Some conditions for ideal chemical grouting

Hang-Gill, Choi

Graduate student, Dept. of Civil Engineering, Tohoku University, Japan

Byung-Sik, Chun

Professor, Dept. of Civil Engineering, Hanyang University

ABSTRACT: In order to design chemical grouting process in soil layers, it is necessary to determine the most suitable grouting conditions depending on the characteristic of soils to be stabilized. For the purpose of finding ideal grouting conditions, one must know how ground depths and soils conditions will affect the consolidation of soils quantitatively and qualitatively.

This experiment focuses on the effect of four different variables -- *gel time, injection rate, overburden pressure and relative density of soils* -- on the growth of chemical grouts. The results presented in this study were drawn from 300 laboratory trials of cylindrical sand specimen whose height and diameters were held constant at 30cm respectively. The materials used for the growth of the grouts were Keisa *No* 6, *No* 7, and natural river sand. In these tests, two different types of chemical grouts were used to get short gel time(5 seconds) and long gel time(300 seconds) grouts and injection rate was changed from 500 cc/min to 2000 cc/min. The overburden pressure was varied from 49 kN/m^2 to 245.2 kN/m^2 for the specimens of loose state(35%) and dense state(70%). The results of this experiment indicate that fracture grouting tends to occur when the gel time is short and the injection rate is relatively slow. However, permeation grouting tends to occur irrespective of other variables when the gel time is long and in this case the grouts result in nearly spherical form of consolidated sand which is said to be a desired condition of grouting. For the cases of short gel time grouts, hydraulic fracturing tended to occur when the injection rate is low and irregular form of consolidated sand was obtained.

When both the overburden pressure and injection rate is high, it is possible to obtain a spherical shape similar to permeation grouting. However it should be noted that when the overburden pressure is high (irrespective of gel time), the volume of the consolidated soil is decreased about 15% ~ 20%.

Key words: chemical grouting, injection pressure P, injection rate q, overburden pressure σ_V, confining pressure

INTRODUCTION

Chemical grouting is one of the most popular methods of soil stabilization to control the ground water movement and strengthening of soft cohesive soils during excavation. It is recognized that soils are desirably stabilized when permeation grouting or allowable permeation -fracture grouting is attained in sand layers during injection. However, it is very difficult to estimate the consolidated volumes and shapes after injection in real ground since there exists ununiformity in soil layers and hydraulic fracturing might occur when the injection was expected high pressure. The most widely held view concerning chemical grouting and the ground improvement mechanism is a fixed standard conception that does not take into consideration the soil conditions and ground depth. This view is supported by different theories developed by following researchers. In a study by Maag[1](1991), the permeation theory is suggested to be comprised by the relation between injection pressure and injection volume. In another study, Baker[2] (1982), suggests 'boundary conditions' which are necessary for the possibility of permeation grouting to occur. In this study, limiting conditions of permeation grouting are studied from the view point of the distribution of grain size and p~t chart.

However, these two factors of criteria do not work well in a real ground and instead hydraulic fracturing does occur even in the permeation conditions. Hydraulic fracturing is usually caused by opening of a crack that is initiated by an over injection pressure during grouting. Mori et. al.[3] (1993) demonstrated that the conditions for permeation grouting with long gel time grouts are strongly dependent upon confining pressures, permeability, and injection volume. A method of determining the critical injection rate[4] considering consolidated shapes using the injection pressure - injection rate curve (so called, p~q curve) has also been proposed in this study. Other studies are concentrated on the fracturing phenomenon in sands' soil. Morgenstern[5], (1963) taking into consideration the increasing pore pressure surrounding the injection borehole, investigated the allowable injection pressure as a method of preventing hydraulic fracturing. When injection pressure becomes as high as the confining pressure of soil, shear failure of the surrounding injection borehole will take place and hydraulic fracturing may occur. Therefore, the boundary of permeation grouting is considered to be limited and the limiting value can be estimated from the ground depth. Horsrud[6], (1982) also investigated hydraulic fracturing theoretically, considering the development of the plastic zone surrounding the injection borehole caused by permeation of grouts based on three dimensional stress analyses. In high confining pressure conditions, permeation grouting is easily attained since it is difficult to form fracture cracks in sand even in rather high injection pressure. Cambefort[7],

(1969) also suggests the possibility in deep soil conditions to estimate sufficient grouting results. This shows that the permeation grouting in the ground seems considerably dependent upon confining pressure. However, only a few studies have been made so far on the soil and grouting conditions in relation to permeation grouting behavior. From this point of view, limiting conditions for permeation grouting are studied through two series of tests are performed on long gel time grouts and short gel time grouts, respectively. Long gel time grouts manifest the permeation grouting behavior, which is only possible in a uniform soil situation, while the short gel time grouts manifest a hydraulic fracturing behavior in the ground. In this study special emphasis was placed on the investigation of the consolidated shape and limiting conditions of injection pressure which will cause the hydraulic fracturing in the soils.

MATERIAL AND TEST PROCEDURE

Three types of sand (Keisa *No* 6, Keisa *No* 7, and Abukuma river sand) were used in this study to examine the effect of grain size on the grouting behaviors. Most of the tests were performed on the Keisa*No* 6 and Keisa*No* 7 with smaller grain size, the natural Abukuma river sands are used to compare the test results of Keisa *No* 6. The grain size distribution curves and the physical properties of the sand samples are shows in Fig.1 and Table.1 respectively.

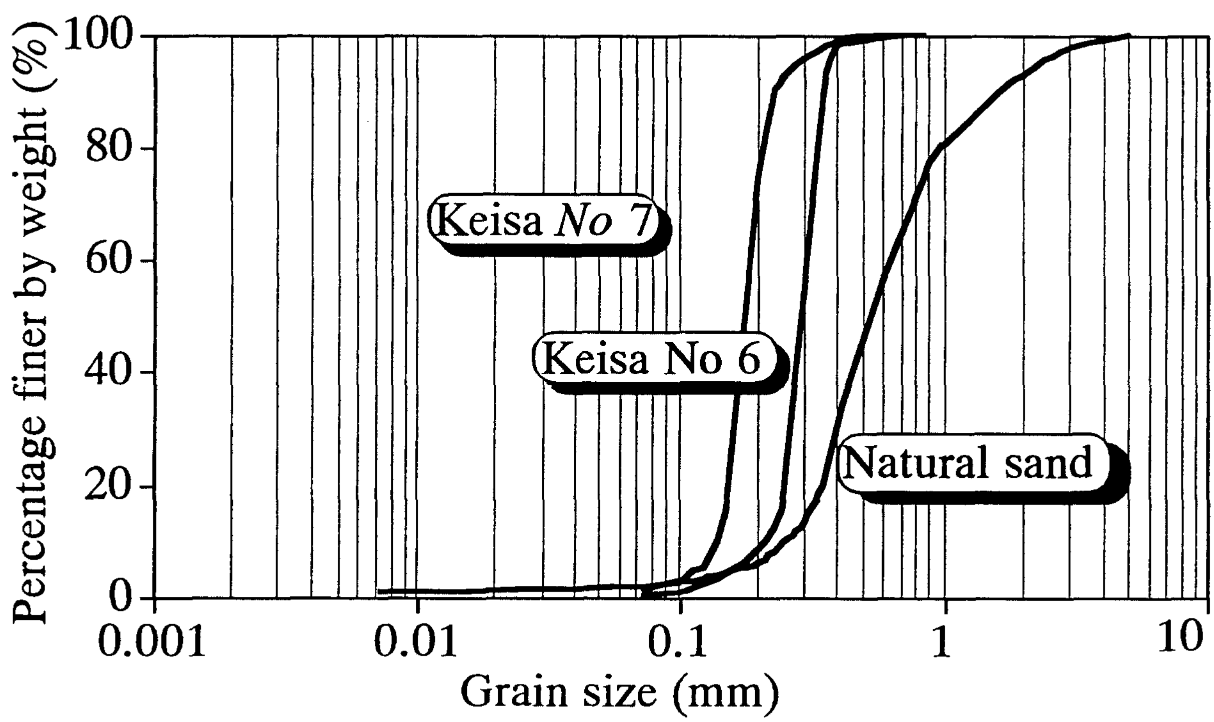


Fig.1 Grain size distribution curves

Table.1 Types of samples

Property		Units	Keisa No6	KeisaNo7	Natural - sand
Specific gravity		g/cm^3	2.637	2.640	2.715
Optimun moisture content		%	14	19	14.5
Maximum dry density		g/cm^3	1.573	1.483	1.654
Maximum density		g/cm^3	1.608	1.512	1.686
Minimum density		g/cm^3	1.279	1.171	1.379
Dry density	Loose	g/cm^3	1.3	1.4	1.6
	Dense	g/cm^3	1.5	1.6	1.7
Coefficient permeability	Loose	cm/sec	6.52×10^{-3}	2.91×10^{-3}	1.56×10^{-3}
	Dense	cm/sec	3.72×10^{-3}	2.02×10^{-3}	1.22×10^{-3}

Fig.2 , Fig.3 shows the testing apparatus with the injection pump. Size of the container of test specimen was 300mm in diameter and 300mm in height. After installation of the injection pipe to the center bottom of mold, line mixer was attached to the top of injection pipe, then test specimen is prepared in the container. Loose specimens of sand were prepared by compacting soils by 5 layers, which was compacted by 50 blows of rammer. Dense specimens of sand were made by 10 layers, each compacted 80 blows of rammer. Then the specimen was saturated by water. Considering the depth of ground, the overburden pressure was applied through rubber membrane, fixed to the cap board on the specimens, ranging from 49 kN/m^2 to 245.2 kN/m^2. Table.2 shows the contents of two types of the grouting material with different gel time used in this study. These two types of Liquid B were obtained by changing the relative amount of hardening agent [$(CH_2O)_2CO$: AronSR - Hi] and an accelerator ($KHCO_3$) contained in the liquid. The liquid A was made by mixing water glass with water by 70% in volume. The same volumes (600 cc) of Liquid A and B were injected into the specimen and they were mixed at the top of the injection pipes by a line mixer. The total injection volume was kept to 1200 cc throughout the cases. The injection of chemical grouts was made by four different injection rates of 500 cc/min, 1000 cc/min, 1500 cc/min, and 2000 cc/min.

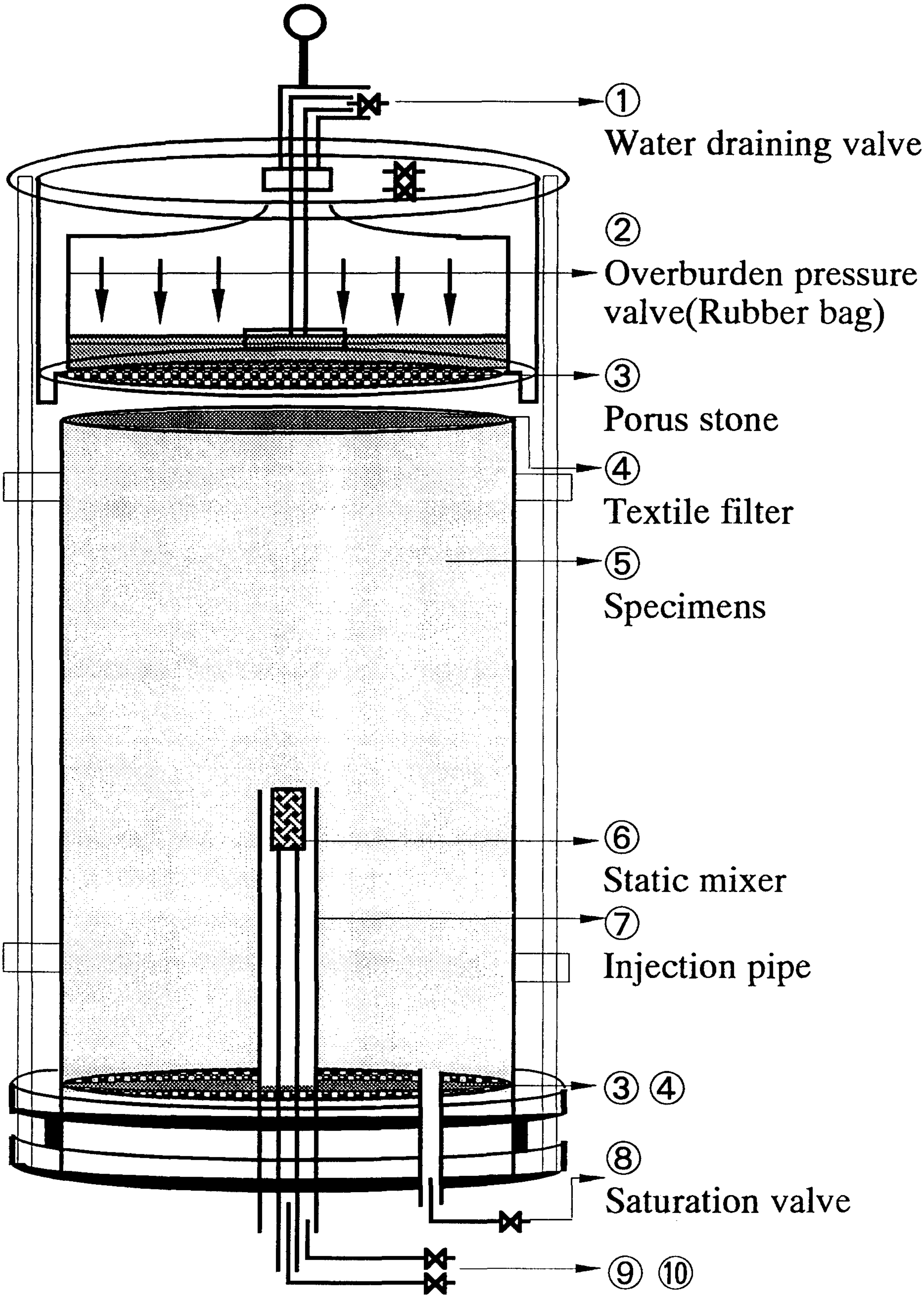
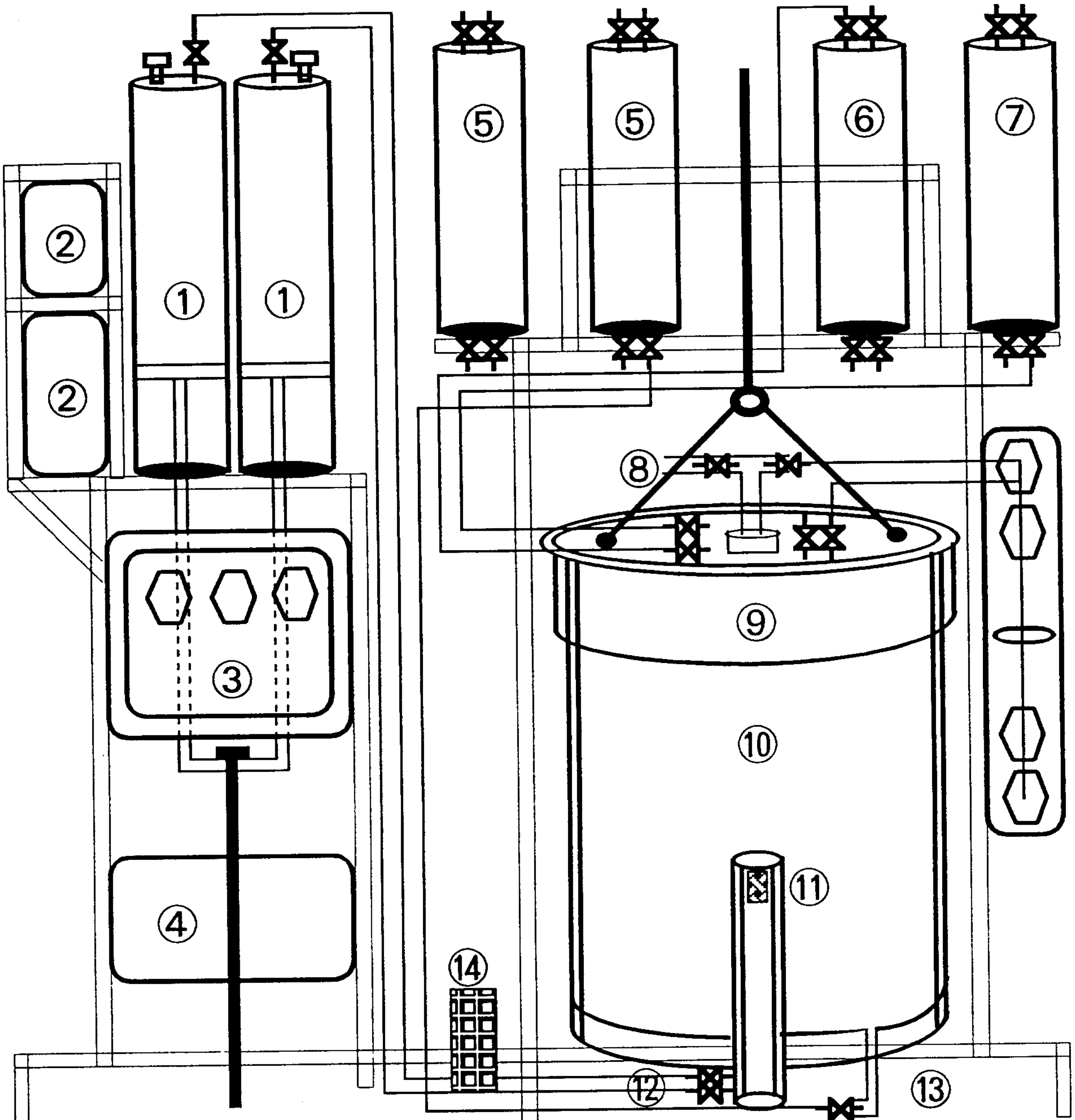


Fig.2 Schematic diagram of mold



① Reservior for liquid A,B
② Data recorder
③ Control panel
④ Injection pump
⑤ Water tank I, II
⑥ Pressure tank
⑦ Vaccum tank
⑧ Water draining valve
⑨ Overburden pressure
⑩ Specimens
⑪ Injection pipe
⑫ Liquid A,B
⑬ Saturation valve
⑭ Pressure sensor

Fig.3 Schematic diagram of injection apparatus

Table.2 Used chemical grouts

Grouts		Injection volume	Manufacturing		
			Total	Gel time	
				5 seconds	300 seconds
Liqid A		600cc	1000cc	700cc + Water300cc	700cc + Water300cc
Liqid B	Hardener	600cc	1000cc	$\frac{30g}{110g}$ +Water	$\frac{60g}{35g}$ +Water
	Accelator				
Total		1200cc	2000cc	1000cc	1000cc

The pore water squeezed out from the specimen during the injection of chemical grouts is drained out through the valve of the cover plate of the container. The variations of injection pressure with elapse time, was recorded by a digital transducer indicator and intelligent recorder. After 24 hours, the cover was removed and the non consolidated soil was removed by digging by hand and then by pouring running water. Then the shapes of consolidated sand were observed and the consolidated volume was measured by submerged weight method.

THE LONG GEL TIME GROUTS

Fig.4 shows an example of the relation between the injection pressure and elapse time (so called p~t chart) when the long gel time grouts were injected into loose specimens. After started injection, the injection pressure of long gel time grouts initially rises, then in the second stage stabilizes at a steady state, whose values increase as injection rate increases.

Fig.5 shows an example from the p~t chart of dense specimens. The variation of injection pressure with time is similar to those of loose specimens. However the values observed are slightly higher than that of the loose sands.

Fig.6 shows the consolidated shape formed in sands when using the long gel time grouts. The consolidated shape seems almost a perfect spherical form irrespective of the kind of sand. In this experiment it can be said that with these grouting conditions, permeation grouting were maintained irrespective of sands and grouting conditions. Therefore we can expect that the consolidated shape is spherical when the permeation grouting are made in uniform sand layers.

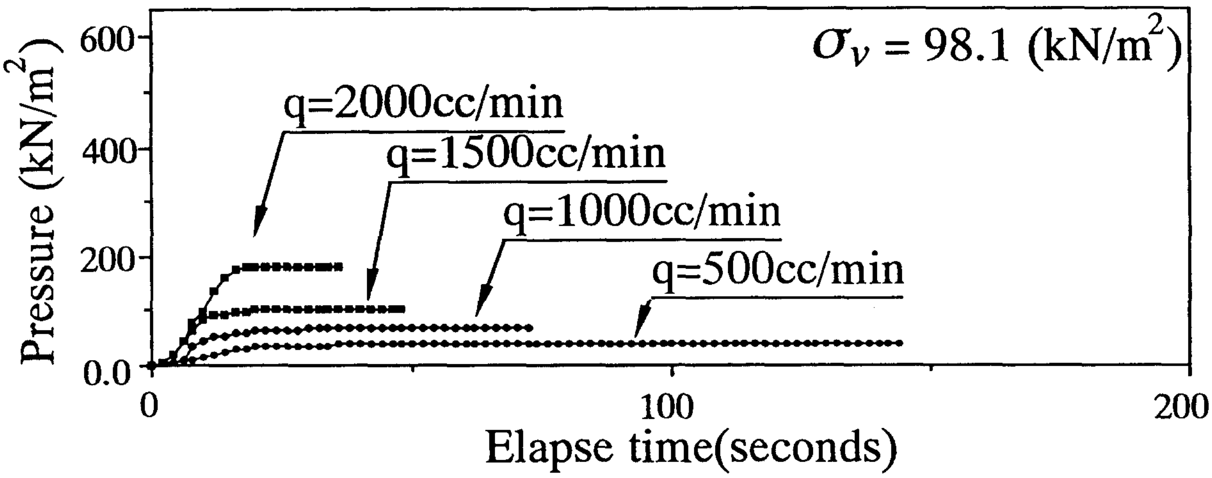


Fig.4 P~t chart on long gel time grouts (Loose specimens)

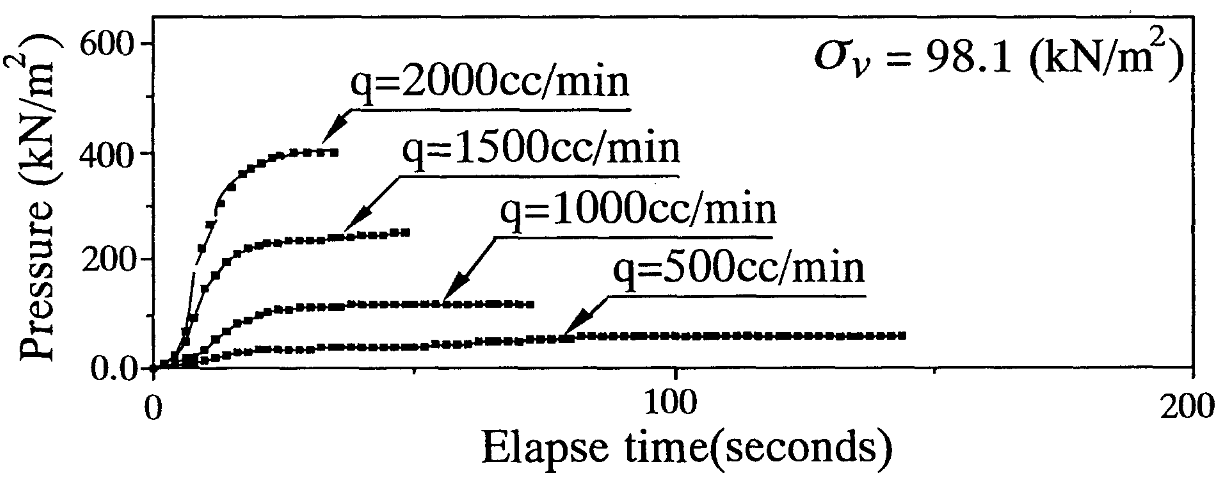


Fig.5 P~t chart on long gel time grouts(Dense specimens)

However, when the overburden pressure was increased from 49 kN/m^2 to 196.2 kN/m^2 the volume of the consolidated shape decreases about 15% in the case of Keisa *No* 6.

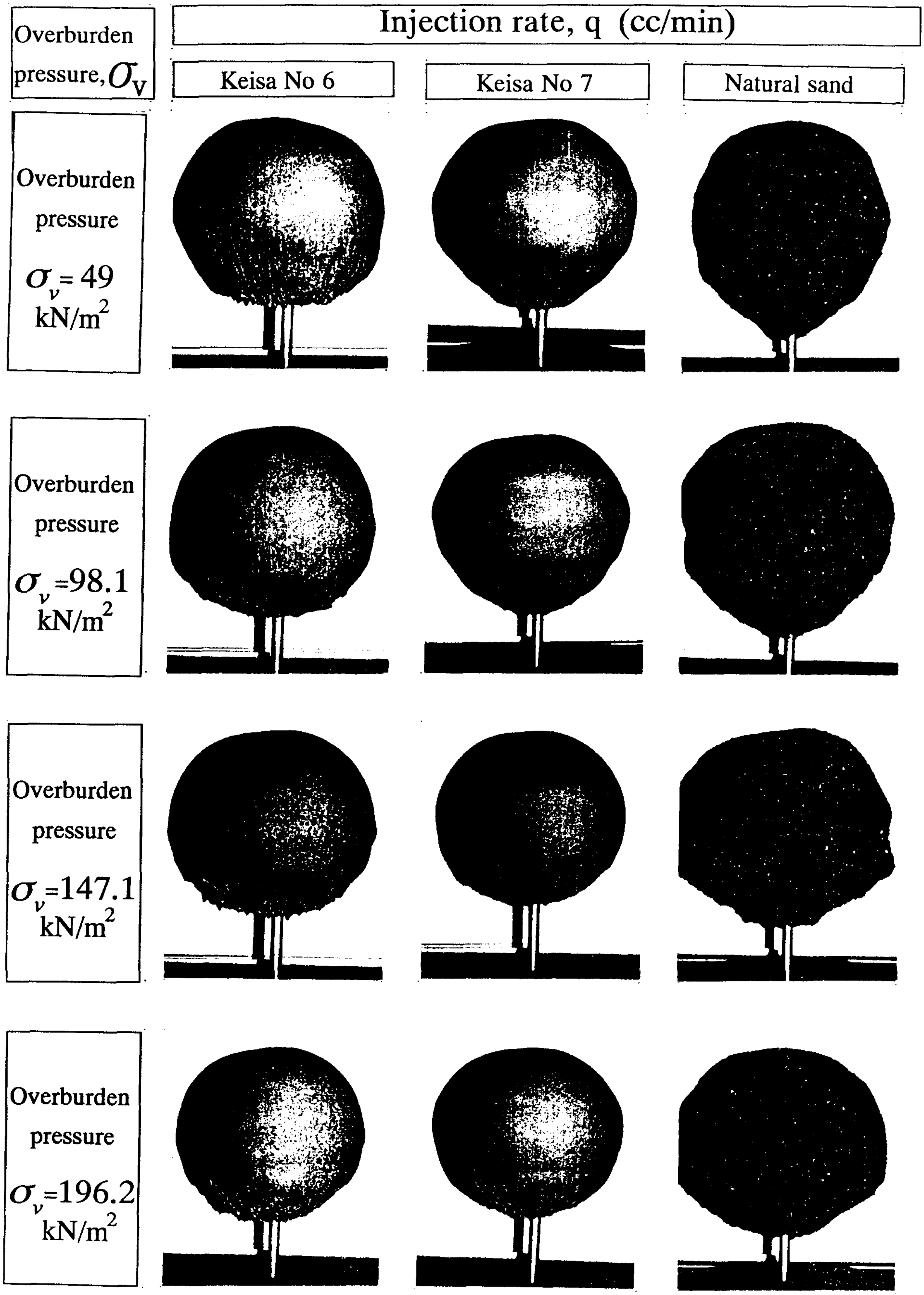


Fig. 6 Consolidated shape by grouting conditions on long gel time grouts

Fig.7 shows the relation between the injection pressure and the injection rate (so calledp~q curve) when overburden pressure are 98.1 kN/m^2. The injection pressure increases in proportion to injection rate irrespective of kinds of sands and grouting conditions. As a matter of fact, there is a little difference in injection pressure between loose and dense specimens; the proportional curve shows higher values in dense sand because of the difference in permeability.

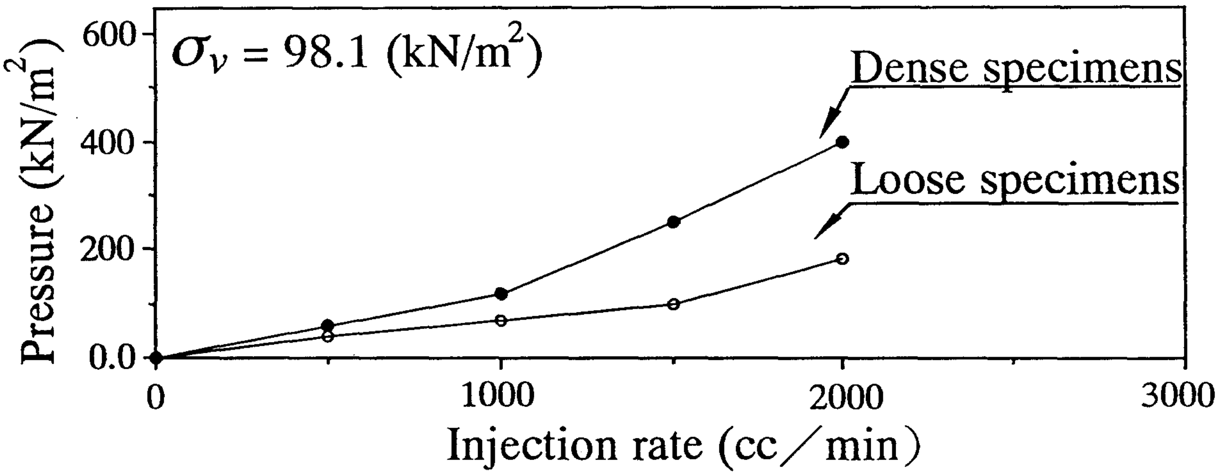


Fig.7 P~q curve on long gel time grouts

THE SHORT GEL TIME GROUTS

In short gel time grouts, of which gel time is shorter than the injection time, the succeeding grouts cannot be injected unless the gelled parts of the preceding grouts are fractured or perforated by permeation.So, the injection behavior of short gel time grouts is fairly different when compared to long gel time grouts, which continuously push forward[8]. However, even in the permeation condition, the grouting which can describe the increase of viscosity of chemical grouts with the gelation has not been established yet because of lack of fundamental understanding of the theory of grouting phenomenon. Therefore, it is necessary to clarify the relation among p~t chart, consolidated shape, p~q curve, and volume shrinkage under differences overburden pressure in short gel time grouts.The p~t chart of the short gel time grouts shows a steeper pressure curve than the grouts of the long gel time. The injection pressure rises rapidly and declining in an irregular undulating curve. This is due to the injection of succeeding grouts being fractured or partially perforating unpermeable parts formed by the gelation of preceding grouts.

Fig.8 shows the p~t chart of short gel time grouts in dense specimens which indicates the influences of overburden pressure and injection rate. Up to the injection rate of 1500 cc/min, the injection pressure in the p~t chart shows an irregular undulating curve regardless of overburden pressure. This seems to be induced by the formation of the hydraulic fracturing crack in the sand.When the injection rate becomes 2000 cc/min, the injection pressure rises very quickly to a higher value. The influences of overburden pressure is negligible when injection rate is relatively low where as fairly large when injection rate is 2000cc/min (both loose and dense specimens). Fig.9 shows the consolidated shape of short gel time grouts in loose specimens in which the overburden pressures were changed from 49 kN/m^2 to 245.2 kN/m^2, and the injection rate was increased from 500 cc/min to 2000cc/min, the consolidated shape is very distorted in any condition. This would be caused by a hydraulic fracturing phenomenon and the fracturing occurs irrespective of grouting conditions. In the case of loose specimens it was impossible to form a spherical consolidated shape even with high overburden pressure. Thus we can assume that the grouting effect is not reliable in loose sand layers irrespective of overburden pressure and the other grouting conditions. Fig.10 shows the consolidated shape of short gel time grouts in dense specimens in which the overburden pressure ranges from 49 kN/m^2 to 147.1 kN/m^2. The consolidated shape is considerably distorted due to fracturing - permeation phenomenon. However, when the overburden pressure becomes 196.2 kN/m^2, and injection rate q=2000cc/min, it is almost a spherical shape similar to the permeation phenomenon. Even though in case of short gel time grouts, we find out that the consolidated shape becomes close to the desired shape and similar to permeation grouting when the overburden pressure is high. However, consolidated volumes decrease as the confining pressure increase. Thus, it can be said that permeation phenomenon is strongly dependent upon confining pressure. In the case of the long gel time grouts, it is easier to form permeation grouting when the injection rate is rather low. However, in short gel time grouts, when injection rate is low, the permeation grouting does not seem to occur. Fig.11 shows the p~q curve of the short gel time grouts. In the case of loose specimens, when the overburden pressure is 49 kN/m^2, the injection pressure increases in proportion to injection rate. However, in other conditions, the curve increases after declining momentary. In the case of dense specimens, similar tendency was seen.This indicates the fact that the p~q curve is not always significantly influenced by the grouting conditions.Therefore the meaning of p~q curve as a controlling parameter of the in situ grouting condition should be carefully examined.

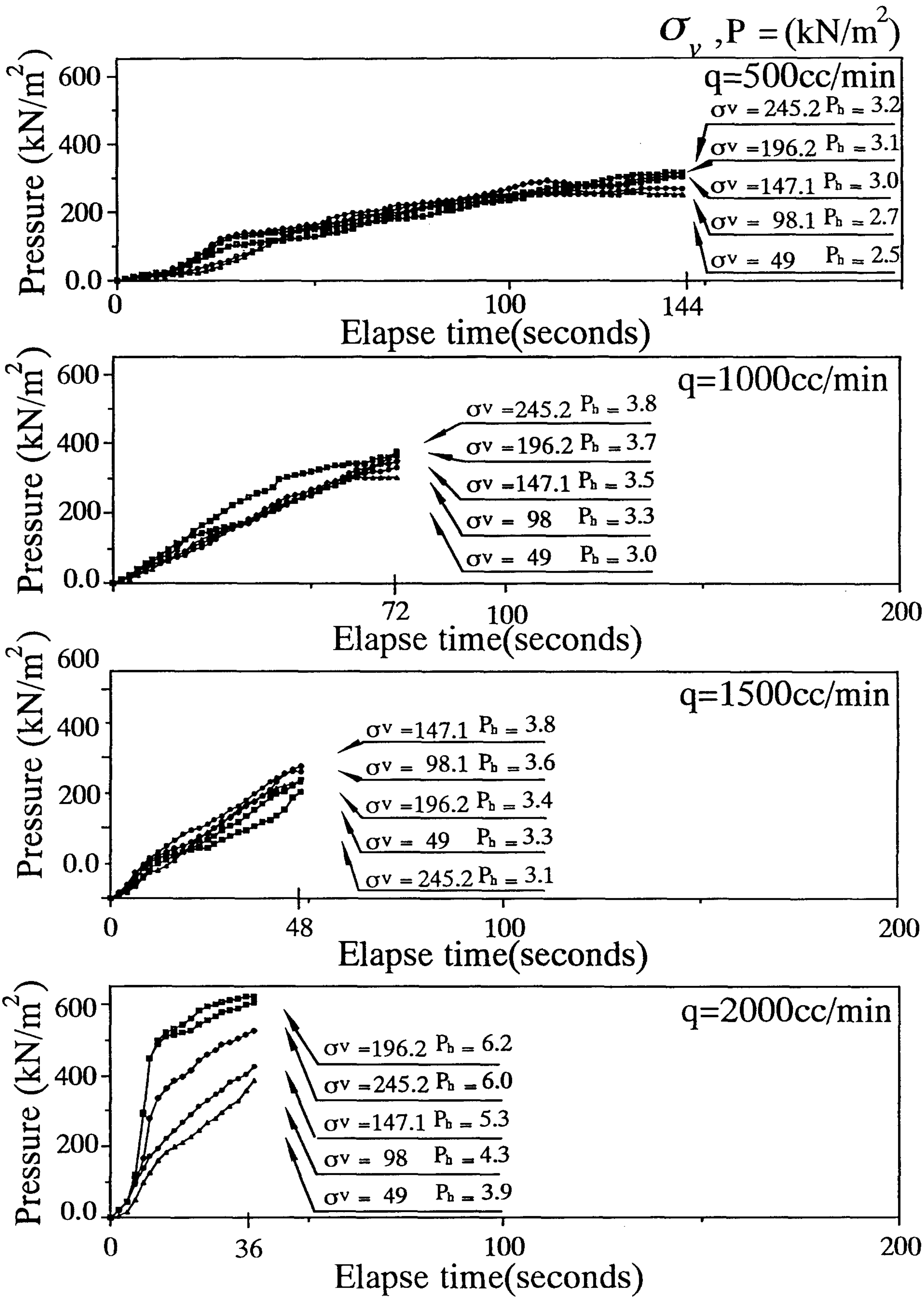


Fig.8 The influence of overburden pressure of each injection rate(Short gel time grouts on dense specimen)

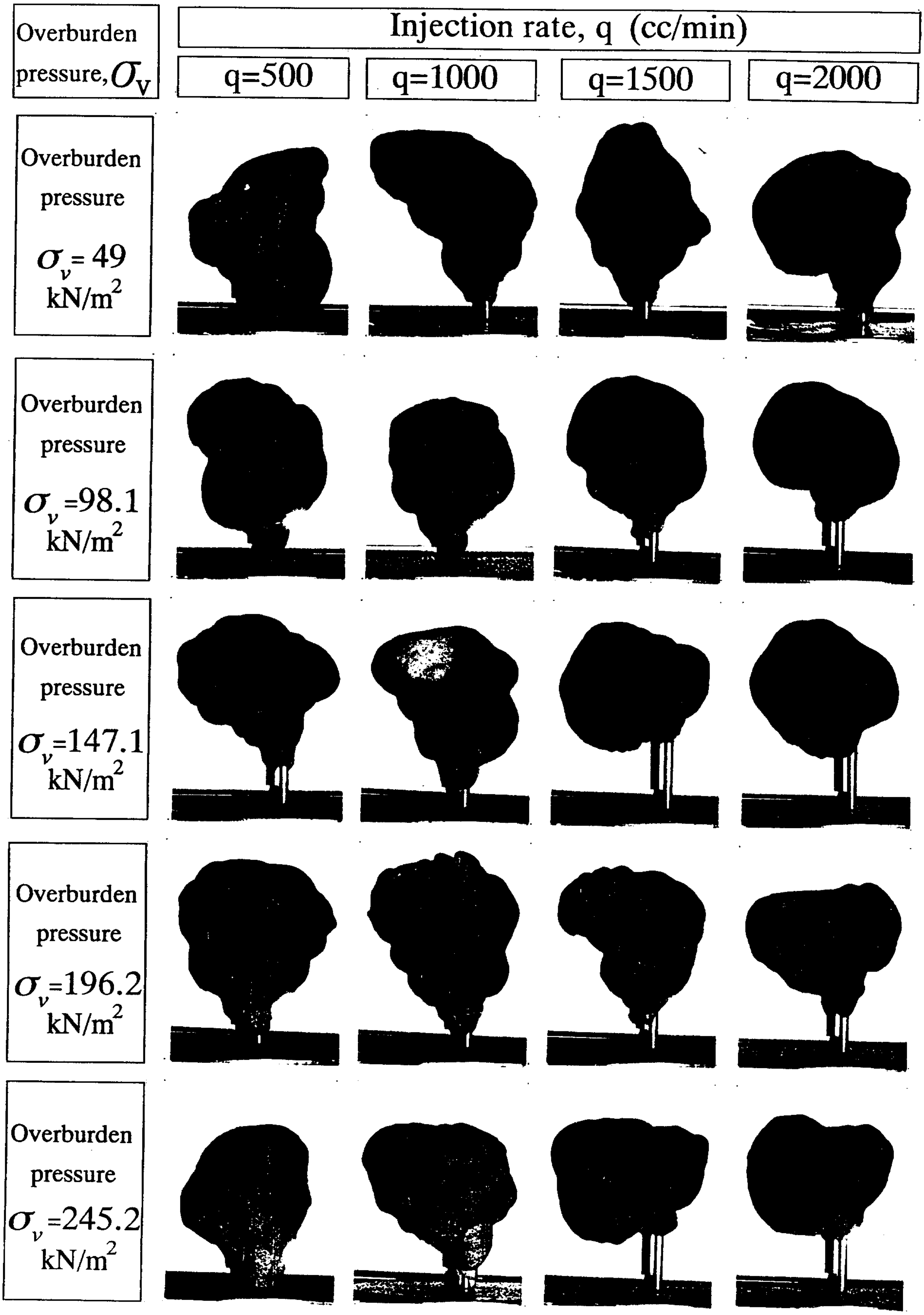


Fig.9 Consolidated shape by grouting conditions on short geling time grouts (Loose specimens)

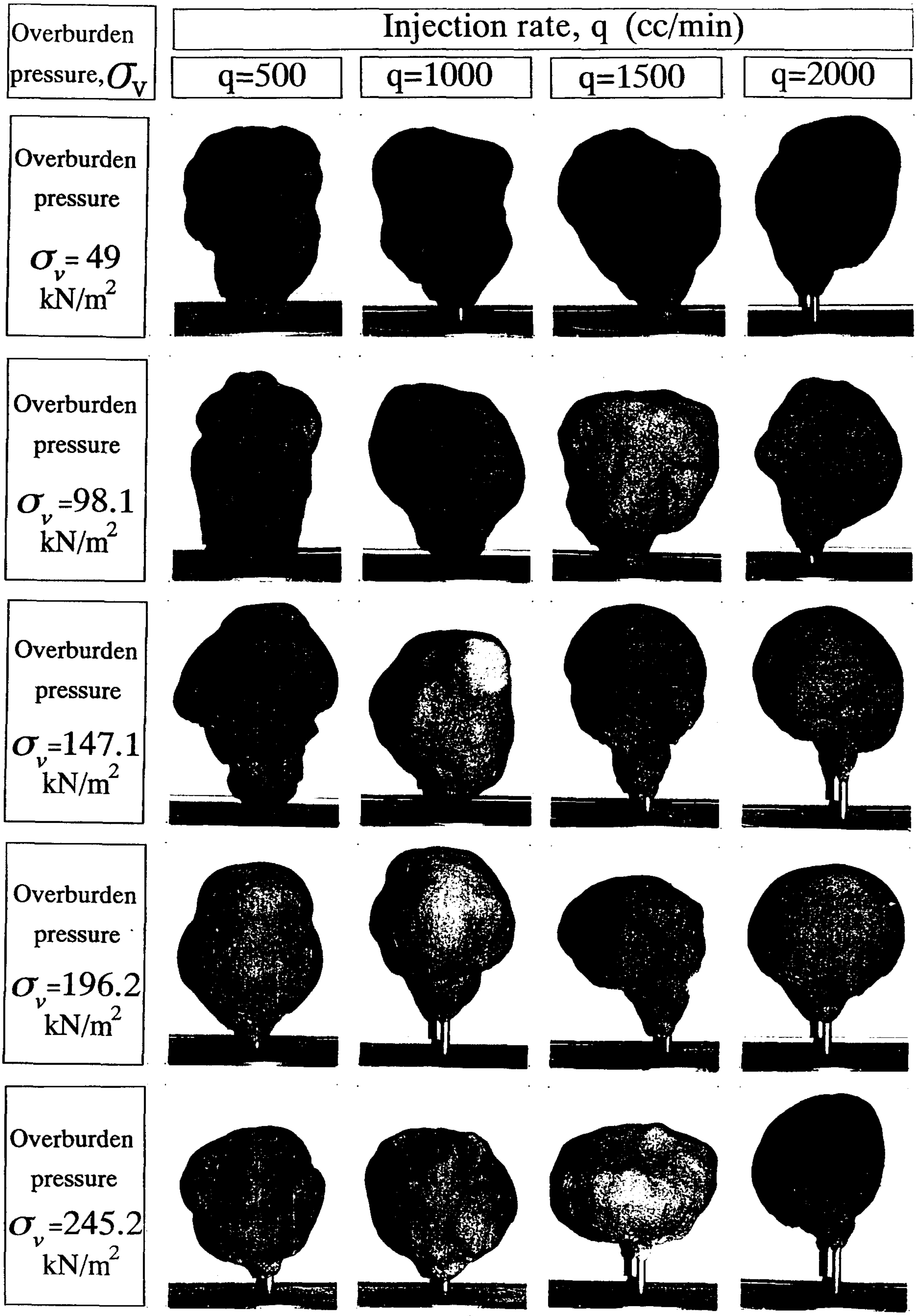


Fig.10 Consolidated shape by grouting conditions on short geling time grouts (Dense specimens)

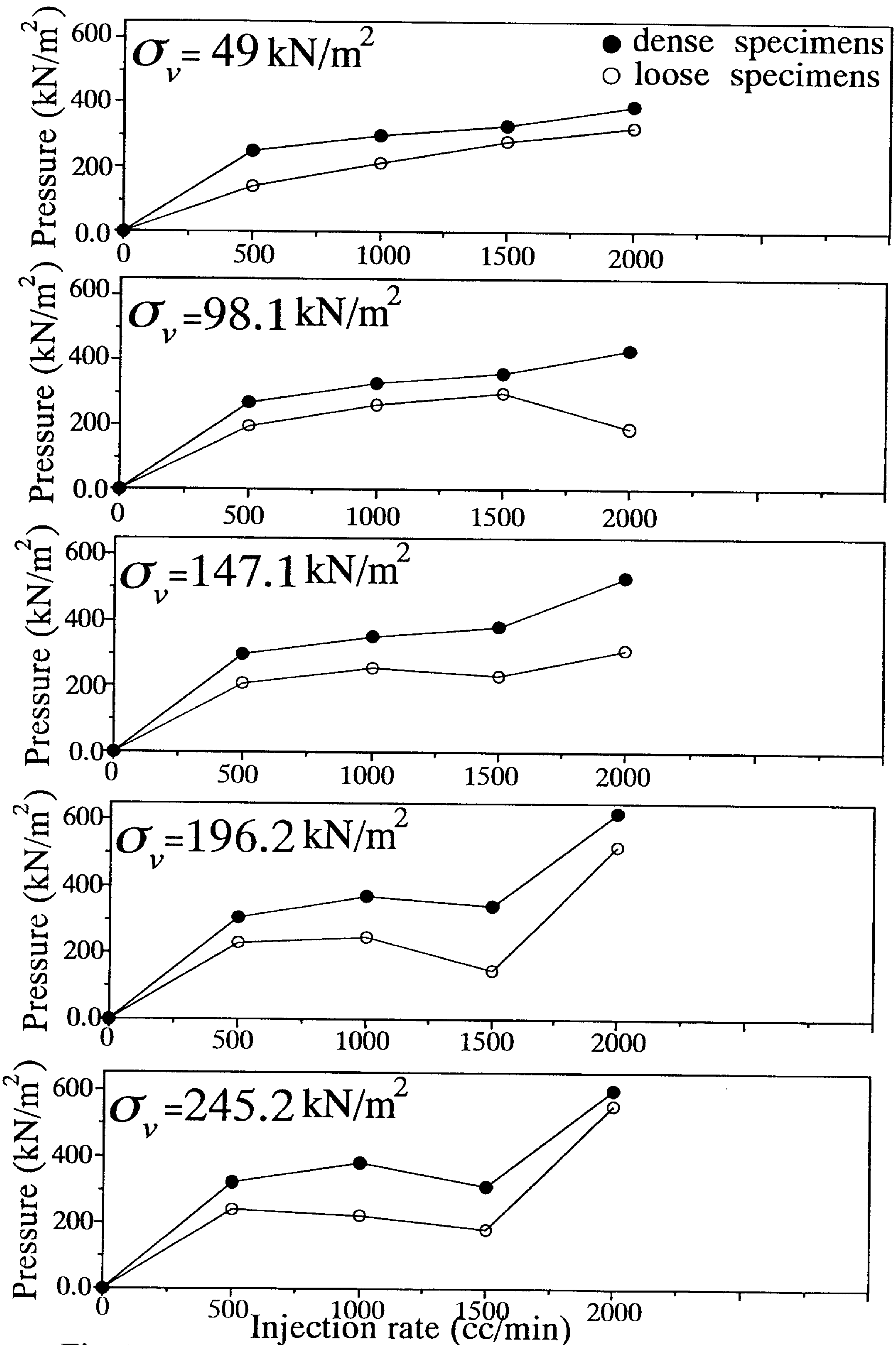
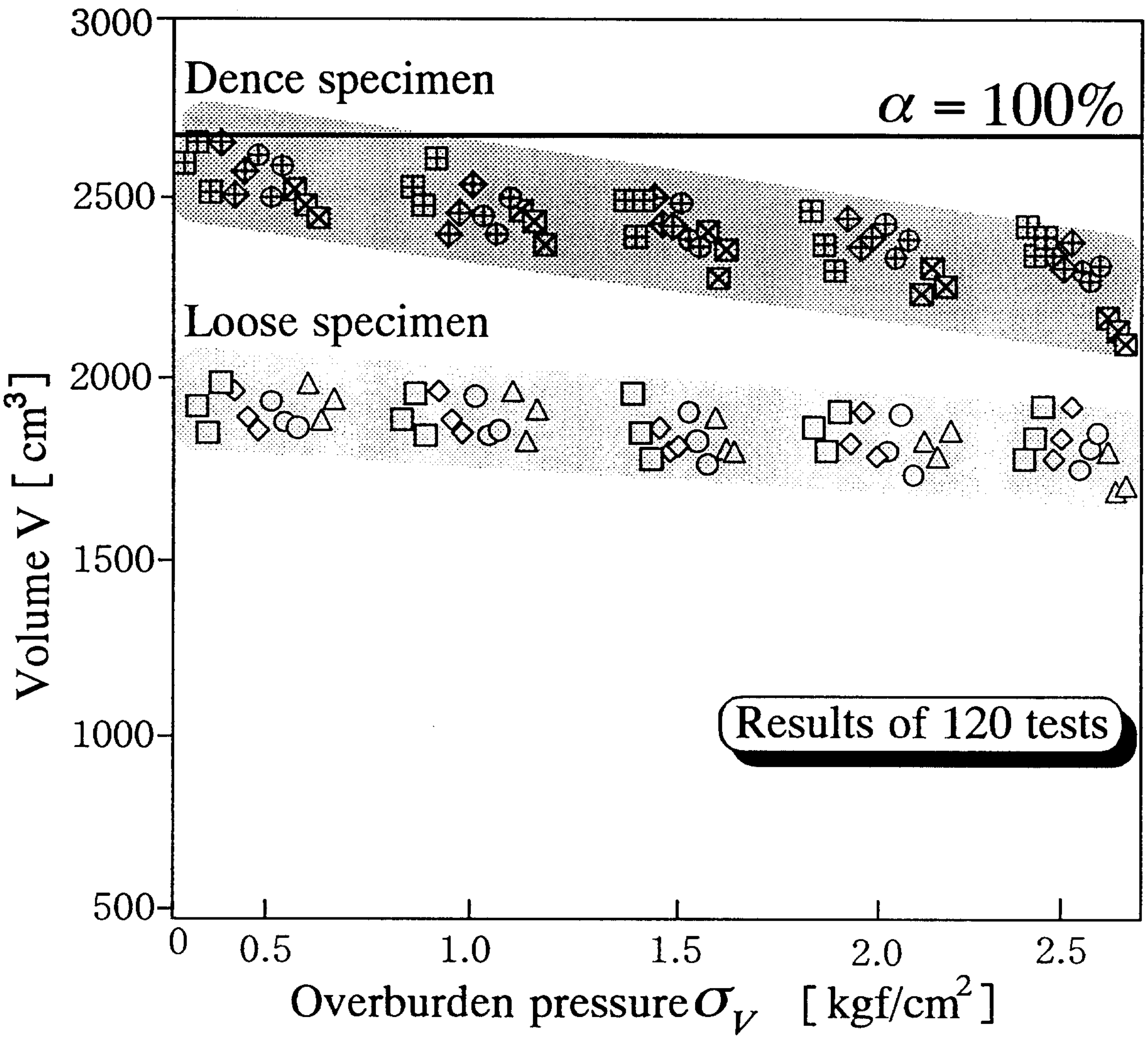


Fig.11 P~q curve by overburden pressure on short gel time grouts

Fig.12,13 shows the variations of consolidated volume as a function of overburden pressure. The dotted line of each figure is the theoretically calculated volume where the grouts perfectly permeated into the sand. The volume expansion must be almost equal to the fracturing cracks in the soils formed by hydraulic fracturing[8]. However the volume increases were only seen when the overburden pressure is 49 kN/m^2 and the biggest fracture cracks were observed in the consolidated soils. The volume changes increase as the injection rate increase when injection rate is 500cc/min, volume shrinks 14% and when injection rate is 2000cc/min, volume shrinks 23%. In particular, in the case of dense specimens the variation of volume increases in proportion to the injection rate.However, in the case of loose specimens (Fig.13), the volume change is smaller than dense specimens. In addition, the amount of volume decrease is irrespective grouting conditions and overburden pressure.



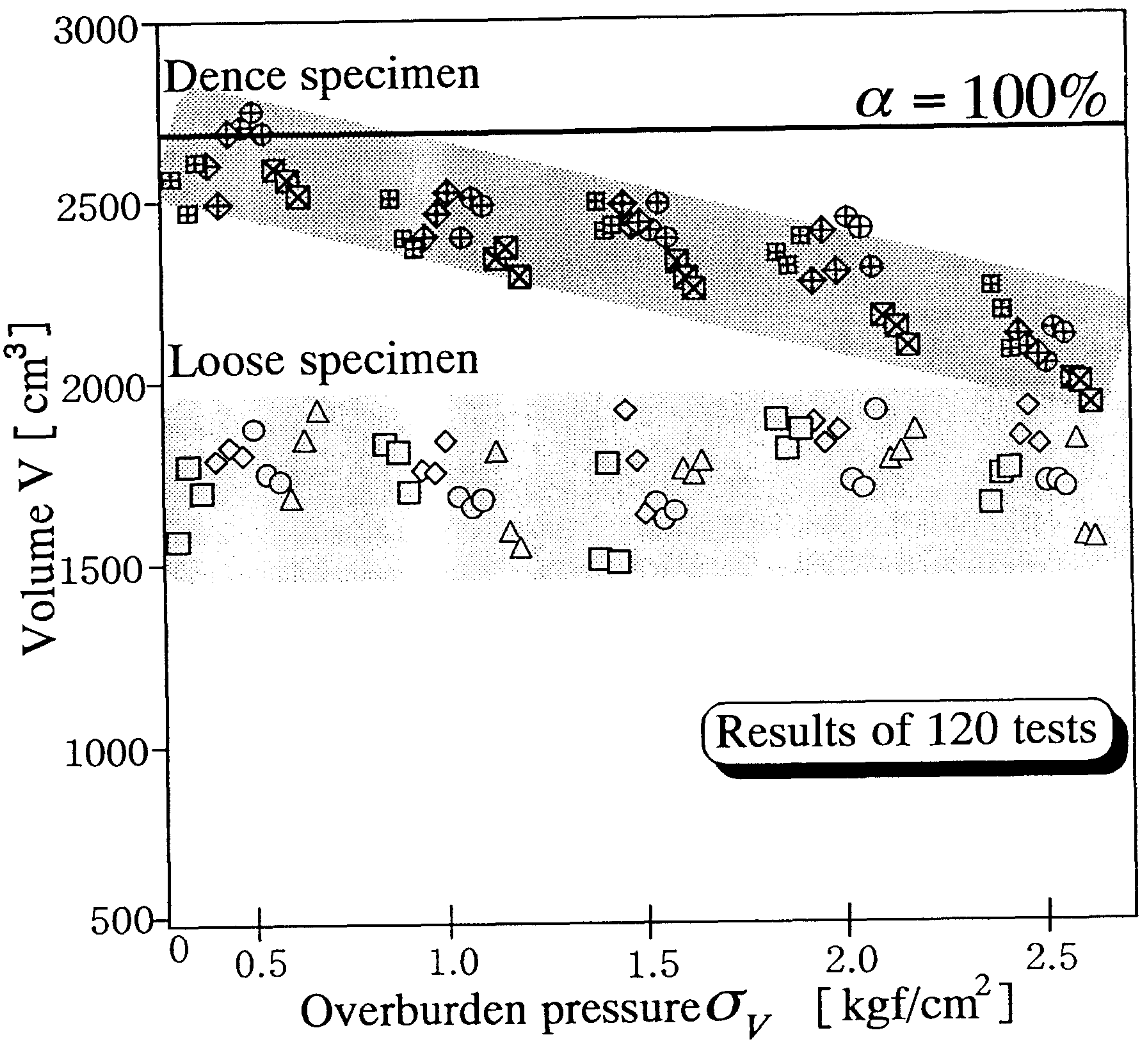
Dence specimen

⊞ q=500cc/min ⊕ q=1000cc/min ⊕ q=1500cc/min ⊠ q=2000cc/min

Loose specimen

□ q=500cc/min ◇ q=1000cc/min ○ q=1500cc/min △ q=2000cc/min

Fig.12 The variation of consolidated volume as a function of overburden pressure(The long gel time grouts)



Dence specimen

⊞ q=500cc/min ⊕ q=1000cc/min ⊕ q=1500cc/min ⊠ q=2000cc/min

Loose specimen

□ q=500cc/min ◇ q=1000cc/min ○ q=1500cc/min △ q=2000cc/min

Fig.13 The variation of consolidated volume as a function of overburden pressure(The short gel time grouts)

CONCLUSION

From the test results presented above, the following conclusion can be made,

1. The results of the experiments indicate that fracture grouting tends to occur when the gel time is short and the injection rate is relatively slow. The permeation grouting can be expected when the gel time is long, irrespective of other variables.

2. The p~t chart of the long gel time grouts initially rises, then in the second stage it reaches to a steady rate irrespective of other variables (overburden pressure, injection rate). However for short gel time grouts, the pressure goes uprapidly and shows an irregular undulating curve.

3. The long gel time grouts tend to form a nearly spherical consolidated sand and obtain the desired results. When the injection rate is low for short gel time grouts, hydraulic fracturing tended to occur. However, when both the overburden pressure and injection rate is high, it is possible to obtain a spherical shape similar to permeation grouting.

4. When the overburden pressure is high (irrespective of gel time), the volume of the consolidated shapes in dense sand is decreased about 15% ~ 23%.

REFERENCE

1) JSSMFE(1991): From inspection, designing to construction of chemical grouting, pp67~71(In Japanese).

2) Baker, W. H. (1982): Planning and Performing Structural Chemical Grouting, Proc. Of conf. On grouting in geotechnical Engineering, New Orleans, pp.515-539.

3) Mori, A., Tamura, M. and Hirano, M.(1987): The Injected Shapes by Long Gel Time Grouts in Sandy Ground and The Governing Condition, JSCE, No 388, pp131-140(in Japanese)

4) Mori, A., Tamura, M, Komine, H. andOgawa, Y. (1993): A Method of Determine the Critical Injection Rate Considering Permeated Shapes in Chemical Grouting, JSSMFE, Vol. 33, No.3, .159-169.

5) Morgenstern, N. R. And Vaughen, P. R. (1963): Some Observations on Allowable Grouting Pressure, Grouts and Drilling Muds in Engineering Practice, London, pp. 36-42.

6) Horsrud, P., Risness, R. and Bratle, R.K. (1982): Fracture initiation pressure in permeable poorly consolidated sands, International Journal of Rock Mechanics and Mining Science &Geomechanics Abstracts., Vol.19, No.1, pp.255-266.

7) Cambefort, H. (1969): Injection Des Sols.

8) Mori, A., Tamura, M. and Haraguchi, K.(1989): Solidified Shapes by Short Gel Time Grouts in Sandy Ground and the Governing Condition, JSCE, No406, III-II, pp157 -166,(In Japanese).