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The Safety Assessment of Chemical Grouting "Sodium Silicate-based" in Indonesian Soils

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ABSTRACT Chemical grouting is a method to improve or accelerate the solidification process on a loose soil. The implementation of improper chemical grouting may lead to affect the safety level of groundwater; thus, the technical ability and safety should be analyzed comprehensively to prevent degenerative effect on environment. Volcanic soil is targeted on this research coherent to the abundancy in Indonesia. In this study, a field scale test was conducted to validate leaching test results that were obtained in the lab and to confirm the safety of sodium silicate-based chemical grouting. In addition, the geoelectric survey was conducted to ensure the flowing of groundwater by observing resistivity of soil layer. On laboratory test result, the significance basic pH was observed, in consequence some test revealed an increase in concentration of heavy metals. The bench test was conducted in Jatinangor area's soil as a representative of Indonesian soil to validate the laboratory result. During the bench test, the pH of ground water was monitored continuously for 5 months, where a slight increase in the pH values of ground water was observed. In addition to that, water samples were collected and analyzed in the laboratory to examine heavy metal contamination in ground water on the 18th day after the chemical grouting injection was started. However, the increased concentration was not found which indicates the pH control shall be the main control of metal leaching. As the conclusion, pH monitoring as early measurement for chemical grouting effect on groundwater is proposed to be set as standard for chemical grouting work.

KEYWORDS Chemical Grouting; Sodium Silicate; Safety; Groundwater; Leached; pH

1 INTRODUCTION

Chemical grouting is a method of flow-able material injection into the ground to alter and improve engineering characteristics as well as the behavior of the underground soil/rock. It is applied to prevent ground water flow and/or reinforcement. Chemical grouting is suitable for the improvement of loose soil to increase its cohesion and reduce permeability, thus make it more stable. This is happened because of high penetration ability of chemical grouting due to its low viscosity, that has broader dispersal areas compares to cement grouting. If comparing to the cement grouting, chemical grouting has lower improvement. However, it can easily penetrate into the loose soil and immediately seal it with solidified gel (Karol, 2003). Therefore, in some cases, chemical grouting is more useful and effective even if the improvement is lower than cement grouting (U.S. Army Corps of Engineers, 1995). In addition, the chemical grouting has able to generate low bleeding ratio as its properties to reach the mechanical properties (Wahyudi et al., 2016).

It is reported that two-solution chemical grouting method was established as a patent for soil improvement method by Jeziorski in 1887 (Herndon and Lenahan, 1976; Warner, 2001). Following enhancement of this method was developed by Joosten in 1926 (Herndon and Lenahan, 1976; Littlejohn, 1985), where he claimed patent of the advance two-shot process by reacting sodium silicate with a calcium chloride reactant type solution. According to Ellis (1963), sodium silicate-based grouting material is the most common chemical grout since 1919 owing to its wide application in construction such as tunnel, highway, and foundation. Moreover, sodium silicate-based chemical grouting is low cost and non-toxic nature (Guyer, 2015). Sodium silicates are, however, alkaline materials and pose hazards to the skin and eyes when physiologically contacted.

It has been well known that the performance of sodium silicate-based grouting material is determined by the components mixed in the grouting material. Therefore, chemical grouting application in Indonesia should be analyzed comprehensively to minimize the misconception on its technical ability. The chemical grouting application in Indonesia was interrupted by past accident case on the poisoned material used on the construction. In fact, the same material was occurring the similar accident worldwide including in Japan. In Japan, the strict regulation of material used is applied for this method after the accident. The sodium silicate based is one of base material that permitted to be used due to the safety consideration. In the case of performance, permeability reduction and strength increase value is the observed improvement variable that counts as the advantage of this method. The characteristics of chemical grouting have a huge influence, yet the effect to Indonesian soils is the priority to be observed due to lack of study about it. On the term of applicability of the method, this study is purposed to ensure the safety of sodium-silicate based chemical grouting in application to Indonesian sandy soils.

2 METHODOLOGY

2.1 Sodium Silicate-based Chemical Grouting Material

In 1887, a patent was granted to Jeziorski for a sodium silicate-based formula which could be mixed and injected on-site (Warner, 2001) in one-shot rapid injection process (Warner, 2004). Since Jeziorski's phenomenal sodium silicate-based grouting material is introduced, several types of material have been developed as an alternative of sodium silicate. Basically, those are a mixture of main materials and its catalysts which might change from solution to solidified in a specified time (gelling time). The most common chemical grouting main materials are sodium silicate, acrylate, lignin, urethane and resin grout (Guyer, 2015). However, although many others chemical grouting solution already introduced, due to its lowest toxicity to the environment, sodium silicate material still becomes the most popular chemical grouting. Sodium silicate, which also known as water glass, is formed by heating sand with Na2CO3. CO2 is released in the process and then finally produce sodium silicate (Na2O.xSiO2). Furthermore, it is usually diluted with water to increase the fluidity.

Based on silicate systems, there are types of system that widely used such as silicate-chloride-amide system, silicate-aluminate-amide system and silicate salt of a weak acid (Malmberg system) (Guyer, 2018) as mentioned in Equation (1). In this research, chemical grouting materials with Malmberg system is used. Reactants that are used in this system are classified as acid, alkali, or ammonium salts. Specific salt used are sodium bisulfite, sodium tetraborate, sodium bicarbonate, potassium hydrogen oxalate, potassium tetra oxalate, sodium aluminate, etc. General simplified formula of this Malmberg system is described below:

$$Na_2O \cdot x\,SiO_2\,(aq) + 2\,NaHCO_3\,(aq) \rightarrow x\,SiO_2\,(s) + 2\,Na_2CO_3 + H_2O \qquad (1)$$

The mixture of a solution of sodium silicate and solution of weak acid salt produces silica gel which is formed in alkaline condition. The setting of gelling time can be modified by its amount. The chemical grouting material product that used has reactant or accelerator component dominated by sodium bicarbonate (NaHCO3) and potassium bicarbonate (KHCO3). Together with sodium silicate, the solutions are mixed to produce 2 types of grouting material that have short gelling time and medium gelling time in order to match with injection method in chemical grouting work in the real construction field. The composition of chemical grouting is shown in Table 1. The characterization test was conducted by testing the gelling time and viscosity of each material.

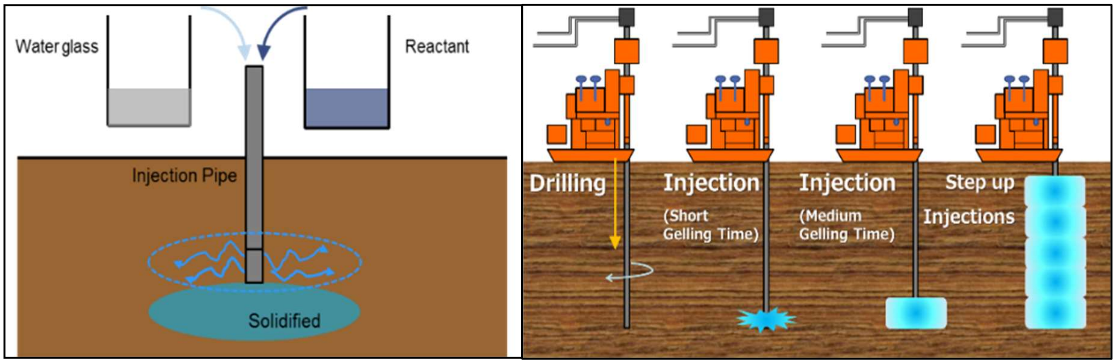

Figure 1. Schemes of chemical grout injecting method with sodium silicate-based

Table 1 Chemical Grouting Composition

Grouting Type	Sodium Silicate		Reactant 1 NaHCO3 (60-80%), KHCO3 (10-30%)	Reactant 2 NaHCO3 (40-60%), KHCO3 (40-70%)
	(% wt)	(% Vol)	(% wt)	(% wt)
Type 1	25.08	25	4.5	-
Type 2	25.31	25	-	2.9

2.2 Laboratory Leaching Test

To investigate the chemical grouting effect to ground water, Dutch Tank leaching test was conducted based on EA NEN 7375 standard (2004). There were 8 cycles of observation time to the leached water, which are 8 hours, 1 day, 2.25 days, 4 days, 9 days, 16 days, and 32 days from test started. In every cycle, a water sample was taken from the tank to be analyzed, afterward, the new distillate water was poured into the tank. Furthermore, water samples were directly analyzed for pH and also trace mineral by ICP measurement were conducted to obtain elements concentration on water sample. By using inductively coupled plasma (ICP), major metal concentrations in leached water were measured. The major metals that measured were Arsenic (As), Boron (B), Selenium (Se), Cadmium (Cd), Chrome (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), and Zinc (Zn). In order to replicate the actual site condition, the volcanic sand material which has well graded sand from Indonesian quarter volcano deposits was utilized on this test. The sand itself is molded and mixed with chemical grouting by pouring the sand layer into unsolidified chemical grouting then cured until the chemical grouting is solidified as illustrated on Figure 2. After cured, the sample is moved to the test tank that contained neutral fresh water. The cycle is started after the sample is placed properly on the observation tank as referred on Figure 2.

Figure 2. (a) Screening of medium well sand and sample creation (b) curing sample (c) Dutch Tank Leaching test

2.3 Bench Scale Test

On this research, double strainer pipe injection technique was applicated in bench scale test, which illustrated on Figure 1. The injection of both chemical grouting solutions is delivered through the pipe with the double chamber to inject sodium silicate and weak acid solution with 2 type gelling time (short and medium gelling time). The gelling time procedure and viscosity were obtained to ensure the applicability of these materials before the safety analysis was conducted.

Bench scale test to confirm the effect of chemical grouting could add confidence by validating the laboratory results. Availability and safety consideration would be the most prominent to be considered yet can be compared to laboratory test. The purposes of this research are to analyze the environmental effects of sodium-silicate based chemical grouting to the surroundings in application on Indonesian sandy soils. A field test was conducted in Jatinangor Area. Administratively Jatinangor is located in Sumedang District, West Java Province (Figure 3). From the geographical position of field test area, it was known that the geological condition of selected area located in a volcanic area. Furthermore, Bandung city itself is surrounded by a volcano with volcanic product covering surfaces of the area.

As shown form Figure 3, based on regional geology map of Bandung quadrangle, field test area lithological classified as part of Young Volcanic Rock (Qyu). These quaternary deposits described as undifferentiated volcanic products mostly from Mt. Tangkuban Perahu and Mt. Tampomas which composed by tuffaceous sand, lapilli, lava, and agglomerate (Silitonga, 1973). Furthermore, in near surface area, it is covered by yellowish gray to the reddish gray soil which are the weathering product of volcanic rock. Based on the description, tuffaceous sand is realistic lithology which might be suitable for chemical grouting injection test.

To determine the targeted layer, preliminary soil investigation was conducted on the point of preliminary hole, which is later will be used as pre-work condition. From the investigation, the depth of well graded sand with silt layer depth was found in 5 m to 6.5 m below the surface. The upper of sand layer is medium to stiff clay layer, with tuff layer on the bed of the targeted layer.

On bench scale test, chemical grouting was injected on 3 injection points in a triangle shape of improved soil. The chemical grouting is injected to a depth of 4 to 7 m into the subsurface layer. The condition after work was conducted from observation hole on distance of 10 m from grouting points. The observation of pH was conducted within 5 months and on 18^{th} day after injection the water sample was analyzed through the hole. The similar leachate materials were tested in the laboratory to confirm the bench scale test's data. By this approach, it is supposed that the effect of chemical grouting on the actual site can be analyzed.

In this study, ground water flow is the main considered parameter on designing of observation holes. Therefore, the observation holes were designed based on the geoelectrical survey data of the field that gave information on the existence of ground water (Christensen and Sørensen, 1998). In this study, the geoelectrical survey data is also used to create 2D model and confirm the stratigraphy of the study area.

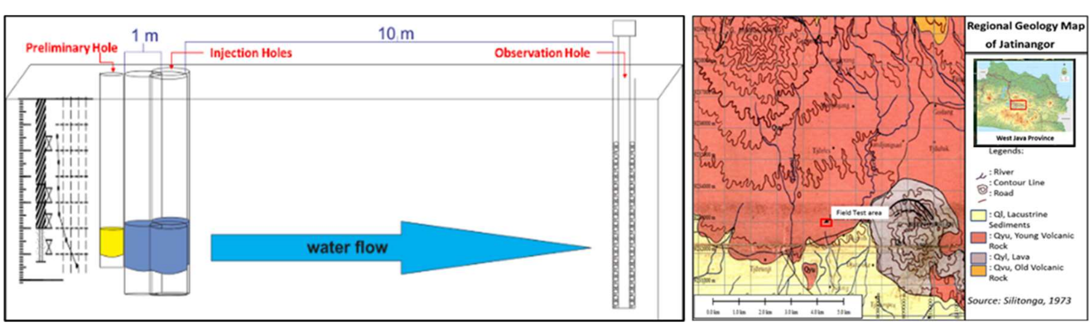

Figure 3. (Bottom Left) Bench scale test set-up and (Bottom Right) geologic map of Jatinangor (Silitonga,1973)

3 RESULTS AND DISCUSSIONS

3.1 Chemical Grouting Characterization

Applicability of the studied chemical grouting materials were studied by investigating the gelling time and viscosity of the materials. Gelling time of chemical grouting material was measured by observing the time required for a solution to gel or become so highly viscous. Viscosity test was conducted by measurement of viscosity of solution every 30 seconds. As the result, as shown at Figure 5a, type 1 chemical grouting material shows a faster gelling time (12s) than type 2 chemical gelling material (160s).

Therefore, the type 1 can be categorized as short gelling time, and type 2 can be categorized as medium gelling time. Considering to the gelling time of Type 1 chemical grouting material and Type 2 chemical grouting material, double pipe strainer injection method shall be considered if these types, particularly the type 1, are used, to avoid clog in the injection pipe when the material is transported from plant to the target injection area through the pipe. The short gelling time chemical grouting material is supposed to seal the existing pores to prevent the flowing of medium gelling time chemical grouting material and ensuring the grouting material permeates homogenously on the contained area. In term of viscosity, within the pre-mixing into gelling process, the viscosity of both types is 1 mPa.s, which is a water-like viscosity (see Figure 5a).

However, the Type 1 chemical grouting material shows a rapid solidification process (in 12s) with the viscosity reached more than 140 mPa.s. While Type 2 chemical grouting material takes 150s to begin the solidification process. The viscosity of type 2 chemical grouting material reaches 140 mPa.s in 125s after solidification is started. Both gelling time and viscosity parameters are complied with the application with double pipe strainer method which demanding water-like flow materials before two solutions mixing and two type gelling time with flash and medium on the each of grouting step.

3.2 Bench Scale Test Setup

To investigate the chemical grouting effect to ground water on the site, observation holes design is very crucial. In this study, the observation holes are designed based on geoelectrical survey data. The geoelectrical survey data is given in Figure 4. Geoelectrical survey resulting the low resistivity layer represented by blue color as indicated saturated layer. As shown on Figure 4, the flow of groundwater is interpreted flowing to the South. Moreover, this interpretation is supported by geomorphic condition from the view of general sloping elevation on the studied area that indicates a similar flowing direction.

Geologically, the result of geoelectric is in accordance with the boring log data, that shows the sandy (permeable) layer is laying on the beneath of Rock layer (Tuff), which is described in red to magenta color. The geological setup is assumed in accordance with the purpose of the research as the permeable layer was trapped by two impermeable layers on the top and the bottom. Considering this information, the observation hole was placed on southern of the injection holes area. Considering the geoelectrical, geomorphological and geological of the study area, observation hole is placed 10 m southern of the injection holes with interpretation that ground water will flow to the south carrying leachate material induced by chemical grouting that is injected to the injection holes.

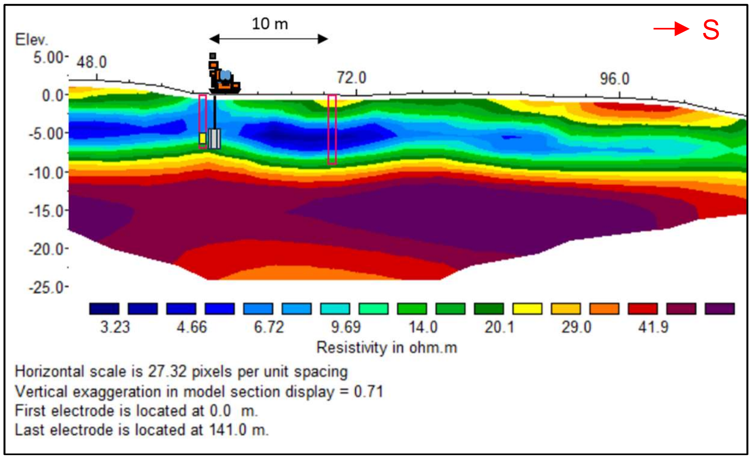

Figure 4. Geoelectrical survey with bench scale test set up

3.3 Safety Confirmation Result

As the result shows on Figure 5b, few changes of pH observed. From the pH observation on laboratory, it shows increased pH value due to the existence of chemical grouting due to the basic condition of solidified chemical grouting. However, on the result of site observation, the fluctuation of pH not significantly affected after grouting work. The water volume on laboratory test is only 5 times sample volume which represents the worst condition.

The leachable metals from the result of laboratory result shows the amount of lead (Pb), copper (Cu), Cadmium (Cd), Arsenic (As), Boron (B), Selenium (Se), Chromium (Cr), Manganese (Mn) and Zinc (Zn) even from the sand itself as shown. The presence of chemical grouting materials could reduce the leaching of Lead, in opposite the Arsenic leaching increased on grouted soil type 1. The other metals are leaching in comparative amount on each sample. The leaching of metals from laboratory test result was suspected to be leached due to the basic condition formed by presence of chemical grouting due to the test is considering the worse condition.

In actual field test result, the leaching behavior as occurred on the laboratory test, it may due to the normal pH on both before and after the grouting work. The observed rising leached material after grouting was found on Boron, otherwise leachate was reduced after grouting. We believe that, chemical grouting presence has minor impact to the groundwater and permeable soil.

The early observation of chemical grouting work effect to the groundwater may observed from pH monitoring accordance to the Japanese chemical grouting design documentation (Japanese Grout Association, 2013). Based on monitoring result of bench test on pH and concentration of heavy metals in ground water within 5 months, changing pH and heavy metals concentration in groundwater is still in the range of normal level of national standard for water quality.

However, due to volume of chemical grouting materials that injected into the soil, it shall be concerned that the sodium silicate-based chemical grouting injection work must be done in accordance with approved standard operating procedures and design. Furthermore, the monitoring on groundwater quality near construction work must be done to secure the groundwater quality around construction site.

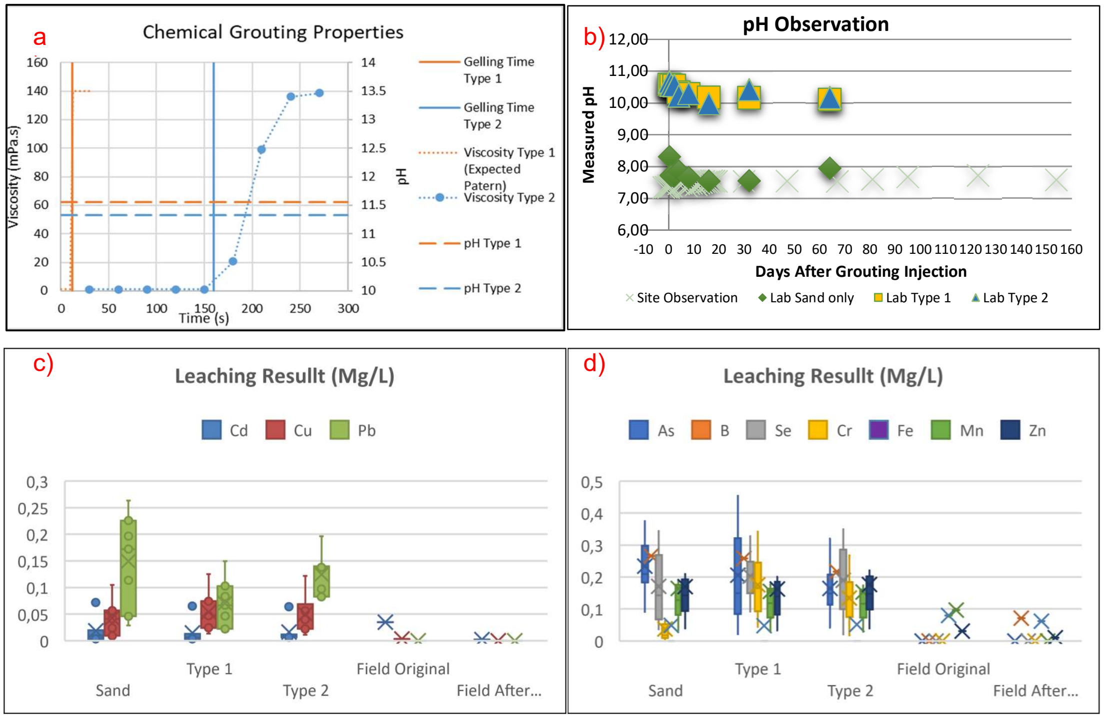

Figure 5. Chemical grouting characteristic, pH observation, leaching test result from laboratory test and field test

4 CONCLUSION

Safety of chemical grouting in Indonesian volcanic soil was carried out by sequences of experiments, started by characterization test of chemical grouting, continued by laboratory test in Indonesian volcanic soil and confirmation test in bench scale test. The results of experiments can be resumed as follows:

a) Properties of chemical grouting shall be accordance to the method selection, the viscosity and gelling time shall be tested and relate to the applicable design with the consideration of technologically proper.

b) The increasing amount of metals leaching is highly influenced by pH of water that shown by leaching result on laboratory that not occurred on bench scale test result. The laboratory result showing the worst-case scenario of leachable materials.

c) Sodium silicate based chemical grouting with weak acid reactant on the bench scale test result shows the chemical grouting leachable material insignificantly occurred as can be considered as environmentally friendly.

d) The monitoring of pH on the near of construction area demanded as early warning of leachate metals on surrounding groundwater to prevent further accident due to misconducted construction procedure.

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