN 0974-5904, Vol. 04, No. 06 SPL pp 169-172,2011b.

[15] J.Yang,Y. Cheng and W.Chen "Experimental Study on Diffusion Law of Post-Grouting Slurry in Sandy Soil", Advances in Civil Engineering, Article ID 3493942,ttps://doi.org/10.1155/2019/3493942, 2019.

[16] G.S.Kumar,M.K.Sumanth and M.Samuel " A review paper on stabilization of sandy soil by using cement grouting technique, Journal of Critical Reviews, ISSN-2394-5125, Vol 7, Issue 14,902-908,2020.