Soil Reinforcement using Waterglass and Sulfuric Acid with Injection Grouting Method

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ABSTRACT

A common problem often encountered in infrastructure development, especially in tunnelling projects, involves non-cohesive soils with high groundwater levels. In tunnelling projects, the existence of non-cohesive soil is very susceptible to collapse, hindering work and even causing loss of life and damage to buildings around the construction area. To prevent such a non-cohesive soil collapse, a barrier or temporary wall is needed for the jacking installation to be carried out safely. An efficient method to achieve this is temporary reinforcement with the injection grouting method using waterglass and sulfuric acid as activators. Waterglass and sodium silicate are widely utilized in construction. This study deploys an experimental approach with two testing concepts to obtain the composition of grout materials. The first test involves simulating tunnelling on unsaturated sandy soil, while the second test is carried out on saturated sandy soil to simulate high groundwater level conditions. The analysis was conducted based on the characteristics of the sandy soil collapse zone, using parameters, such as the coefficient of permeability, direct shear test results, soil density, and index properties. The test was carried out using grouting injection with waterglass and sulfuric acid, which proved effective, since they formed a gel layer that prevents the collapse of non-cohesive soil, even under high groundwater level conditions. The novelty of this study lies in the combination of waterglass and sulfuric acid with an optimal composition with the change to gel faster to improve time efficiency during construction.

Keywords-grouting; waterglass; sulfuric acid; non-cohesive soil

I. INTRODUCTION

Microtunneling is a common underground construction method employed for tunnels or pipelines, particularly in urban areas. It is usually carried out to complement infrastructure by serving wastewater disposal from densely populated or industrial areas. To avoid damage in the vicinity, the work must be carried out by paying attention to the existing conditions. Microtunneling work utilizing the jacking pipe method uses two shafts: the starting pit/shaft and the arriving pit/shaft in which there are pipes installed using jacking tools. This work is very risky when carried out on loose or non-cohesive sandy soils, which are very susceptible to subsidence and high groundwater levels (immediate settlement) [1-4]. Improvements are needed to be made to sandy soils for accidents during construction to be prevented. At the start of the jacking work, it is necessary to enhance the entrance hole in the starting pit before the cutter head of the jacking tool is released so that landslides do not occur.

Various improvement or reinforcement methods for non-cohesive soils have been utilized [5]. Such an approach is the injection grouting method using chemicals [6-8], which is carried out in the entrance hole area. Several previous studies have examined various grouting injection materials using cement. However, cement requires a long setting time, thus affecting the construction process duration [8-10]. An alternative to save time without reducing workability and still strengthen non-cohesive soils before landslides or collapse occurs is waterglass and sulfuric acid utilization as grout materials, where waterglass acts as an activating agent [10, 14].

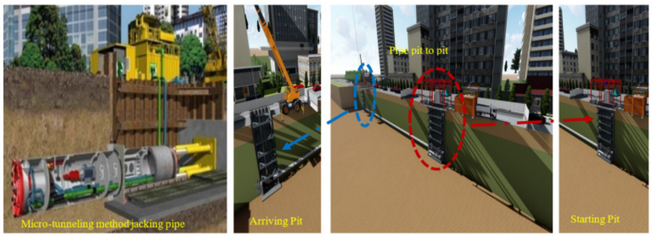
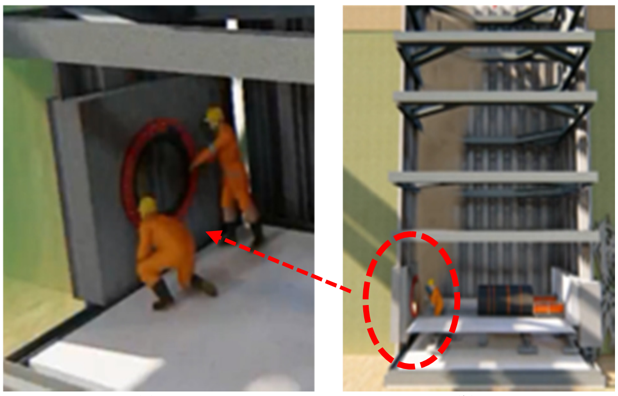


Fig. 1. Jacking pipe process.

Fig. 2. Realization jacking pipe process.



(a) (b)

Fig. 3. Overview of the entrance hole in the starting pit area: (a) entrance hole at starting shaft, (b) cutter head inside jacking tools.

Fig. 4. The Injection process at the entrance hole in the starting pit area.

Several studies have shown the effectiveness of numerous chemical materials in increasing soil strength [11-13, 17]. Chemical material usage for non-cohesive soil reinforcement has a significant impact in terms of time efficiency, while it also speeds up the construction process [18]. One of the injection/grouting materials that can save time without reducing workability is waterglass or sodium silicate [12, 20-28]. However, no previous research has specifically discussed the use of a waterglass and sulfuric acid combination on sandy or non-cohesive soils. In this study, modeling was performed on a small scale with a combination of waterglass and sulfuric acid inserted in sandy soil through an injection method. The present work aims to obtain the best composition of grouting materials using waterglass and sulfuric acid chemicals for optimal soil improvement to be obtained.

II. MATERIALS AND METHODS

A. Materials

The materials used in this study are loose sand soil as the object of research, and waterglass and sulfuric acid as grouting materials. Other materials utilized can be seen in Figure 5.

Fig. 5. (a) Sandy soil, (b) waterglass, (c) sulfuric acid, (d) grouting tools, (e) modeling drums, (f) grouting sample boxes, (g) grouting material storage bins.

1) Characteristics of Grouting Material

This study employs two types of injection/grouting materials, illustrated in Tables I and II. The waterglass material from the factory has a solution proportion of 45% with a molarity value of 3.687 M, while sulfuric acid has a solution proportion of 52% with a molarity value of 5.302 M. The material utilized in this study is corrosive, hence personal protective equipment was deployed and proper handling was performed.

To obtain the most optimal injection/grouting composition using waterglass and sulfuric acid materials, research was carried out. Trial and error testing was performed on seven composition types, as can be seen in Table III.

During the mixing process, temperature changes were observed, as well as a period when the composition began to lose liquidity, and a subsequent transition to a fully gelled state. The experimental results exhibited that composition 6 gets faster reaction results than other composition variations, followed by composition 3. The only difference between these two compositions is the ratio of waterglass to water, while that of sulfuric acid is the same.

TABLE I. CHARACTERISTICS OF GROUTING MATERIAL

Waterglass (sodium silicate)		
Description	**Value**	**Annotation**
Proportion of solution	34-55%	Against water
Molecular formula	Na_2SiO_3	-
Molecular weight	122.063 g/mol	-
pH	11-12	-
Melting/freezing point	< 1600 °C / < 0 °C	-
Boiling point	>2230°C	-
Oxidizing agent	184.04	-
Relative specific gravity	1.00	At 20°C
Sulfuric acid		
Description	**Value**	**Annotation**
Proportion of solution	52-100%	Against water
Molecular formula	H_2SO_4	-
Molecular weight	98.08 g/mol	-
pH	1	-
Melting/freezing point	10.36 °C	(purity 93-100%)
Boiling point	290-270 °C	°C
Vapor pressure	1,33 hPa	At temp. 145.8°C
Relative specific gravity	1.84 g/cm³	At temp. 25°C

According to the test results, the mixture variation with a 50:50 waterglass to water ratio exhibited a gelation time of more than one min, specifically 64 and 70 sec. As for the most optimal composition of sulfuric acid, this is its 4.5:95.5 ratio to water. This can be seen from the reaction time it takes to become a gel in the 3rd and 6th compositions, where each composition reacts into a gel within 6 and 10 sec. However, the most optimal composition, in terms of reaction time and material efficiency, was the sixth mixture, consisting of a 60:40 waterglass to water ratio, and a 4.5:95.5 sulfuric acid solution to water ratio.

TABLE II. COMPOSITION VARIATIONS USING WATERGLASS AND SULFURIC ACID

Composition	Waterglass ratio	Sulfuric acid ratio	Chemical molarity (waterglass)	Chemical molarity (sulfuric acid)
Comp. 1	50:50	4:96	1.843	0.212
Comp. 2	50:50	4.5:95.5	1.843	0.239
Comp. 3	70:30	4.5:95.5	2.581	0.239
Comp. 4	70:30	5:95	2.581	0.265
Comp. 5	60:40	4:96	2.212	0.212
Comp. 6	60:40	4.5:95.5	2.212	0.239
Comp. 7	60:40	5:95	2.212	0.265

2) *Characteristics of Soil*

Regarding the laboratory testing resluts for sandy soil, its physical and mechanical properties are portrayed in Table III. The physical test results, including sieve analysis [29, 30] indicate that the material used is predominantly coarse-grained at 96.6%, with fine-grained soil consisting of silt and clay at 3.2% and 0.2%. Based on the sieve analysis, it can be concluded that the utilized soil is non plastic, and therefore, Atterberg limits testing was deemed unnecessary. The sieve analysis results reveal that 96.6% of the material is reatined on siefe/sieve No. 200. According to the test results, the soil sample contains less than 35% passing/ less than 35% of the soil sample passes through sieve No. 200, classifying it as a granular or coarse-grained material, falling within the A-1, A-2, or A-3 categories.

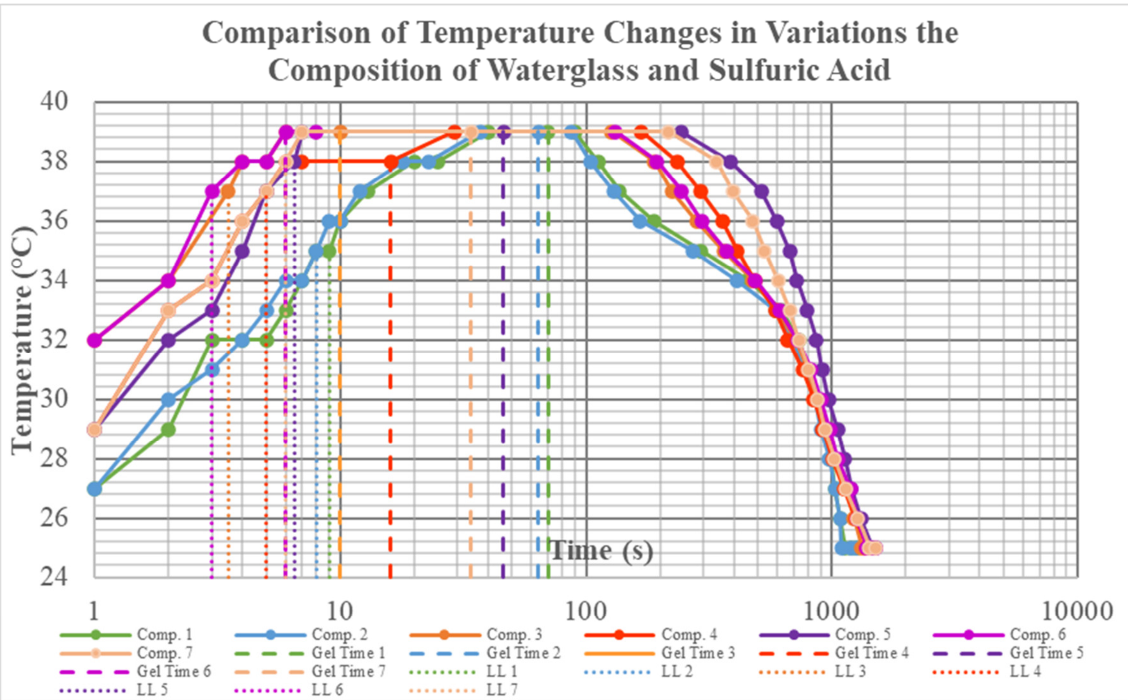


Fig. 6. Comparison graph of temperature changes in composition variations of waterglass and sulfuric acid.

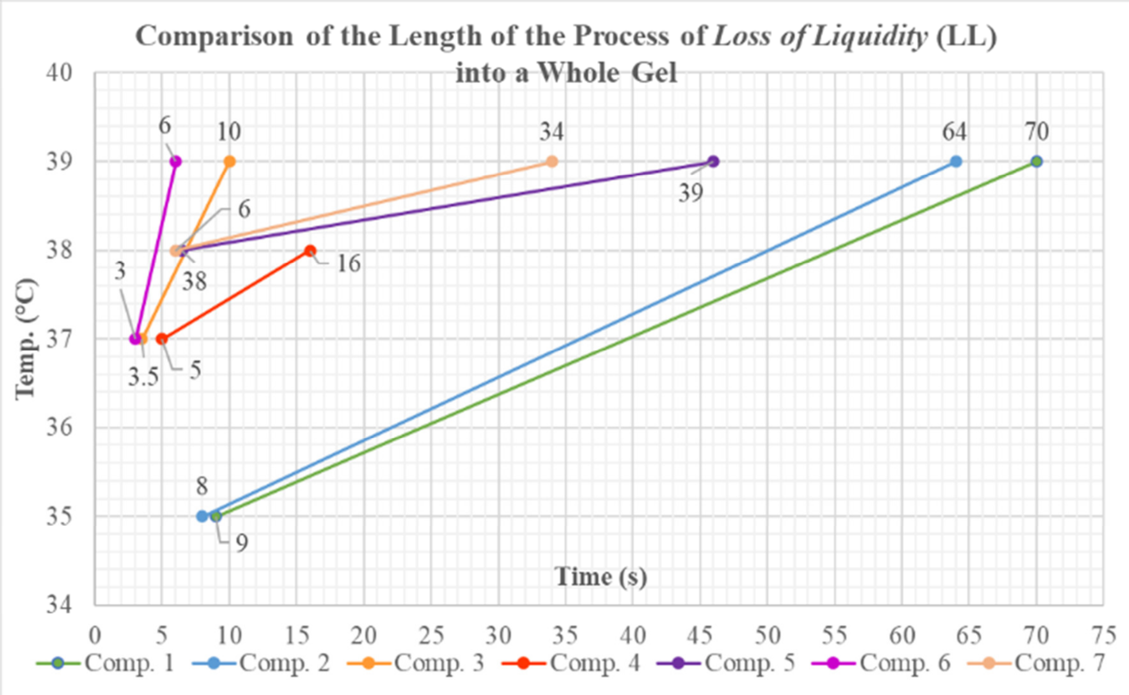


Fig. 7. Graph of time comparison to a complete gel on variations in the composition of waterglass and sulfuric acid.

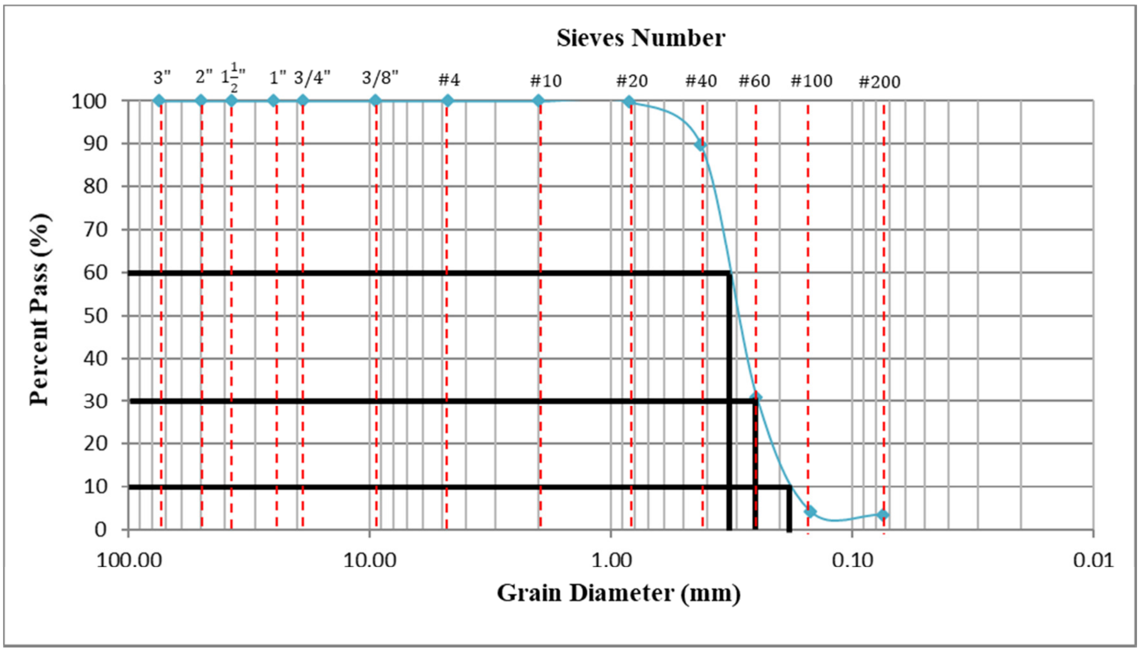


Fig. 8. Soil particle size distribution graph.

TABLE III. GROUTING MATERIAL COMPOSITION

	Container 1		Container 2	
	Waterglass	Water	Sulfuric acid	Water
Solution (L)	120	80	9	191
Total	200		200	
Ratio	60:40		4.5:95.5	

The tested sample has 89.8% passed through sieve No. 40 and 3.4% through sieve No. 200. As depicted in Table III, the soil used in this study falls under the A-3 category, meeting the criteria of at least 51% of it passing sieve No. 40 and a maximum of 10% passing sieve No. 200 [30]. Considering the USCS Classification, more than 50% of the test material is reatined on sieve No. 200, being categorized as sand. Additionally, the percentage passing sieve No. 200 is less than

5%, being classified as clean sand. Furthermore, with a coefficient of uniformity (Cu) < 6.0 and/or a coefficient of curvature (Cc) outside the range of $1.0 \leq Cc \leq 3.0$, the sand used in this study is classified as Poorly Graded Sand (SP), while with less than 15% gravel content, the soil classification remains SP [31].

The mechanical property testing results are: The standard compaction test yielded a maximum dry density of 1.76 g/cm³ and an optimum moisture content of 10.4% [33, 34].

TABLE IV. SOIL CHARACTERISTICS

Testing	Value
Water content %	5.1
Specific gravity	2.63
Sieve analysis	
Gravel %	0.0
Sand %	96.6
Silt	3.4
Clay %	0.0
USCS classification	SP
AASHTO classification	A-3
Standard proctor	
Maximum dry unit weight (g/cm^3)	1.760
Optimum water content	10.4

B. Research Methods

This study employs a quantitative method, relying on experimental data collected in the field. The research approach is designed based on previous studies and new findings that are relevant and interconnected [15-16]. ASTM and SNI standards are used as references, including standards for testing physical and mechanical properties [32]. The research procedures are conducted in a structured and comprehensive manner, ensuring that the results of each test or analysis can be integrated. Figure 10 illustrates the detailed steps of the injection/grouting tests used in the modeling of tunneling or underground pipeline works.

Four test schemes were conducted: the first involved no injection or grouting, under both unsaturated and saturated soil conditions. The second test scheme entailed injection/grouting under both unsaturated and saturated soil conditions. The test steps are carried out by inserting soil into the test drum with a predetermined height. The total height of the non-cohesive soil that enters the drum is 60 cm high; the density of the sample is in accordance with previous research. After that, for saturated conditions, water is put into a drum that already contains soil. Water filling is stopped when water has come out on both taps in the upper position. This indicates that the groundwater level has risen significantly.

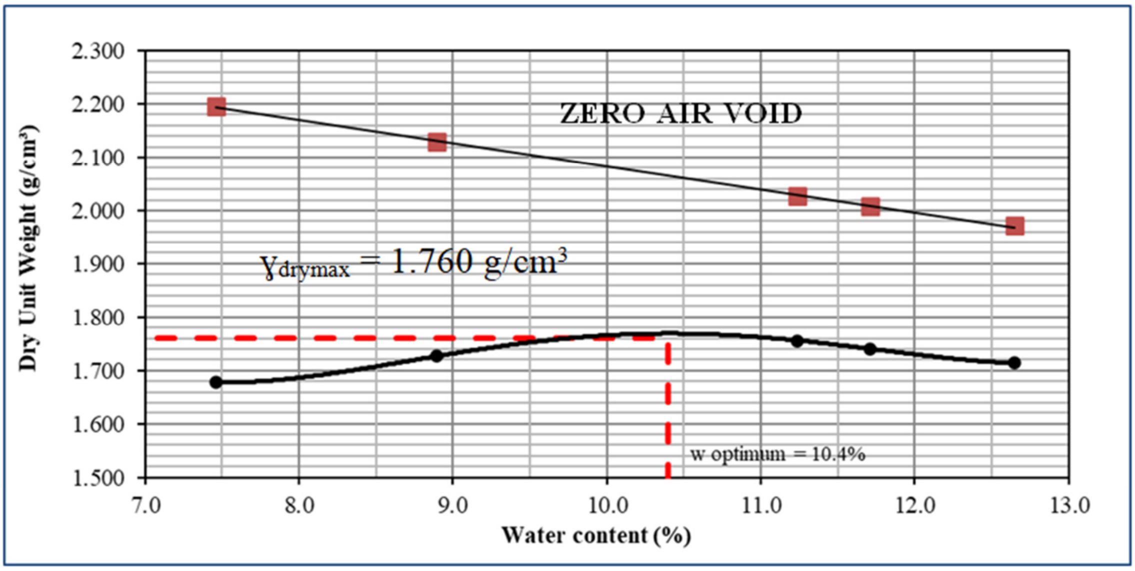


Fig. 9. Compaction test results..

III. RESULTS AND DISCUSSION

The results demonstrated that the non-cohesive soil does not collapse and is held back by the gel wall created from a mixture of waterglass and sulfuric acid.

After performing the grouting modeling, samples were taken to the lab for testing. The results of direct shear tests after grouting for non-cohesive soil using waterglass and sulfuric acid on a laboratory are shown in Table V. Direct shear tests were conducted under two conditions: unsaturated and saturated, [35, 36], as well as before and after injection/grouting. The test results exhibited an increase in cohesion values by 79.63% and 210.53% under unsaturated and saturated conditions, respectively. Conversely, the internal friction angle decreased by 10.07% and 41.75% under the same conditions. The permeability test results, outlined in Table VI, demonstrated a 47.5% reduction in the permeability coefficient, indicating that the soil's pore spaces were filled by the injection/grouting fluid.

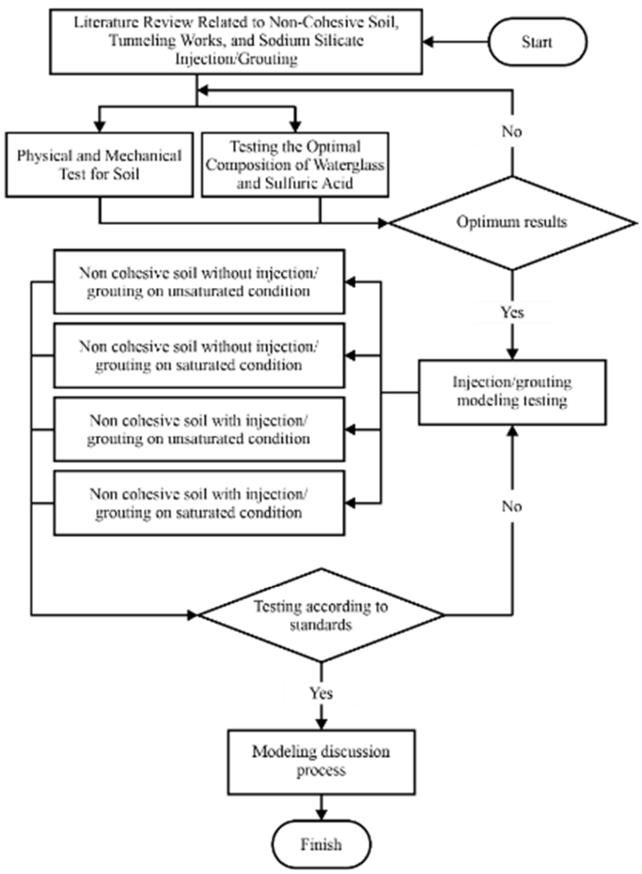


Fig. 10. Flowchart of the testing procedure for evaluating soil improvement through injection/grouting in tunneling applications.

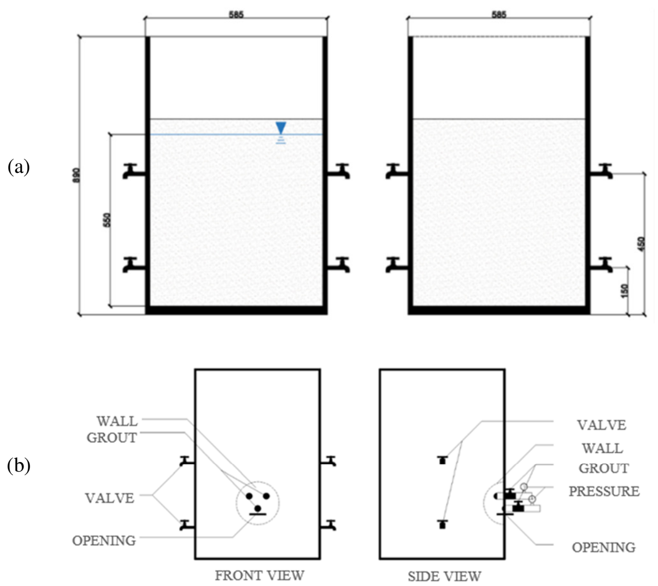


Fig. 11. (a) Visualization of the test model tank under saturated (left) and unsaturated (right) soil conditions used for grouting evaluation. (b) Front view and side view of the test model tank.

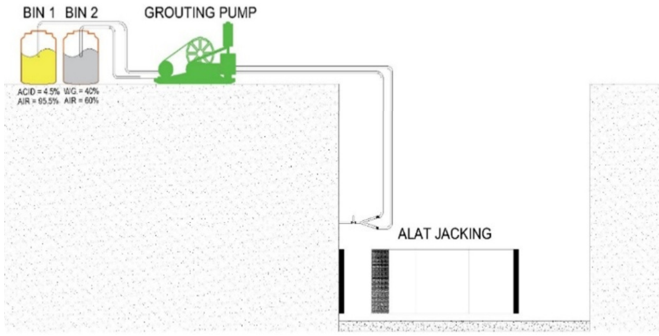


Fig. 12. Visualization of the equipment setup during field application at the construction site.

(a) (b)

Fig. 13. (a) The soil collapse without injection/grouting for modeling, (b) the soil collapse on site without injection/grouting.

Fig. 14. The soil does not collapse after being grouted for modeling.

TABLE V. PROPERTIES OF SOIL BEFORE AND AFTER INJECTION/GROUTING

No	Parameter	Sandy Soil before grouting (unsaturated /saturated)	Sandy Soil after grouting (unsaturated /saturated)
1	Cohesion (kg/cm^2)	0.07/0.04	0.13/0.11
2	Internal friction (^{o})	24.77/22.91	22.27/13.3
3	Wet unit weight (g/cm^3)	1.799/2.100	1.620/1.833
4	Dry unit weight (g/cm^3)	1.630/1.814	1.190/1.449
5	**Deformation (cm)**		
	Load 5 kg	0.09/0.41	0.09/0.06
	Load 10 kg	0.070.37	0.16/0.07
	Load 20 kg	0.09/0.40	0.23/0.18
6	Void ratio (%)	0.61/0.45	1.28/0.82
7	Water content (%)	10.40/15.65	39.20/26.44
8	Porosity (%)	38.00/31.02	54.77/44.92
9	Saturation degree (%)	44.63/92.32	76.42/86.40

Fig. 15. The soil did not collapse after being injected at the entrance hole in the pit of the construction area.

TABLE VI. PERMEABILITY TEST RESULT

Parameter	Before grouting	After grouting
Cross-sectional area of the sample in cm^2 (A=1/4pD^2)	33.696	33.696
Height of water in cm (h)	22.5	22.0
Height of the sample in cm (L)	13.5	13,5
Elapsed time increment in sec (t)	60.0	60.0
Temperature in ^{o}C (T)	28.0	28.0
water discharged in cm^3 (Q)	150	77.0
Coefficient of permeability in cm/sec (Q.L / h.A.t)	0.0445	0.0234

The soil property test results are presented in Figures 16-23.

Fig. 16. Comparison graph of permeability coefficient values before and after grouting.

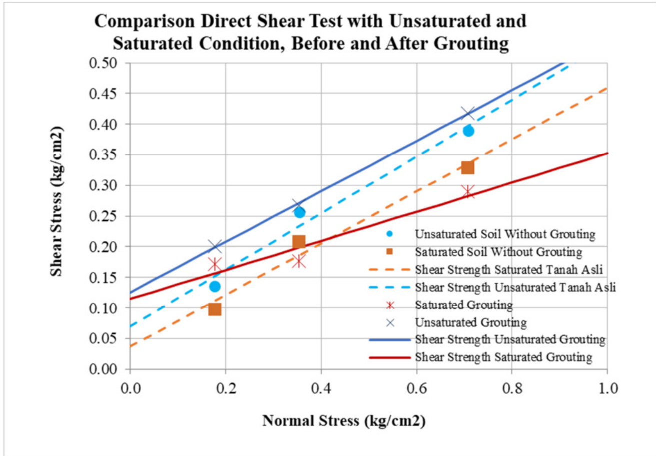


Fig. 17. Comparison chart of direct shear test results before and after grouting.

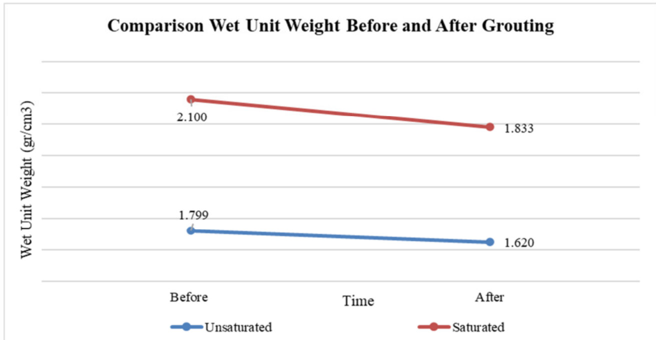


Fig. 18. Comparison chart of wet unit weight before and after grouting.

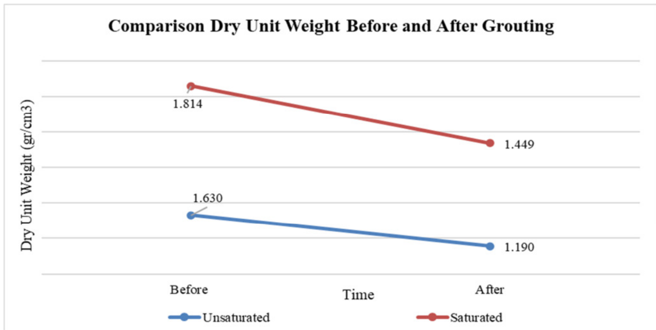


Fig. 19. Dry unit weight comparison chart before and after grouting.

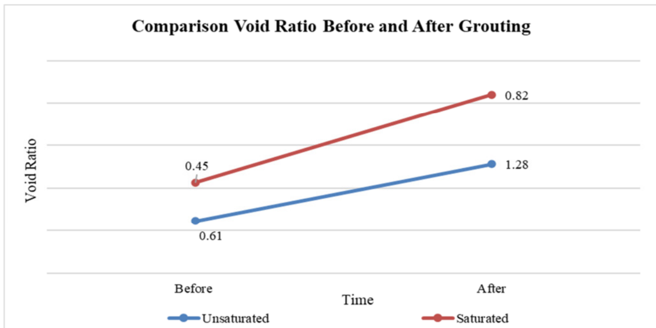


Fig. 20. Comparison graph of void ratio before and after grouting.

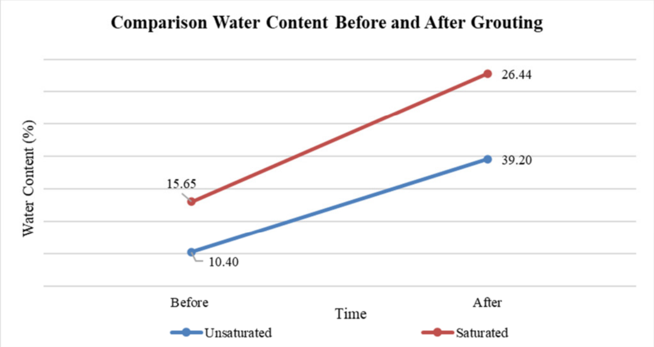


Fig. 21. Moisture content comparison graph before and after grouting.

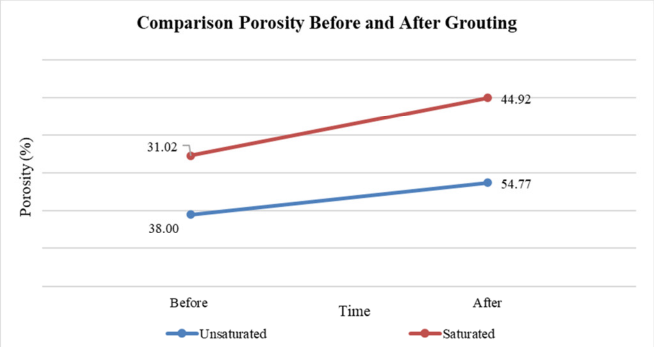


Fig. 22. Porosity comparison chart before and after grouting.

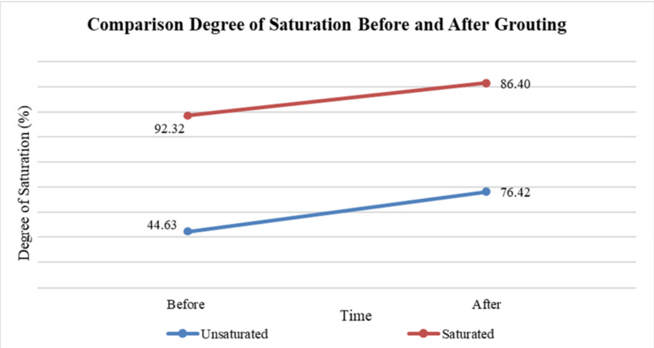


Fig. 23. Comparison graph of saturation degree before and after grouting.

IV. DISCUSSION

The test results show that injection/grouting used with a combination of waterglass and sulfuric acid effectively improves the mechanical properties of non-cohesive soil in both unsaturated and saturated conditions. In the direct shear test, cohesion values increased by 79.63% under unsaturated conditions and 210.53% under saturated conditions. This demonstrates the effectiveness of the waterglass and sulfuric acid combination in reinforcing coarse-grained soil, which is prone to collapse, especially in areas with high groundwater levels.

However, the internal friction angle decreased by 10.07% and 41.75% under unsaturated and saturated conditions, respectively. This decline indicates that the injected material fills the soil pores, reducing inter-particle friction. Additionally, the permeability coefficient decreased by 47.5%, indicating that the grouting fluid successfully filled the soil's pore spaces, reducing water flow and enhancing soil stability.

Compared to traditional methods, such as cement use, this method is more time-efficient and provides comparable or superior results in terms of soil stability. These findings align with those of previous studies on the effectiveness of chemical grouting for soil stabilization [12, 19-20]. However, a significant distinction is the use of the waterglass and sulfuric acid combination, which offers better time efficiency and optimal stability.

V. CONCLUSION

This study shows that the injection/grouting method using a combination of waterglass and sulfuric acid is highly effective in preventing the collapse of non-cohesive soils. An increase in the cohesion value and a reduction in the permeability coefficient are key indicators of this method's effectiveness. The observed reduction in the internal friction angle should be considered as part of the reinforced soil characteristics.

In conclusion, the combination of waterglass and sulfuric acid provides a practical solution for soil stabilization in tunnel and underground pipeline work, especially in areas with non-cohesive soils and high groundwater levels. The study also introduces a new, more efficient approach compared to traditional methods, with relevant applications for future infrastructure projects.

A. Key Findings

- In the trial-and-error test on the composition of the injection material, composition 6 obtained the fastest result from Loss of Liquidity to become a complete gel from 6 to 10 sec.
- Cohesion values significantly increased after grouting, by 79.63% in saturated conditions and 210.53% in saturated conditions.
- An internal friction angle decrease of 10.07% in the unsaturated condition and 41.75% in the saturated condition was observed, indicating that the grouting material filled the void, reducing particle friction.
- The coefficient of permeability reduced by 47.5%, demonstrating the effectiveness of grouting in filling soil pores and reducing water flow. This result in line with the result of porosity and internal friction angle parameters.

B. Practical Implications

- This method offers a practical solution for soil stabilization, especially in tunnel and underground pipeline construction.
- The use of this material combination accelerates construction time without compromising soil stability.

C. Novelty and Contribution

This study presents a new combination of waterglass and sulfuric acid for soil stabilization, filling a gap in previous research that mostly focused on cement-based grouting.

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