Investigation the performance and limitations of fracture grouting in sand

Investigation de la performance et de limites d'injection de claquages dans le sol sablonneux

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ABSTRACT

Grouting was increasingly used as a remedial measure for handling the undesirable behaviour of problematic soils. The grouting acts as a soil improvement technique. Developing of new urban areas and utilizing several underground structures leads to introduce grouting techniques as a remedial tool. Although grouting has many different applications, but until now there is no agreement on specific guidelines for using it. In the present work; Fracture grouting process has been investigated in a laboratory model test. Twenty six tests had been performed in a sand mould of internal dimensions 1.40 m width, 1.60 m breadth and 0.70 m height. Various parameters were tested. Results showed that grouting efficiency was highly affected by soil density and as well as grout Rheology.

RÉSUMÉ

À côté de l'utilisation des moyens traditionnels pour améliorer les caractéristiques du sol, on a commencé à utiliser la technologie de l'injection du sol comme moyen d'améliorer le sol qui q des problèmes. La recherche a essayé de découvrir les facteurs les plus importants qui influencent l'injection par l'usage des claquages et cela à travers un programme d'expériences fait sur un modèle de dimensions 1.60 x 1.40 x 0.70 mètres.On q effectué 26 tests afin d'explorer l'effet des différents facteurs sur l'injection on a utilisé l'intensité du sol ainsi que de divers mélanges d'injection qu'on a testé. On q dégagé des résultats l'absence des claquages dans le sol sablonneux mais on a trouvé apparaitre des formes irrégulières de masses d'injection. L'analyse des résultats des tests a révélé les facteurs les plus importants qui a un effet sur l'injection.

Keywords: fracture, grouting, bleeding

1. INTRODUCTION

Grouting is increasingly specified as a remedial measure for problems where the active controls of the vertical position of buildings or structures are needed. Fracture grouting technique has been successfully applied on many applications, such as settlement recovery, controlling ground movement and increasing soil stiffness.

Fracture grouting uses hydraulic fracturing to get a heave that can compensate the settlement. Hydraulic fracturing of competent material is studied in the oil industry where it is used successfully to enhance the capacity of oil wells (Kleinlugtenbelt et al, 2006). (Schweiger et al, 2004) utilized Fracture grouting technique as a remedial tool in soft clay to re-level petroleum tank; rested on raft on piles, through numerical analysis to predict the behaviour of fracture grouting using finite element program. Hydraulic fracturing technique has also an unwanted side effect as in tunnelling or horizontal drilling when high pressures can cause a blow-out that starts with a hydraulic fracture (Bezuijen et al., 2001).

Fracture grouting technique has been influenced by engineering properties such as grout rheology that means fluid properties of the grout; it was controlled by two parameters; Yield point and Plastic viscosity. Grotenhuis (2004), explained the two terms of plastic viscosity and yield point. Where the yield point defined as the energy needed to set the flow in motion while plastic viscosity as extra energy which is needed to increase the rate of motion.

In the present research, a laboratory model who considered the grout and soil parameters that may be affected on grouting efficiency, stresses and bleeding effect were studied to investigate the mechanisms for Fracture grouting through sand.

2. FRACTURE MECHANISM

Fracture grouting mechanism has been explained by many researchers; (Soga, et al. 2000), (Wisser, 2005), In fracture grouting injection high pressure liquids leads soil to deform into plastic manner, Subsequently, these plastic deformations may accelerate locally or hydraulically fracturing that in some cases suddenly occur, leading to penetration of the grout into fingers, thin sheets or lenses pattern. Grotenhuis (2004) stated that hydraulic fracturing generally occurred; due to tensile or shear strength. The fracture mechanism in rock can be explained as the tensile stress near the fracture exceeds the strength of rock. In sand, no tensile strength can be developed but Injection of a liquid in sand will lead to elastic and plastic deformations will lead to fracture generation (Kleinlugtenbelt et al, 2006).

3. TEST SETUP

Prism container with internal dimensions 1.4 m x 1.6 m and height 0.75 m was used to model grouting process. Soil mould was filled by soil up to 0.60 m height. Fig (1) is a schematic drawing showed the used model and its internal dimensions. Soil mould was covered by a steel plate, stiffened with I-beams, rubber seal was used to prevent any air leakage from the connection between tank body and the cover; therefore it was possible to pressurize the sand sample, using air pressure, simulating higher confinement stress levels. A pipe 1- inch diameter with rubber sleeve was used to only allow outflow of the grout material under the applied pressure, but it prevented sand from inflow through the pipe.

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M. Hamza et al. (Eds.)

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Plastic rings were located at top and bottom of the rubber for preventing inflow the grout parallel to pipe wall.

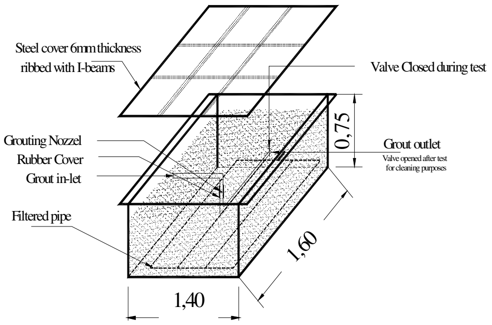


Fig (1) schematic drawing for the tank with internal dimensions.

Four injected nozzles were located at the middle of the grouting pipe; the nozzles were apart from tank bottom by distance 0.35 m above. Stress monitoring for vertical and confinement stresses were achieved by pressure cells located 20 cm apart from the injection point by. Saturation for sand was achieved by four filtered pipes located at the bottom of sand layer. Dried sand was rained into container, after that water pumped with high pressure from filtered pipe underneath the sand to simulate ground water table. Sand with different densities was tested. Compressed air was used to pre-stress the sand sample before grouting. Grout liquid was injected by plunger pump.

4. GROUT MATERIALS

Grout materials were tested through laboratory program to define its characteristics. Sand, cement and bentonite were tested as followed. Tests that performed on sand were (d60 = 0.57 mm, d50 = 0.50 mm uniformity coefficient =1.24, minimum dry density = 1.55 gm/cm3 and max. dry density = 1.85 gm/cm3). Sand Grains size distribution curves are shown in fig (2)

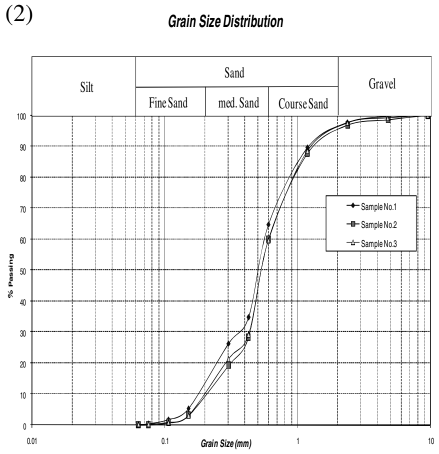


Figure (2) Grain size distribution for Tested Sand

Ordinary Portland cement used for preparing different grout mixes. Blaine test and sieve analysis were performed to determine the surface area of the used cement and bentonite. The surface area = 420 m^2/kg for cement and 120 m^2/kg for bentonite. The percentage retained on sieve No. 170 = 12.00% for cement and 4.00% for bentonite. The Specific weight was 2950 kg/cm2 for cement and 2750 kg/cm2 for bentonite. Chemical analysis for cement and bentonite was performed to define the main components of two materials. Chemical analysis results of two materials were located in Table (2).

Table (2) Chemical Analysis for Cement and Bentonite

Components	Cement%	Bentonite%
SIO_2	28.00	53.00
CaO	49.00	4.50
AL_2O_3	11.00	17.80
So_3	2.10	2.00
$P2O_3$	0.0	0.20
$Fe2O_3$	3.50	4.60
Na_2O	0.40	3.50
MgO	1.90	3.50
K_2O	1.0	0.80
Rest	3.10	10.10

5. TESTED PARAMETERS

Tested parameters have three main axis; injection parameters, grout parameters and soil parameters. Injection parameters include injection rate and injection volume, injection pressure was not considered because it is not controlled as a result lake of soil reaction. The tested parameters covered grout and sand parameters. For grout parameters plastic viscosity, yield point and filteration properties were covered, while in sand all physical and mechanical properties such as relative density and shear parameters were investigated.

6. RESULTS AND OBSERVATIONS

Different stress levels were applied on the laboratory model, ranged from 50 kPa up to 275 kPa. Injection Pressure was recorded and the pressure ratio between injection pressure and vertical stress was maintained constant.

Grout volumes were ranged from 1 liter to 6 liter. It was cleared that increasing injected volume leads to increase injection pressure. Injected volume depends on many factors such as soil properties, stress levels and water solid ratio. Tests result showed that loose sand needs higher injected volume than dense sand. Injected volume was investigated and it was ranged from 0.20 to 0.35 % from the soil treated, it may be noted that this injected volume was represented 35% to 65% form soil voids ratio.

Various Discharge rates were tested, ranged from 0.32 l/min to 15 liter/min. Injection pressure was increased as discharge rate increased. Cavity expansion was the most probable shapes. In case of loose sand No Fractures were observed. Figure (2) shows the cavity expansion process at discharge rate = 0.32 l/min. It may be noted that injection pressure is directly affected by discharge rate.

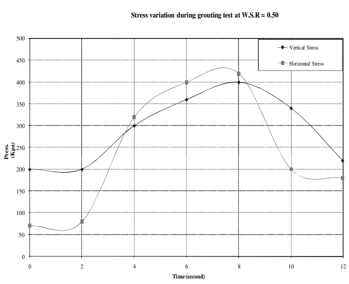
Different water solid ratio (WSR) and bentonite ratio were tested. Plastic viscosity of the grouts were ranged from 760 Mpa/sec at WSR = 0.50 to 15 Mpa/sec at water solid ratio = 1.50. Results showed that injection pressure was increased as plastic viscosity increased. Injection ratio ranged from 1.75 to 10.00 times the overburden pressure where water solid ratio ranged from 0.50 to 1.50. Plastic viscosity increased as water solid ratio decreased as well as injection pressure increased. Extrusive relationship between plastic viscosity and injection pressure this may regard to plastic viscosity presented the fluid motion resistance where this resistance was increased; result in injection pressure increased.

Fig (2) Grout bulb, Test No. (5), Discharge rate = 0.32 L/min and water solid ratio = 0.50

Different sand densities were tested. Injection pressure was increased as sand density increased. Three different sand densities were tested; it was ranged from 40 % to 85 % from maximum dry density. Fracture was occurred at sand relative density 85%. Short and thick fractures were occurred while water solid ratio = 0.70 for grout mixture.

(Kleinlugtenbelt 2006) defined Bleeding or consolidation effect as the changing for the grout from liquid to granular material just at boundary between soil and grout. Bleeding was measured during different tests; measuring the volume loss due to bleeding and consolidation effect by comparing the resultant volume with the injected volume. The grout volume was measured after a complete bleeding and consolidation (24 hours from end of the test. It was found that only 40% from the original injected volume in case of water solid ratio 1.5 and 75% in case of WSR = 0.5 which stated that water solid ratio increased leads to bleeding effect increase as well as grouting efficiency decrease.

Great attention was paid to stress monitoring; Vertical and confinement stresses were increased simultaneously. Confinement stresses increased up to higher than vertical stress;



then fracture was occurred and rapidly drops in vertical and confinement stresses. Stress monitoring is shown in figure (4).

Fig (4) total stress variation during injection at W.S.R = 0.50

7. ANALYSIS AND DISCUSSION

The obtained shapes of grouted bulb are too different from assumed by most of literature (Grotenhuis 2004) and that are reported in literature from field tests (Watt, 2002). Slender long cracks were not observed. Cavity expansion was the most probable shapes. Absence of fracture may be regarded to the boundary conditions between grout and soil; therefore filtration properties of the grout which prevents grout moves through soil and establish a filter cake that prevent grout from introducing. Higher soil density = 85% leads to fracture propagation. Fracture may be occurred at higher discharge rate or higher water solid ratio. Boundary between soil and grout played an important factor in fracture generation; increase permeability of the grout mix by adding water leads to extension grout through the soil and decrease permeability lead to prevent fracture from extension and tends to built up cavity expansion. Cement bentonite mixtures are preferable than cement mixes only because bentonite decrease permeability of the grout mix which prevents grout from escaping. Theoretically fracture dimensions may be controlled using small bentonite percentage; bentonite was helping in grout controlling which lead to higher efficiency. From previous observations it was cleared that Fracturing process was affected by many factors such as water solid ratio, stress level, discharge rate and soil density. Water solid ratio increased may lead to fracture propagation with limited efficiency.

Pressure time relationship was one of the main monitoring data which was very important to give an indication for the grouting process. Figure (5) showed one curve for test No. 4. It was cleared that there was no dip in the graph that would indicate to propagation of cracks.

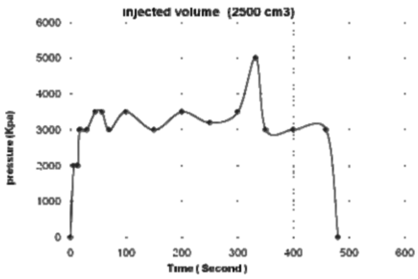


Fig (5) pressure time relationship at discharge rate = 0.32 l/min.

Higher water solid ratio more than one leads to less controlled grout at stress level up to 250 kPa, grouting efficiency was decreased as water percent increased; due to increasing bleeding effect.

Grouting efficiency was affected by many parameters such as soil density, stress level, injection rate and water solid ratio. Grouting efficiency increased as soil density increased. Higher water solid ratio may lead to uncontrolled grout therefore efficiency was decreased. Fracture propagation started to generate as injection rate increased as well as injection pressure increased, this resulted in increase bleeding effect as a result of increase filtration pressure. It was concluded that grouting efficiency decreased as injection rate increased.

Extrusive relationship was investigated between water solid ratios (WSR) and bleeding; bleeding was increased as water solid ratio increased and plastic viscosity decreased. Bleeding and consolidation was measured as a percentage of volume decreased. Volume of grouted bulb was measured after 24 hours from tests and it was found equal 75 % from the original injected volume at WSR = 0.50 and 40 % at WSR = 1.50.

Relationship between injected volume and grouting efficiency was investigated. Grout efficiency increased as injected volume increased up to certain limit, after that grout was split on the ground surface through artificial fracture, efficiency was reduced artificially. Many parameters affected on injected volume such as stress level, water solid ratio and soil relative density. Maximum injected volume represented 0.35 % from the soil treated. Injected volume has been related to soil voids ratio and it was represented 65 % from voids ration; therefore loose sand accepted higher injected volume than dense sand.

Different soil densities were tested ranged from 40 % to 85 % from dry sand density. Injection pressure was increased as soil density increased; this may be regarded to soil particles tend to compact and moves up to reach minimum voids ratio through this process injected pressure was increased up to plastic deformation was occurred. Low relative density has high voids ratio therefore soil particles tend to move and compact while in case of dense sand voids ratio were the minimum and soil deformed in plastic manner which resulted in fracture behaviour. This may explain the main reason for the higher injection pressure in case of higher soil density.

Results showed that increasing water solid ratio leads to decreasing plastic viscosity up to 12 Mpa/sec which result in uncontrollable grout as well as result in lower efficiency due to escape of the grout away from injection point; therefore it is preferable that water solid ratio did not exceed 1.00 in case of vertical stress up to 250 kPa.

8. SUMMARY AND CONCLUSIONS

Fracture grouting was affected by the injection parameters as well as soil parameters.

Fracture generation had been affected by many parameters such as stress levels, grout rheology, water solid ratio, discharge rate and relative density for the sand; therefore design for grout mixtures were a complex problem because it depends on all the previous parameters.

The shape of grout was found different assumed by literature; long slender fractures were not occurred but instead of fractures more irregular shapes this may regard to the bleeding or consolidation of the grout which changes the grout from liquid to granular material.

Different injection ratio was observed, it was shown that increase water solid ratio leads to decrease injection pressure. The ratio between injected pressure and vertical stress ranged from 1.75 to 20. Higher injection ratio means fractures process did not occur which assured from measuring for relative density of sand and the shape of grout bulb.

Higher discharge rates leads to higher bleeding effect due to increasing driving pressure required for bleeding which result in grouting efficiency was decreased.

Cement Bentonite mix with percentage 5% is preferable than Cement mix only. Because Bentonite enhancement the filtration grout properties and decrease grout permeability; this permeability which was controlled the grout movements.

Design grout mix depends on many parameters such as stress condition, soil density and grouting purposes. Up to stress = 250 kPa, Water solid ratio more than 1.00 leads to escaping of grouting which means less efficiency and increasing bleeding effects.

Increasing injected volume leads to increasing grouting efficiency until specific limit, after that limit, grouting was escaped on the surface and caused artificial efficiency decreasing. This specific volume depends on Grout Rheology, stress levels and soil parameters which make the predetermination volume are too hard, on these tests the allowable injected volume was ranged from 0.20-0.35 % from volume of soil treated which represented 35 – 65 % from soil voids ratio. Soil density has a major effect on both injection pressure and grout efficiency.

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