Role of Bentonite in Improving the Efficiency of Cement Grouting in Coarse Sand

T. G. Santhoshkumar[1], B. M. Abraham[2], A. Sridharan[3], and B. T. Jose[4]
[1]*Principal, JBCMET, JB Campus, Kochi-683556,*
[2]*Prof. of Civil Engineering, CUSAT Kochi – 22,*
[3]*Sr. Scientist INSA & Former Prof. of Civil Engg, IISc Bangalore*
[4]*Emeritus Professor, Cochin University of Sc&Tech.Kochi –22,*
[1]*E-mail*: santhoshkumartg65@gmail.com
[2]*E-mail*: bennymabraham@gmail.com
[3]*E-mail*: asridhran@yahoo.com
[4]*E-mail*: babutjose@gmail.com

ABSTRACT: Grouting generally is used to fill the voids in the ground (fissures and porous structures) with the aim of increasing resistance against deformation, to increase cohesion, shear strength and uniaxial compressive strength or finally (even more frequently) to reduce conductivity and interconnected porosity in an aquifer. In the case of loose sandy soils, the very low bearing capacity of the foundation bed causes shear failure and excessive settlements. Cement grouting technique is one of the possible solutions to the foundation problems for improving the properties of soil at shallow depths. Various authors have recommended a number of additives that can be used in cement grouting. Admixtures like antibleeder increases viscosity of the cement grouts, at the same time reducing sedimentation to a considerable extent. Bentonite can be considered as a cheap and effective admixture for cement grouts with regard to stability. This paper presents the results of experimental studies conducted in the laboratory, in this direction. It was found that addition of small percentages of bentonite and detergent increases the lateral flow of cement grout in coarse sand. The results clearly indicate that addition of even a small amount of bentonite to the cement grout increases the grouting efficiency in coarse sand.

KEYWORDS: Cement grout, Loose sand, Bentonite, Grouting efficiency.

1. INTRODUCTION

Grouting is commonly used in geotechnical engineering either to reduce the permeability or to improve the mechanical properties of soil and rock. Success in a given grouting operation requires that the desired improvements in the properties of the formation are attained. Grouts are generally categorized as suspension or particulate grouts, which are prepared with ordinary Portland or other cements, clays or cement- clay mixtures, and fine sand in some cases; and solution or chemical grouts which include sodium silicate, acrylamide, acrylates, lignosulfonates, phenoplast and aminoplast as well as other materials that have no particles in suspension (Zebovitz et al. 1989).

The concept of a limiting effect or a boundary effect of grouting is of great value in both theoretical research and the practical application of grouted sand. The selection of grouting for a specific job is mainly affected by the amount of improvement in strength and/ or stiffness that can be achieved and the limitations for this improvement with increased depth or confinement (Ata and Vipulanandan 1999). Particle size distributions are used in characterizing the soil and to determine the groutability of soils (Vipulanandan and Orgurel, 2009).

The safe construction and operation of many structures frequently require improvement of the mechanical properties and behavior of soils by permeation grouting using either suspensions or chemical solutions. The former has lower cost and are harmless to the environment but cannot be injected into soils with gradations finer than coarse sands. The latter can be injected in fine sand or coarse silts but are more expensive and, some of them pose a health and environmental hazard (Karol 1982). Grouting has a minimal effect on the angle of internal friction of sands or yields an increase of up to 4.5º. There are strong indications that pulverized, cementitious fly ash with appropriate additives can be effectively utilized for permeation grouting of coarse sands (Markou and Atmatzidis, 2002).

The permeability and strength of grouted sand is strongly influenced by the method of grouting because different mechanism governs the deposition and packing of cement particles within the pore structure. During the injection process, preferential flow paths allow the migration of cement particles into the soil, and micro-structural packing undoubtedly varies within the pores of the grouted sand, which is in contrast to the more uniform distribution of cement particles in hand-mixed specimens (Schwarz and Krizek, 1994).

Among the various properties of grout suspensions, fluidity and stability are of prime importance (Nonveiller, 1989). Fluidity is an inverse function of initial viscosity, bearing an approximately linear relationship with viscosity. In the case of coarse grout, fluidity is affected principally by dynamic interparticle forces of attraction and repulsion and/or by dilatancy of the moving suspended particles. A coarse grout can only be pumped easily when it contains sufficient fluid to prevent dilation of the particle matrix during shear while injecting. A reasonable percentage of fines are also desirable to increase the specific surface area of the grout particles and thereby prevent the separation of liquid and solid phase (Shroff and Shah, 1992).

In order to take into account the effect of cement grout in the pores of the granular material, adhesive forces were added at each contact point to the mechanical forces determined from the external stresses applied on the granular assembly, in the experiments performed by Dano et al. (2004). The magnitude of those adhesive forces depends on the nature of the grout and on the concentration of the grout in cement particles. According to them, this adhesive force can be expressed as a function of cement content.

Introduction 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. Weakly cemented sand shows a brittle failure mode at low confining pressures with a transition to ductile failure at higher confining pressures. For brittle type cementing agents, the cementation bonds are broken at very low strains while the friction component is mobilized at large strains. Density, grain size distribution, grain shapes and grain arrangements all have a significant effect on the behavior of cemented sand (Clough et al. 1981).

The strength of grouted sand was influenced by particle size and distribution and fines content of soil while the permeability of grouted sands did not vary with soil properties (Ozgurel and Vipulanandan, 2005). Cement grouting is an effective technique to improve the bearing capacity and reducing the settlement of loose sandy soils (Kumar et al. 2011a).

The addition of accelerators caused a decrease in viscosity upto an optimum dosage beyond which it increased. This point is very useful in the field of grouting because the addition of bentonite makes a cement grout more stable and at the same time the reduction in viscosity makes it possible to inject more material into the formation voids. Retarders are found to be more effective in reducing the viscosity. Antibleeders also caused a reduction in viscosity upto an optimum dosage as in the case of accelerator beyond which it increased (Shroff and Shah, 1992; Kumar et al. 2009). Expander caused considerable increase in viscosity of cement-bentonite mixes. The utility of bentonite as an excellent antibleeder of cement grout has been previously brought out (Lovely et al. 1998). This paper discusses the results of studies carried out on the effectiveness of bentonite in improving the lateral flow of cement grouts in a coarse sand.

2. MATERIALS AND METHODS

River sand procured from Kalady, which is a branch of the Periyar River - was dried and sieved into different fractions. River sand of two grades - medium (425 µm- 2 mm) and coarse (2mm- 4.75mm) fractions as per ASTM (D2487-10) and BIS (1498 -1970) classifications were used in the present study. The grain size distribution curves and the properties of these fractions of sand are shown in Figure 1 and Table 1 respectively.

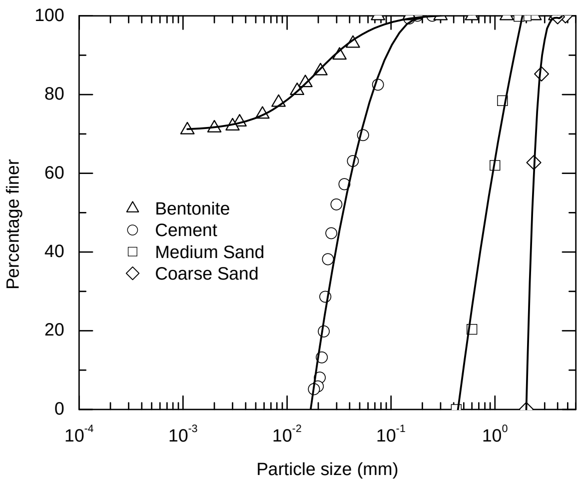

Figure 1 Grain size distribution Curves

Table 1 Properties of the sand used

Sl. No.	Soil	Unit wt. (in loose state)	Unit wt. (in dense state)	Angle of internal friction (degrees)		Permeability (m/sec) in loose state
				Loose state	Dense state	
1	Medium sand	13.1	16.2	27	39	1.86×10^{-4}
2	Coarse sand	14.0	16.2	34	39	2.69×10^{-4}

Forty three grade ordinary Portland cement conforming to BIS 8112 – 1989 was used for the preparation of cement grouts. The physical properties of cement are presented in Table 2 and its grain size distribution curve is shown in Figure 1.

Table 2 Properties of the cement used

Sl.No.	Property	Characteristic value
1	Standard Consistency	28%
2	Initial setting time	131 minutes
3	Final setting time	287 minutes
4	Blaine's Sp. Surface	298500 mm^2/g
5	Sp. Gravity	3.14
6	Compressive strength (i)7days (ii) 28days	 35.1 N/mm^2 44.0 N/mm^2

Admixtures are used in cement grouts to serve as accelerator, retarder, and lubricant or to increase the strength of the grout. The main admixture used in this study is commercially available highly expansive bentonite. The properties of the bentonite are given in Table 3 and the grain size distribution curve is shown in Figure 1.

Table 3 Properties of bentonite

Sl. No.	Property	Characteristic value
1	Specific gravity	2.8
2	Liquid limit (%)	410
3	Plastic limit (%)	45
4	Plasticity index (%)	365
5	Shrinkage limit (%)	1.34
6	Volume change (%)	97.5
7	Linear shrinkage (%)	49.61
8	Activity	5.03
9	Free swell index (cc/g)	17.5
10	Cation exchange capacity (meq/ 100g)	60.8
11	pH	7.4
12	Surface area (m^2/ g)	87.5
13	Conductivity (µs /cm^2)	10800
14	Organic matter (%)	1.48

Predetermined quantity of cement with or without admixtures was taken and thoroughly mixed with a definite amount of water. The slurry was thoroughly mixed for 10 minutes at 3000 rpm using a standard stirrer. The grouting set up consists of a grout chamber with agitator, air compressor, grouting nozzle and a regulating valve.

The grouting nozzle consists of an inner pipe of thin stainless steel tube of 10 mm diameter passing through an outer pipe which is made of PVC having inner diameter 20 mm. The lower end is provided with a stainless steel nozzle with 24 numbers of 4 mm diameter holes and the end tapered for easy penetration of the nozzle, through which the grout flows to the sand bed.

The grouting nozzle was kept in position (at 5 cm above bottom level of tank) and the sand bed was prepared in a tank of size 45 cm x 45 cm x 60 cm / 1 m x 1 m x 0.60 m at the loosest state (unit weight of 14 kN/m^3 and an initial void ratio of 0.98). Sand was filled in the tank by pouring through a funnel maintaining steadily the height of fall as 1 metre. Then the slurry (grout) was poured into the grout chamber. In order to reduce the possibility of settling of the grout in the grout chamber, an agitator was provided inside the grout chamber. Grout was pumped under a constant pressure of 500 kPa into the prepared sand bed. The grouting set up is shown in Figure 2. The grouting nozzle was raised during the grouting operation at regular intervals in order to get uniform flow of grout over the entire thickness of the sand bed. Once the grouting was over, the grouted sample was kept under moist conditions for curing.

Figure 2 Grouting set up

3. RESULTS AND DISCUSSIONS

3.1 Estimation of cross sectional area of intact grouted mass

A preliminary idea about the grouting efficiency can be obtained from the cross section area of the actual grouted medium at different depths. For this purpose, once the grouting is over and after allowing sufficient time for curing (28 days), the side walls of the tanks were removed so that the dimensions of various cross sections of the intact grouted mass at different depths can be taken. Figure 3 shows the three dimensional view of coarse sand grouted with 2% cement. Lateral measurements were taken from the centre of the grout hole to the corners and centres of the side walls and additional measurements were also taken in case of uneven shapes. For this purpose, a cage made of steel bars with the same lateral dimensions as that of the tank was fabricated. With this cage encompassing the grouted mass, facilitated easy measurements of the cross section dimensions. All the measurements were taken at 10 cm intervals from the top of the grouted bed and recorded. With the help of these measurements, cross sections were drawn and the area was calculated at different intervals.

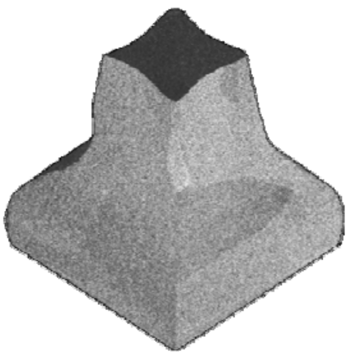

Figure 3 Three dimensional view of coarse sand grouted with 2% cement

The cross sectional areas of coarse sand grouted with 2, 4, and 6 % cement at different depths are shown in Figure 4. It can be seen that the sample grouted with 4 % cement indicate a slight increase in effective grouted cross sectional area compared with 2 % and 6 % cement.

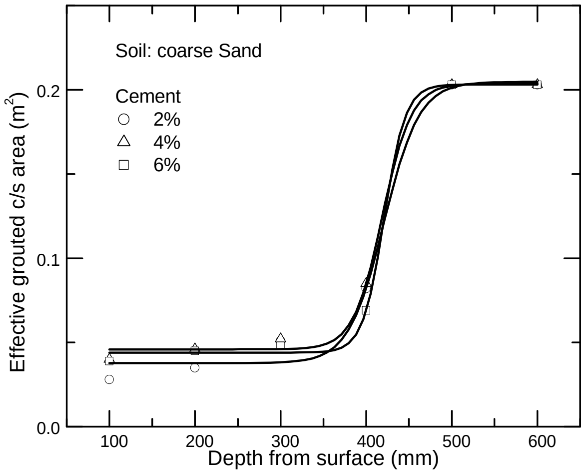

Figure 4 Comparison of cross section areas of grouted samples at different depths

A comparison of the effective grouted cross sectional area of medium and coarse sand is presented in Figure 5. The effective grouted cross sectional area is more upto a depth of 400 mm for medium sand, but it is overtaken by coarse sand at 500 mm depth. Eventhough the effective cross sectional area is much more at shallow depths in medium sand, there is not much difference in total effective cross sectional area.

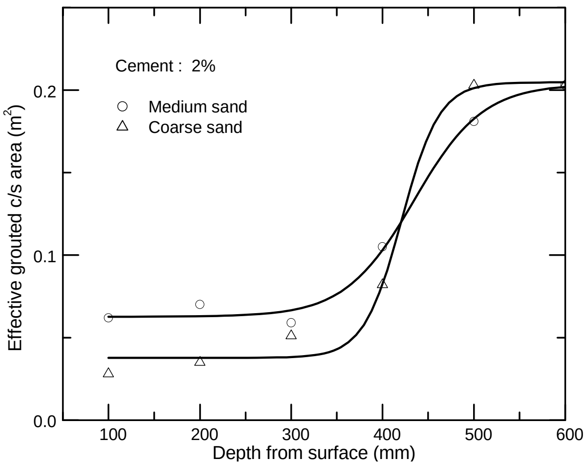

Figure 5 Comparison of cross section areas of grouted medium & coarse sand

Figure 6 shows the effective cross sectional area of intact grouted mass in case of medium and coarse sand, grouted with 4 % cement. It can be seen that cross sectional area of medium sand is much more compared to that of coarse sand.

The effective cross sectional area of medium and coarse sand grouted with 6 % cement is shown in Figure 7. Up to a depth of 400 mm, the medium sand shows significant increase in c/s area than coarse sand. Eventhough the same amount of cement is used in both cases, the cross sectional area and thereby the volume of the intact grouted mass is much more in case of medium sand compared to the coarse sand.

It can be seen from Figures 5, 6 and 7 that cement grouting is more effective in medium sand compared to coarse sand. Further, 4 % cement grout yields better results in comparison with 2 and 6 % cement grouts.

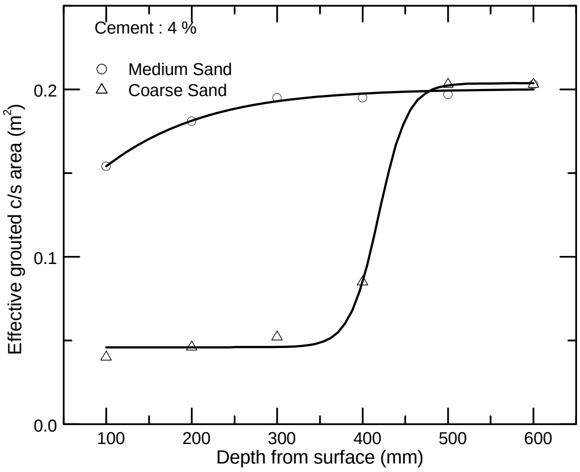

Figure 6 Comparison of cross section areas of grouted medium & coarse sand

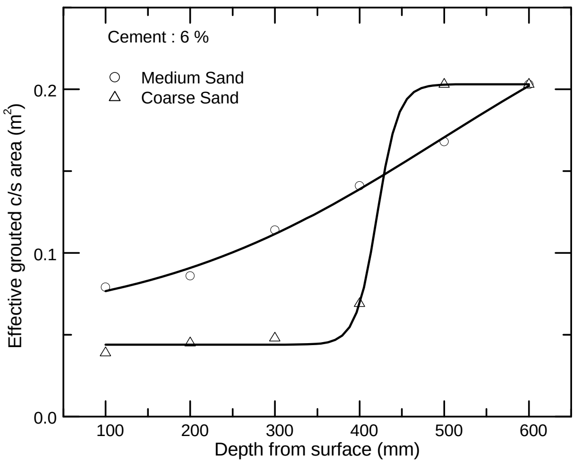

Figure 7 Comparison of cross section areas of grouted medium & coarse sand

The earlier results show that the lateral flow of the grout is very poor in the case of 6% cement compared to 4 % cement. This may be due to the low stability and viscosity of the 6% cement grout. The effectiveness of antibleeders and fluidisers in increasing the stability and viscosity of cement grouts has already been established. Hence studies were made in this direction to verify whether the antibleeders and fluidiser could enhance the lateral flow of the cement grout.

The addition of bentonite to cement yielded a suspension which has interesting synergistic properties and has been widely used as a permeation grout. Depending on the amounts of cement, bentonite and water, grouts will have different properties. Deere (1982) observed a striking influence on viscosity of cement grout by addition of a small percentage of bentonite. He has also observed that there is a significant increase in Marsh funnel viscosity. Small amounts of bentonite appear to be preferable and sufficient to reduce sedimentation and bleeding, but not so great as to impair significantly the pumpability and penetrability.

The admixtures used in the present study to make the grout more stable include bentonite (antibleeder) and detergent (fluidiser). These admixtures can influence the efficiency of the grout, when grouting is done in coarse sand. Figures 8 and 9 clearly bring this out. Figure 8 gives the increase in the effective grouted cross section area when a combination of different percentages of bentonite and 0.05 % detergent were used along with the cement grout. It can be seen that the best results are obtained by the combination of 15 % bentonite and 0.05 % detergent along with the 6 % cement grout. Figure 9, which shows the increase in grouted volume on using these admixtures along with 6 % cement, in grouting coarse sand, underlines the above statement. Some photographs typical of these grouted samples are shown in Figure 10.

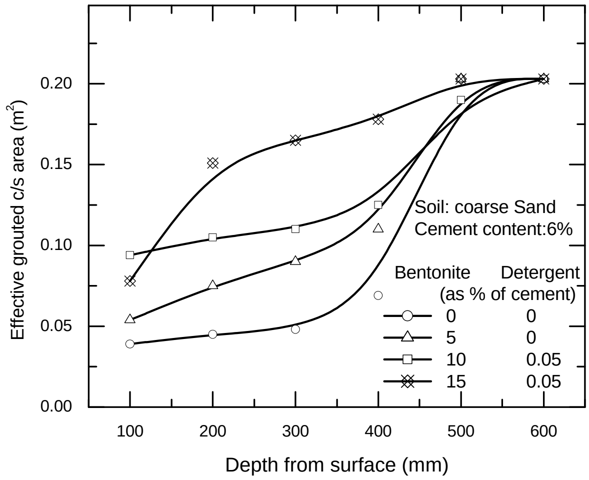

Figure 8 Effect of antibleeder & fluidiser on the flow of grout

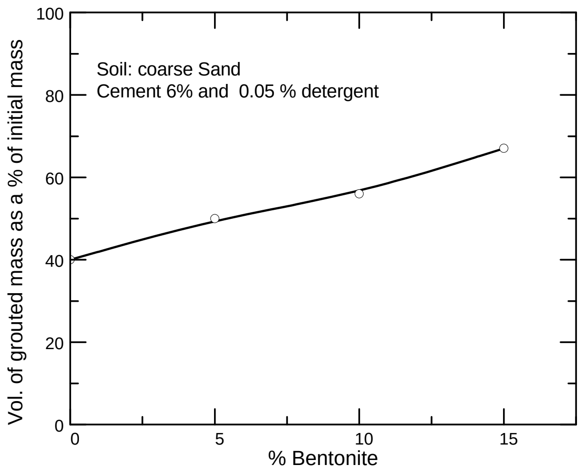

Figure 9 Influence of % bentonite on the grouted volume

(i) (ii)

Figure 10 Typical photographs of grouted samples

3.2 Determination of cement content

The efficiency of grouting mainly depends upon the penetration of cement grout through the pores of sand. Therefore cement content determination is very much necessary to assess the amount of lateral flow of the grout into the soil mass (Kumar et al. 2011). The test method covers the determination of cement content by chemical analysis of hardened soil-cement mixtures. ASTM standards designation D806-00, 'Standard test method for cement content of hardened soil- cement mixtures' was used for this purpose.

The results of cement contents at different depths and at different radial distances, determined when coarse sand is grouted with different grouts i.e., 2, 4 and 6 % cement are presented in Figures 11, 12 and 13 respectively. Figure 11 gives a clear indication that 2 % cement is not at all effective; whereas the flow of grout is better in the case of 4 % and 6 % cement grouts (Figures 12 and 13) even without the use of any admixtures. A comparison of the effect of these three cement contents at a particular depth i.e. 300 mm is presented in Figure 14. It can be seen that 4 % cement is more effective in grouting the coarse sand.

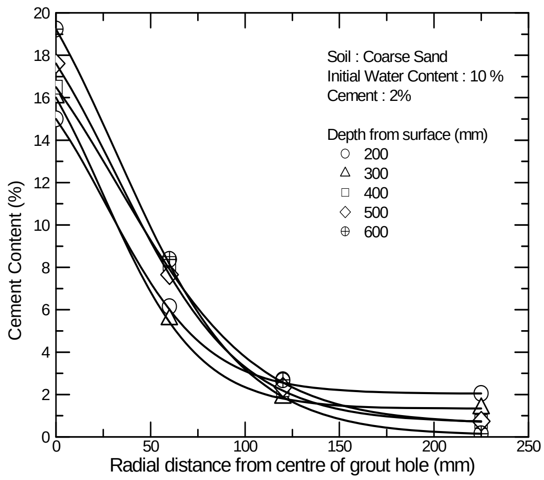

Figure 11 Variation of cement content with travel distance of the grout

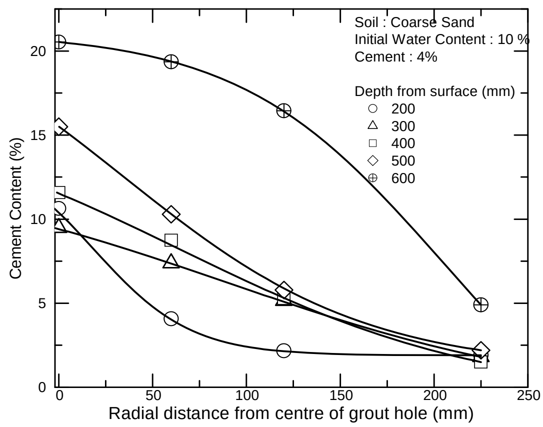

Figure 12 Variation of cement content with travel distance of the grout

Figure 9 and its discussion clearly brings out the effect of admixtures in improving the lateral flow of the grout in coarse sand. Since the combination of 15 % bentonite and 0.05 % detergent was found to be the most effective, cement contents were determined by taking samples at different depths and at different radial distance from the coarse sand grouted with 6 % cement along with these admixtures. The results presented in Figure 15 clearly show the improvement in the efficiency of the grout in reaching farthest places. The much higher cement content (~ 4 %) at these points is an indication of a more or less uniform and effective lateral flow of this grout in coarse sand.

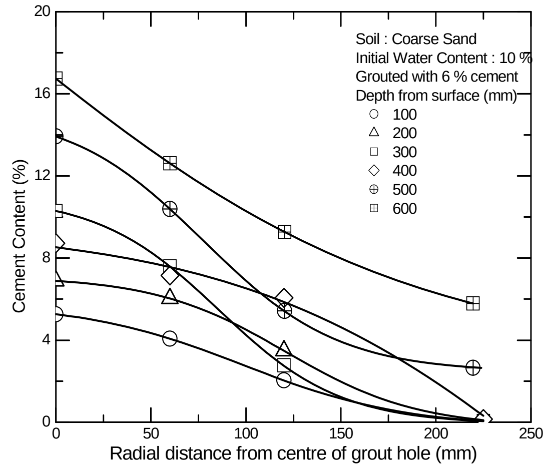

Figure 13 Variation of cement content with travel distance of the grout

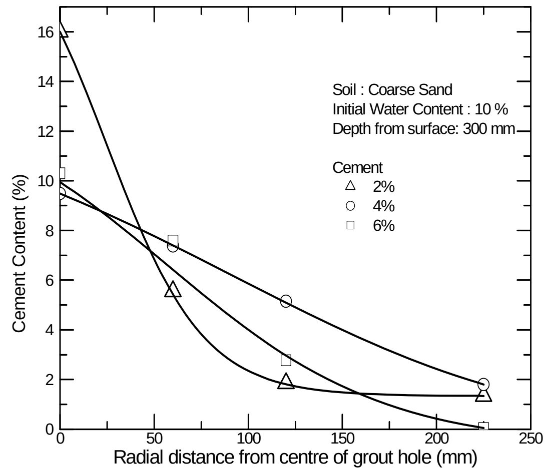

Figure 14 Variation of cement content with travel distance of the grout

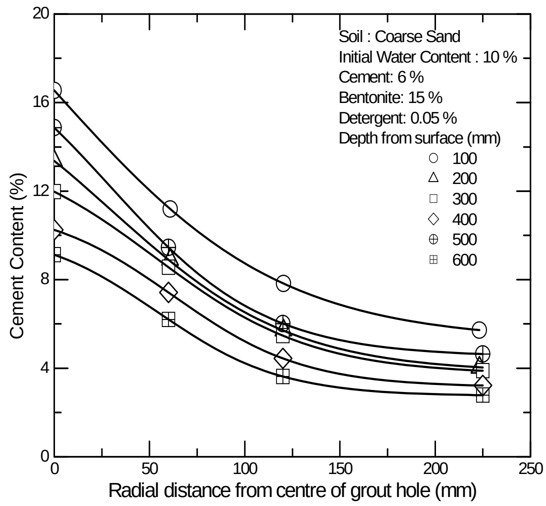

Figure 15 Variation of cement content with travel distance of the grout

3.3 Load - settlement behavior of the grouted mass

The results and discussions in the previous sections show that the grouting efficiency can be assessed reasonably well from the effective grouted cross section area and also by the determination of cement contents at different radial distances. But it was felt that a more realistic picture could be obtained if load tests were conducted on these grouted sand beds.

Thus, the efficiency of the grouting process was also verified through load tests conducted on ungrouted and grouted sand beds. Initial tests for assessment of the improvement in load carrying capacity through densification were conducted by filling the sand at the loosest and densest densities in tanks. For estimating the load carrying capacity of grouted beds, the grouting operations were done in large tanks of size 1mx1mx0.6m. The sand was filled in the tank at the loosest state (unit weight -14.0 kN/m^3) in case of coarse sand. Grout was injected into the sand bed using different percentages of cement with or without admixtures. The top 100 mm of the sand bed was removed and the grouted bed was kept in humid conditions for curing for a period of 28 days. The cured sand bed was loaded through a plate 20 cm x 20 cm with the help of a hydraulic jack. The loading setup is shown in Figure 16.

Figure 16 Loading set up

The load settlement curves of the coarse sand at the loosest state grouted with 2, 4 and 6 % cement, is shown in Figure 17. It can be seen from the plots that the ultimate stress at the loosest state (unit weight 14 kN/m^3) is only 16.9 kN/m^2. Maximum compaction yielded a unit weight of 16.2 kN/m^3 and the corresponding ultimate stress was 301 kN/m^2. It is interesting to note that for the grout with 2 % cement at loosest density, the ultimate stress was only 220 kN/m^2 against 301 kN/m^2 for the ungrouted sand at the densest state. The ultimate loads for 4 % and 6 % cement grouted coarse sand were 989 kN/m^2 and 1023 kN/m^2 respectively. i.e., 4 % and 6 % cement grout yielded almost the same strength, which is around 60 times that of the ungrouted coarse sand at the loosest state.

A comparison in the strength behaviour between medium sand and coarse sand when grouted with 4% cement is given in Figure 18. The strength of the grouted coarse sand is much higher when the deformations are small and it exhibits a brittle type failure. But the load carrying capacity of the grouted medium sand exceeds that of the coarse sand at higher deformations.

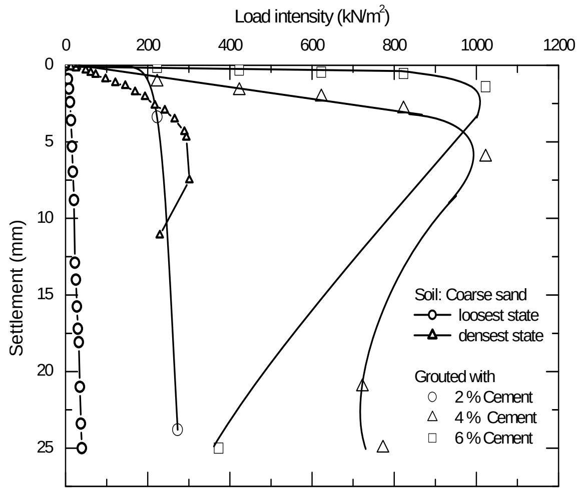

Figure 17 Load settlement curves for grouted sand bed (coarse sand)

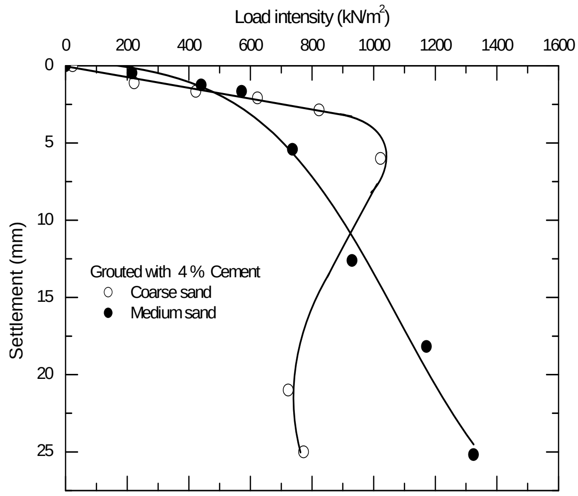

Figure 18 Load settlement curves of sand grouted with 4% cement

Figure 19 shows the increase in strength of the medium and coarse sand with the increase in cement content in the grout. In the case of grouted medium sand, the increase in strength is at a steady rate, whereas for grouted coarse sand, the rate of increase in strength is quite high as the cement content is increased from 2 to 4 %. Further, in the case of coarse sand, a minimum cement content is required for the grouting to be effective. This may be due to the increased pore space available in the case of coarse sand compared to medium sand.

The tremendous improvement in the lateral flow of the grout when admixtures are used in the case of coarse sand grouted with 6 % cement – 15 % bentonite and 0.05 % detergent, and the results are presented in Figure 20. In this case, in addition to making the sand bed more ductile, the admixtures help to increase the load carrying capacity (twice the strength compared to the sand bed grouted without admixtures). This can be attributed to the increased lateral flow of the grout when admixtures are used along with cement in grouting coarse sand beds.

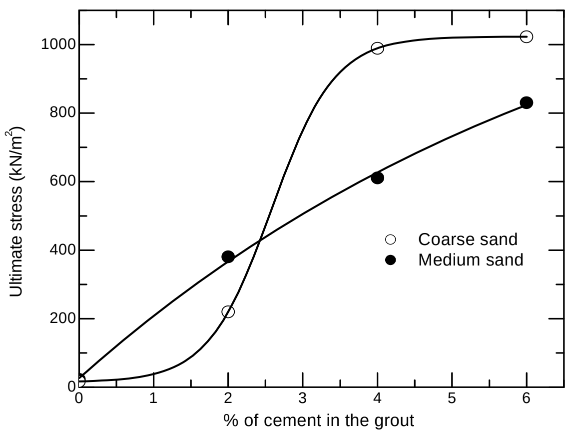

Figure 19 Variation of ultimate stress of grouted sand with % of cement in the grout

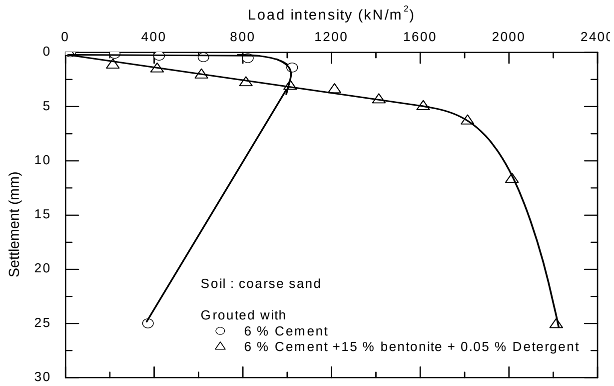

Figure 20 Effect of admixtures on the load settlement behaviour (coarse sand)

4. CONCLUSIONS

This investigation examines the scope of improving granular soils of low strength with cement grouting. Results of systematic studies carried out on strength of cement grouted coarse sand from the view point of bearing capacity are scanty. Based on the experimental investigations and test results, the following conclusions are made.

Grouting with 4% cement gave the maximum areas of cross section of the grouted intact mass in the case of coarse sand, which is less than that of medium sand. The admixtures play an important role in increasing the efficiency of grouting, in the case of coarse sand. Fifteen percent of bentonite and 0.05 % of detergent (by weight of cement) prove to be a very effective admixture when used along with 6 % cement grout in coarse sand.

Four percent cement grout is more effective in medium sand and coarse sand when compared to 2 % and 6 %, while considering the travel distance of the grout and the cement contents at various points in the grouted mass. Use of admixtures enhances the lateral flow in the case of both medium & coarse sand. A combination of 15 % bentonite and 0.05 % detergent along with 6 % cement grout is found to be very effective in the case of coarse sand.

Comparison of the strength behaviour of medium and coarse sand when grouted with 4% cement shows that the strength of the grouted coarse sand is much higher and it exhibits a brittle type failure. For coarse sand a minimum cement content is required for the grouting to be effective. This may be due to the increased pore space available in the case of coarse sand when compared to medium sand. Eventhough there is a slight reduction (around 20%) in strength in medium sand, the admixtures make the grouted sand bed to be more ductile, thus eliminating the chances of a sudden failure of foundations.

In the case of coarse sand, the admixtures help to increase the load carrying capacity (twice the strength compared to the sand bed grouted without admixtures). This can be attributed to the increased lateral flow of the grout when admixtures are used along with cement in grouting coarse sand beds.

5. REFERENCES

Arenzana, L., Krizek. R. J. and Pepper, S. F. (1989) "Injection of dilute micro fine cement suspensions fine sands", 12thInternational Conference on Soil Mechanics and Foundation Engineering, Brazil, 18/2, pp131-1334.

ASTM D2487–11 (2011) Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

ASTM Standards D: 806-00 (2000) Standard test method for cement content of hardened soil- cement mixtures.

Ata, A. and Vipulanandan, C. (1998) "Cohesive and adhesive properties of silicate grout on grouted-sand behavior", Journal Geotechnical and Geoenvironmental Engineering, ASCE, 124(1), pp38–44.

Ata. A, and Vipulanandan, C. (1999) "Factors affecting mechanical and creep properties of silicate-grouted sand", Journal Geotechnical and Geoenvironmental Engineering, 125 (10), pp868–876.

BIS 1498 : (1970) Classification and identification of soils for general engineering purposes.

BIS 8112: (1989) 43 Grade ordinary Portland cement – specification.

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

Consoli, C. N., Prietto, P. D. M. and Ulbrich, L. A. (1998) "Influence of fiber and cement addition on behavior of sandy soil", Journal Geotechnical and Geoenvironmental Engineering, ASCE, 124(12), pp1211-1214.

Dano, C., Hicher, P. Y. and Tailliez, S. (2004) "Engineering properties of grouted sands", Journal Geotechnical and Geoenvironmental Engineering, ASCE, 130(3), pp328-338.

De Paoli, B., Bosco, B., Granata, R. and Bruce, D. A. (1992) "Fundamental observations on cement based grouts (1) Traditional materials", Proceedings of Conference on Grouting in Geotechnical Engineering, New Orleans, ASCE, New York, pp474- 485.

Deere, D.U. (1982) "Cement – Bentonite grouting for dams. Proceedings of Conference on Grouting in Geotechnical Engineering", New Orleans, ASCE, New York, pp279- 300.

Karol, R. H. (1982) "Seepage control with chemical grouts", Proceedings of the Conference on Grouting in Geotechnical Engineering, New Orleans, ASCE, New York.

Kumar, T. G. S., Abraham, B. M., Jose, B. T. and Sridharan. A. (2009) "Influence of Admixtures on Strength of Cement Grouted Soils", Indian Geotechnical conference (IGC 2009), Guntur, pp435-438.

Kumar, T. G. S., Abraham, B. M., Sridharan, A. and Jose, B. T. (2011) "Determination of Cement Content of Grouted Sandy Soils", International Journal of Earth Sciences and Engineering, ISSN 0974-5904, Volume 04, No 06 SPL, pp 169-172.

Kumar, T. G. S., Abraham, B. M., Sridharan, A. and Jose, B. T. (2011a) Bearing Capacity Improvement of Loose Sandy Foundation Soils through Grouting. International Journal of Engineering Research and Applications, ISSN: 2248-9622 Vol. 1, Issue 3, pp1026-1033.

Lovely, K. M., Jose, B. T., Sridharan, A. and Abraham, B. M. (1998) "Effect of admixtures on the properties of cement-bentonite grouts", 2nd Internal Conference on Ground Improvement Techniques, Singapore, pp319-326.

Markou, I. N. and Atmatzidis, D. K. (2002) "Properties and performance of a pulverized fly ash grout", Journal Geotechnical and Geoenvironmental Engineering, Vol. 128, No. 8, pp682-691.

Nonveiller, E. (1989) "Grouting- theory and practice", Elsevier publishing company, New YorK.

Ozgurel, H. G. and Vipulanandan, C. (2005) "Effect of grain size and distribution on permeability and mechanical behavior of acrylamide grouted sand", Journal Geotechnical and Geoenvironmental Engineering, ASCE, 131(12), pp1457–1465.

Schwarz, L. G. and Krizek, R. J. (1994) "Effect of preparation technique on permeability and strength of cement-grouted sand", Geotechnical Testing Journal, 17(4), pp434–443.

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

Vipulanandan, C. and Orgurel, H. G. (2009) "Simplified relationships for particle size diatribution and permeation groutability limits for soils", Journal Geotechnical and Geoenvironmental Engineering, ASCE.

Zebovitz, S., Krizek, R. J. and Atmatzidis, D. K. (1989) "Injection of Fine Sands with Very Fine Cement Grout", Journal of Geotechnical Engineering, 115(12), pp1717-1733.