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CHEMICAL SOIL STABILIZATION RECENTLY DEVELOPED IN JAPAN

日本における最近の化学的土質安定工法

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1. Introduction

With the industrial development, Japanese cities have been actively redeveloped to meet the modern requirements. Most of the cities are formed on alluvium near coasts or plateaus of diluvium. Accordingly, many kinds of soil stabilization are needed in foundation works to cope with the soft clay and unsolidified sandy soil.

For the sandy soil, the chemical grouting is commonly used. In Japan, many kinds of chemical grouts are brought into market to help the fittest selection of the grout. Recently, an isocyanate type chemical grout has been developed, attracting public attention.

The vertical drain system or wellpoint system has been applied to soft clay. In addition the late and common method is forming column-shaped solidified body in the ground by agitating and mixing with *in-situ* cohesive soil, using an ultra-high pressure jet stream of solidifying chemical solution.

The dewatering and consolidation of the high water content soil as the volcanic cohesive soils have been practiced by the insertion of quick lime in the form of column for these years.

In this essay, the author will discuss the present situation and problem of the latest chemical soil stabilization in the soil stabilization methods mentioned above, putting emphasis on the development in which the author have participated.

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2. Chemical Grouting

(1) Problems of Chemical Grouting to Sandy Soil

In the chemical grouting, it is most important that pressure-grouted chemicals are uniformly penetrated and solidified among soil particles. This method, therefore, can not be generally applied to the ordinary soil except for sandy soils having more than $10^{-3}-10^{-4}$ cm/sec coefficient of permeability. But, when the acrylamide and urea resin are grouted in tightly compacted tuffaceous sands, a part of catalysts is adsorbed upon the soil particle surfaces and the strengthening effect may not occur at some parts away from the injection pipe.

Generally, the chemical penetration depends not only on the viscosity of the chemical but also the affinity between the chemical and soil particle. For example, an isocyanate chemical, which has been newly developed in Japan and gels with water, shows good penetratibity as the chemical having 1/5 coefficient of viscosity, generating carbonic acid gas at its reaction.

(2) Chemical Grouts Used in Japan

The chemical grouts commonly used in Japan are those of water-glass types, chrome lignin types and acrylamide types. Some of isocyanate chemicals, which are water-soluble or water-insoluble, have been both manufactured in Japan. This original chemical shows more than 50 kgf/cm^2 unconfined compression strength and high solidifying property in water-flowing soils but it is too expensive. From the economical viewpoint, water-glass type chemicals are most commonly grouted in Japan, totalling about 350 million liters a year.

If much more strength is needed, urea resin chemicals are used, totalling presumably 120 million liters a year.

(3) Testing Methods for Grouting

For the adequate application of the grouts in the field, the test of chemicals should be made previously, taking the relation between the grout and soil into consideration, and the author will suggest the following four in-door experiments:

1) Loose Sand Injection Test

The sand having the grading curve specified in Fig. 1 (a) is compacted by watering to have 10^{-2} cm/sec coefficient of permeability in the mold indicated in Fig. 2.

Then, a chemical is grouted to the full, according to the procedure specified in Fig. 2. When the correlation between the unconfined compression strength and the modulus of deformation is

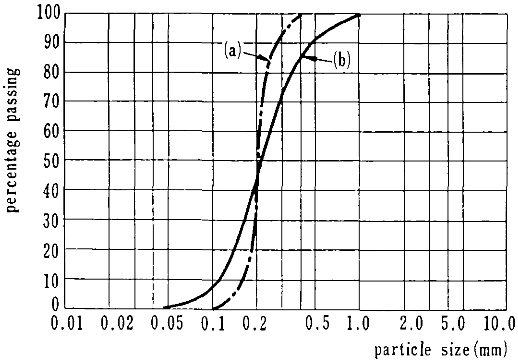


Fig. 1 Particle size distribution curves

plotted as in Fig. 3, the strengthening property of the chemical is shown very well. The correlation between the permeability coefficient and the failure strain, as illustrated in Fig. 4, can demonstrate clearly the impermeabilisation ability of the chemical. In these figures, the determined results of the chemicals commonly used in Japan are compared.

2) Dense Sand Injection Test

To know the penetratibity of a chemical, using sand in the field, a dense sample having $2-5\times 10^{-4}$ cm/sec coefficient of permeability, which is generally considered to be the limit of chemical penetration is prepared. In the center of this sample, the filter sand pillar is installed and the chemical is pressure-grouted from the pillar (Fig. 5). Measuring the penetrometer resistance at the some points of the solidified sample, the equal magnification curves of penetrometer resistance as in Fig. 6 is formed, compared to the penetrometer resistance of the ungrouted sample differently measured. The magnification and curve pattern give clearly the penetratibity of the chemical.

3) Water Flowing Sand Injection Test

A long mold divisible into two as in Fig. 7, is prepared and filled with the sample sand. Flowing the water of constant head, water flowing of up to 1 cm/sec seepage velocity is prepared. Then, approximately. 150 ml chemical is grouted, as observing the solidifying state. Taking out the

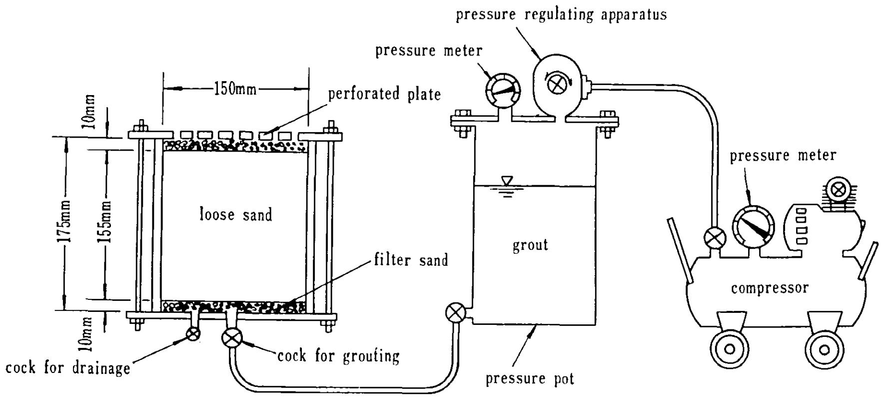


Fig. 2 Loose sand injection test

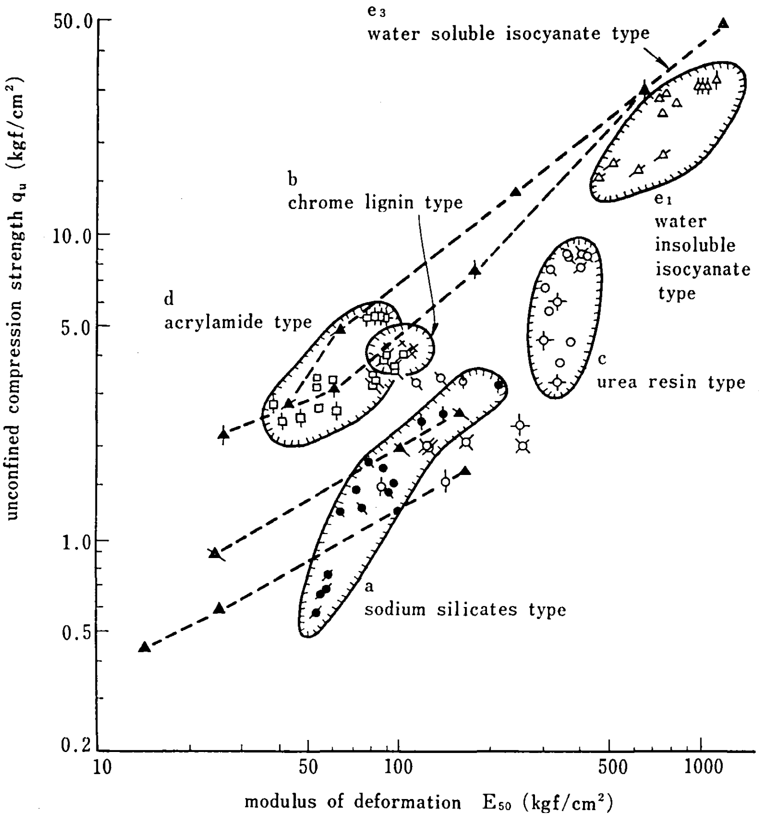


Fig. 3 Strength of solidified sand

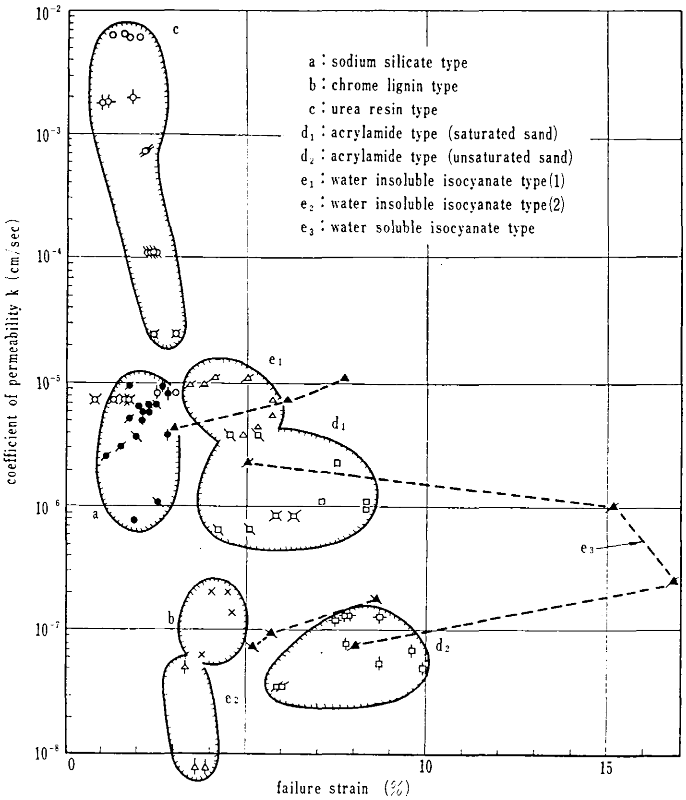


Fig. 4 Permeability of solidified sand

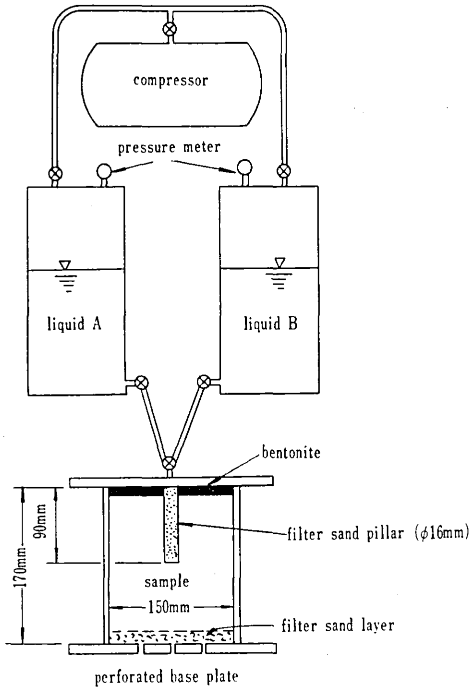
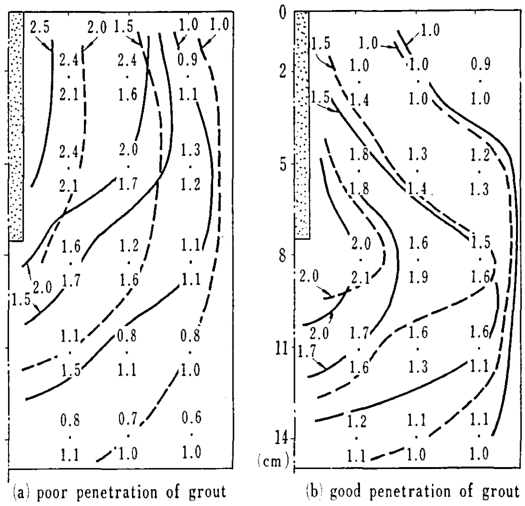


Fig.5 Dense sand injection test.



(—: unsaturated case, ---: saturated case)

Fig. 6 Equal magnification curves of penetrometer resistance.

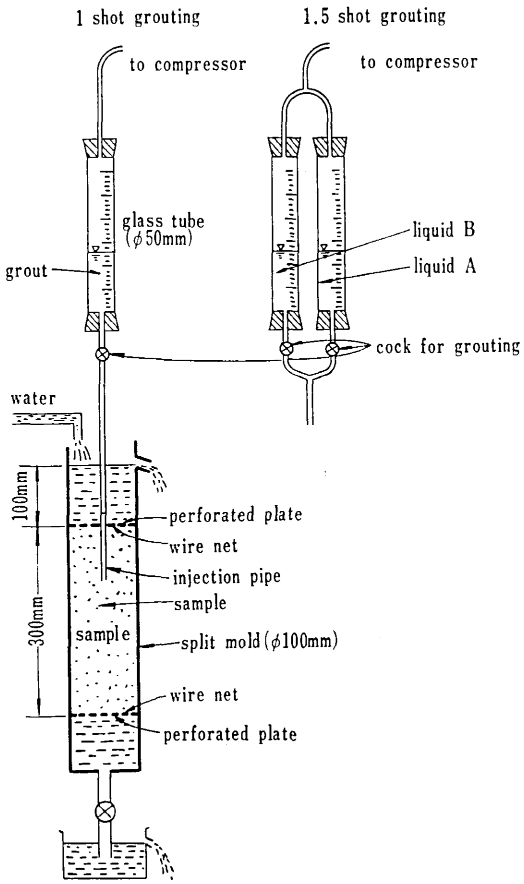


Fig. 7 Water flowing and injection test.

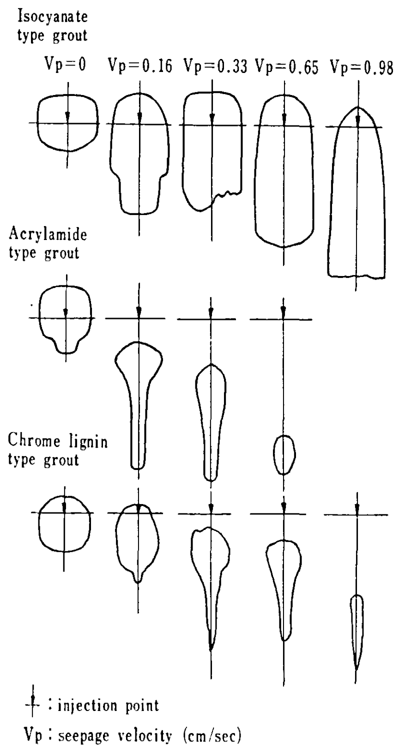


Fig. 8 Profile of solidified part in water flowing sand.

solidified parts, the strength and permeability, are tested, if necessary Fig. 8 shows an example of the profile of solidified parts.

4) Dense Sand Percolating Test

Percolating the chemical set to 60 minute gelling time through the densely compacted sample soil, according to the procedure in Fig. 9, the chemical percolated at the lower part is progressively collected and its gelling is observed. If the collected chemical remains not gelled, one must add the contents of the chemical expected to be adsorbed by the sample soil and see it gels or not. This process can make out the kinds of the contents adsorbed. Table 1 shows the result of the test made by the sample of tuffaceous sand having the grading curve showed in Fig. 1 (b) and compacted to 5×10^{-4} cm/sec coefficient of permeability. These adsorptions are made sure when gelation occurs, adding an activator into a acrylamide type grout and a solidifying agent into a urea resin type grout.

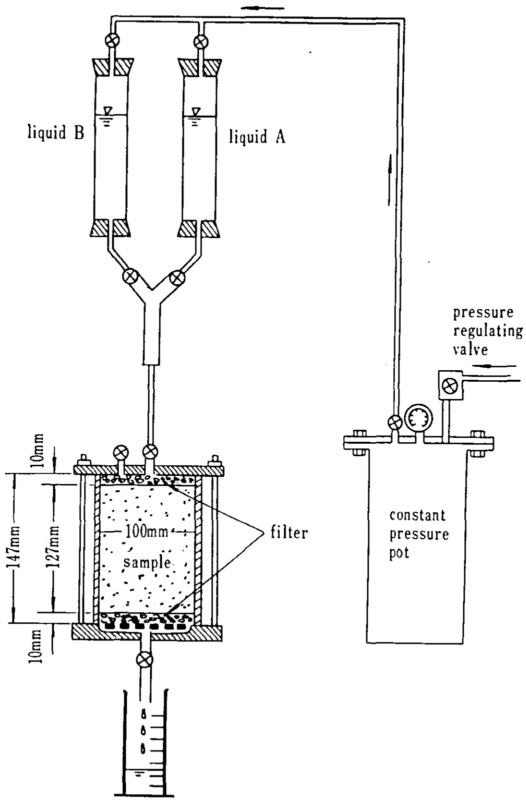


Fig. 9 Dense sand percolating test

Table 1 Gelling of percolating Grout

Percolating Step	1	2	3	4	5	6
Acrylamide type	X	X	0	0	0	0
Urea resin type	X	X	X	X	X	X
Chrome lignin type	X	0	0	0	0	0

0 : Gelling is completed.
X : Gelling does not occur.

3. Agitating and Mixing Construction Method

This method is such that a cement-contained chemical solution for soil solidification is burst

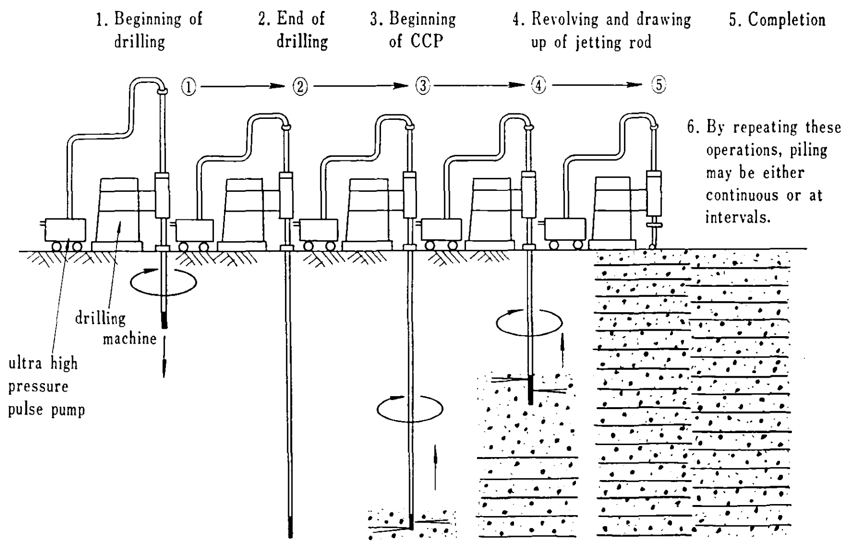


Fig. 10 Stages of the soil stabilization by chemical churning pattern (CCP)

out of nozzle at the top of the rod, with an ultra-high pressure, into the ground to have soil excavated, with soil and solution forced to be agitated and mixed to constitute a column-shaped solidified body in the ground.

The construction procedures are as shown in Fig. 10, with discharge pressure applied in the range from 200 to 250 kgf/cm^2. A column-shaped solidified soil of 30 to 60 cm in diameter can be formed in the *in-situ* soil per rod, so that this method is available for construction in a cohesive ground with difficulty of uniform chemical penetration, and usable for underpinning and impermeabilisation. Now, we have been studying the development of a low-priced chemical solution used for this method, which is to have a compressive strength more than 50 kgf/cm^2 in mixing the solution of cement and water-glass as its main agents, with cohesive soil.

4. Conclusion

As for some features seen recently in soil stabilization methods in Japan, a wide variety of chemical grout types, such as water-glass, urea resin, chrome lignin, and acrylamide has been used. And most recently, chemical solutions of isocyanate type by which not only a high strength but also a good solidifying ability in water-flowing ground can be obtained, have been developed. These are chemical solutions capable of accelerating solidification only by the reaction to water, which are classified into two types ; one is water-soluble and water may be used to have original chemical diluted, and the other water-insoluble, requiring a solvent for dilution. In this paper, four standard test methods and instances of test results are referred also to clarify the properties of these chemical grouts.

As for the chemical soil stabilization methods used for cohesive soils with difficulty in uniform grout penetration, a method developed is such that a chemical solution for solidification is forced to be agitated and mixed with the ground soil by the use of a jet stream, so as to form a column-shaped solidified body in the *in-situ* soil. This method will have a wider scope of application, such as underpinning and impermeabilisation, when a chemical solution especially suitable for the method is developed.

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