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Proposed Grout Mix Design and Application Orientation of Silicate-Cement Injection in Project Management for Seepage Control in Sandy Foundations of Hydraulic Structures

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KEYWORDS

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ABSTRACT

This study investigates the potential of Silicate-Cement grout mixtures for emergency seepage control in sandy foundations of hydraulic structures. Laboratory experiments were conducted to assess the effects of three key parameters: Silicate-to-Cement (S/C) ratio, Water-to-Cement (W/C) ratio, and Silicate-Cement solution to Sand (S-S-C/Sand) ratio on gelation time, compressive strength, and permeability. The findings reveal that each factor significantly influences the material's workability, seepage resistance, and mechanical performance. The optimal mix designs for different technical objectives were determined, including fast gelation for emergency situations, effective soil reinforcement for loose sand foundations, and sealing fine voids. The Silicate-Cement system provides rapid gelation, excellent penetrability, and controllable setting times, making it ideal for use in urgent foundation treatments in regions prone to high seepage velocities. This paper also discusses the potential applications of Silicate-Cement grout for enhancing hydraulic infrastructure and other civil engineering projects under challenging geological conditions. The study contributes to standardizing techniques and optimizing grout mix compositions for practical implementation in Vietnam, aiming to improve construction efficiency and environmental sustainability in seepage control.

1. Introduction

With the intensification of global climate change, extreme weather events such as prolonged heavy rainfall, flash floods, and tidal surges are occurring with increasing frequency and intensity. These phenomena pose serious threats to the stability and safety of hydraulic infrastructure systems, including earth dams, culverts, pumping stations, and dike networks. Among the most critical geotechnical risks is subsoil seepage, which often leads to piping, internal erosion, differential settlement, and even catastrophic structural failure. In emergency construction scenarios or remote locations where conventional ground improvement techniques are difficult to deploy, the selection of a grouting material that is both technically effective and environmentally sustainable becomes a major engineering challenge.

Conventional grouting methods-such as permeation grouting, pressure grouting, and jet grouting-have been widely applied in Vietnam over the past decades. These approaches typically employ cement-based or cement-bentonite suspensions, which are economical and well-established. However, in sandy foundations with high permeability and active seepage, these traditional grout mixtures often exhibit delayed gelation and poor penetrability. Consequently, grout washout and incomplete setting frequently occur before the material can effectively seal the seepage pathways, reducing field performance and leading to costly remediation efforts.

To overcome these limitations, chemical grouting solutions-particularly those involving sodium silicate (commonly referred to as liquid glass)-have garnered increasing interest. When combined with Portland cement, the sodium silicate-cement grouting system demonstrates favorable properties, including rapid gelation (ranging from a few seconds to several minutes), improved mechanical strength, and enhanced infiltration capacity in loose, granular soils. Furthermore, the material system offers the potential for customizable setting times through careful adjustment of component ratios, making it suitable for time-sensitive construction tasks. Although this approach has seen preliminary application in several regions of Vietnam (e.g., Ca Mau and parts of Central Vietnam), a comprehensive scientific investigation of its behavior under controlled conditions remains limited.

This study aims to fill that gap by conducting a series of laboratory experiments to evaluate the effects of three primary mix design parameters-Silicate-to-Cement ratio (S/C),Water-to-Cement ratio (W/C), and grout-to-sand ratio-on key technical performance indicators. These include initial setting time, unconfined compressive strength (UCS), and the coefficient of permeability. The results are expected to provide critical insights into the optimization of chemical grout compositions for emergency seepage control in sandy soils and to support the development of standardized technical guidelines for future engineering applications in Vietnam.

By establishing a scientific foundation for the practical use of silicate-cement grouting systems in hydraulic and geotechnical

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engineering, this research contributes to enhancing infrastructure resilience in the face of climate-induced disasters. It also opens new directions for environmentally compatible ground treatment techniques tailored to the challenges of Vietnam conditions.

2. Theoretical background and material overview

2.1. Theoretical Basis of Chemical Jet Grouting

Chemical jet grouting is a ground improvement technique that involves injecting a low-viscosity chemical solution-typically free of suspended solid particles-into soil or rock formations to enhance their geotechnical properties such as permeability, strength, and stability. Upon injection, the grout penetrates the voids and pores within the soil matrix. A subsequent chemical reaction occurs, forming either a gel membrane or a hardened mass that binds soil particles together. This results in the formation of impermeable zones or reinforced strata, effectively reducing seepage and improving structural performance.

Unlike conventional cementitious grouts, chemical grouts offer a high degree of controllability over setting time, which is a critical parameter in emergency seepage treatment scenarios. In environments with high seepage velocity, rapid gelation is essential to prevent grout washout before the material sets. Additionally, the small molecular size of chemical grout components enables superior penetration into loose or sandy soils, where traditional cement-based grouts-due to their larger particle sizes-often fail to infiltrate effectively.

According to the U.S. Army Corps of Engineers (1995) [1], commonly used chemical grouting materials include silicates, acrylates, polyurethanes (PU), resins, and lignin-based compounds. Among these, silicate-based systems-particularly those utilizing sodium silicate-are widely regarded as the most effective overall. This is attributed to their excellent permeability characteristics, adjustable setting times, low toxicity, and relatively cost-effective nature. Sodium silicate's ability to form durable gels in various soil conditions makes it especially suitable for applications requiring rapid response and long-term performance.

2.2. Overview of Silicate-Cement Materials

2.2.1. Sodium Silicate (Liquid Glass)

Chemical jet grouting (CJG) is a technique that involves injecting a liquid chemical solution-free of suspended solid particles-into soil or rock formations to improve properties such as permeability, strength, and overall structural stability [2]. The solution permeates into pore spaces and voids within the ground, where it undergoes a chemical reaction to form either a gel membrane or a solidified mass that binds soil particles together. This process results in the creation of impermeable barriers or reinforced zones within the treated ground. Compared to conventional cementitious grouts, chemical grouting materials offer a distinct advantage in terms of adjustable gelation time, allowing for flexible setting control. This feature is especially beneficial in emergency situations involving high seepage velocities, where rapid gelation is critical to prevent grout washout before the reaction completes. Furthermore, the small molecular size of chemical grouts enhances their ability to infiltrate sandy or loose soils, where traditional cement-based grouts-due to larger particle sizes-often face penetration limitations. Among the various chemical grout materials available, sodium silicate is widely regarded for its overall effectiveness. It demonstrates strong penetrability, fast setting, low toxicity, and cost-efficiency, making it a practical and reliable choice for real-world field applications [3]-[5].

Portland cement is used as a hydraulic binder to enhance the mechanical strength of the grout mixture after the initial gelation of the silicate component. When cement is combined with a sodium silicate solution, a secondary chemical reaction occurs between calcium hydroxide ($Ca(OH)_2$)-a product of cement hydration-and the silicate ions. This reaction produces additional gel-like compounds, increasing both the viscosity and the long-term strength of the grouted mass. The typical chemical reaction can be expressed as follows [6]:

$$Ca(OH)_2 + Na_2SiO_3 \rightarrow CaSiO_3 + 2NaOH \quad (1)$$

This reaction leads to the formation of calcium silicate hydrate (C-S-H), a key binding phase responsible for strength development in cementitious systems. The formation of C-S-H gel contributes to reducing permeability and improving the cohesion of soil particles, thus enhancing the durability and effectiveness of the silicate-cement grouting system. Calcium silicate ($CaSiO_3$) is formed as a gel-like product that plays a crucial role in binding sand particles, forming impermeable membranes, and enhancing interparticle adhesion. The incorporation of cement into the chemical grouting solution not only facilitates the chemical reaction with sodium silicate but also significantly improves the mechanical performance of the hardened grout. Specifically, the addition of cement results in a final mixture with higher compressive strength, long-term stability, and load-bearing capacity. These attributes are critical for meeting the stringent technical requirements of construction applications, particularly in projects that demand durable seepage control or long-term ground reinforcement, such as earth dams, pumping stations, and underground culvert systems. By integrating both the chemical gelation properties of sodium silicate and the structural enhancement offered by cement hydration products, the silicate-cement system represents an effective and adaptable solution for complex geotechnical conditions.

2.2.2. Outstanding Advantages of the Silicate-Cement Material System

The silicate-cement grouting system demonstrates a range of technical advantages that make it particularly suitable for emergency seepage control and foundation treatment in hydraulic engineering projects. Its unique properties arise from the synergistic interaction between sodium silicate and cement, offering both rapid gelation and long-term structural integrity.

Key benefits of the system include:

Controllable Gelation Time: Easily adjustable from 10 to 600 seconds, depending on site conditions and mix design.

Superior Penetrability: With particle sizes ranging from 5 to 50 nanometers, the grout can permeate sandy or loose soils with high efficiency.

Environmental Safety: Non-toxic, non-flammable, and environmentally benign-suitable for use near water bodies and ecologically sensitive areas.

High Compressive Strength: When optimally formulated, the grout can achieve compressive strengths exceeding 8 MPa after 28 days of curing.

Excellent Seepage Resistance: The hardened mass exhibits a permeability coefficient below 0.1 × 10^{-5} cm/s, making it highly effective for forming impermeable barriers.

Table 1. Typical Technical Indicators of Sodium Silicate Grouting Solutions.

Parameter	Technical Value
Gelation time	10 - 600 seconds (adjustable)
Molecular size	5 - 50 nm (high permeability)
Environmental compatibility	Non-toxic, non-flammable
Compressive strength (28 days)	> 8 MPa (with optimal mix design)
Permeability coefficient (K)	< 0.1 × 10^{-5} cm/s

Overall, the silicate-cement system has both theoretical and practical support to serve as an effective solution for emergency seepage control in sandy foundations, particularly in hydraulic structures. However, the optimal mix design and execution protocols are still under experimental development. Therefore, the following sections of this paper will present the adopted research methodology and preliminary laboratory results, aiming to advance practical applications of this promising material system.

2.3. Research Methodology

To identify potential initial mix proportions for the silicate-cement grouting system applied in emergency seepage control for sandy foundations, a series of controlled laboratory experiments was conducted. The objective of these experiments was to examine the influence of key variables on the technical performance of the grout mixture.

The experimental program was designed to evaluate three core performance indicators:

Gelation time, reflecting the material's workability and suitability under time-sensitive field conditions;

Compressive strength, representing the mechanical durability and load-bearing capacity after setting;

Permeability coefficient (K), indicating the effectiveness of the mixture in reducing seepage and forming impermeable barriers.

These parameters were selected based on their relevance to both engineering design and field performance, particularly for hydraulic structures requiring rapid response and long-term stability. The testing framework aimed to simulate practical conditions while isolating the effects of mix design variables for analytical comparison.

2.3.1. Materials

In this study, all selected materials were chosen based on clear origin, stable quality, and compatibility with real-world construction conditions in Vietnam.

Sodium silicate (commonly referred to as *liquid glass*) was used in the form of a transparent aqueous solution with a specific gravity ranging from 1.30 to 1.35 g/cm^3, high alkalinity (pH > 11), and a SiO_2/Na_2O molar ratio between 3.2 and 3.5. This type of silicate is characterized by rapid reactivity and flexible gelation time, especially when combined with hardening agents such as Portland cement or calcium salts. These properties make it particularly suitable for seepage control in sandy foundations under high-flow conditions.

Portland cement (PCB40 grade) was selected as a commonly used domestically manufactured binder. It has a minimum 28-day compressive strength of 42.5 MPa, providing sufficient load-bearing capacity and excellent bonding with soil particles following gelation. Its availability and reliability make it a practical choice for field applications.

Yellow sand (natural river sand) was used to simulate loose sandy foundations. Prior to testing, the sand was sieved to remove fine particles, ensuring a mean particle size of 0.25-1 mm and high purity. This preparation aims to reproduce realistic soil conditions commonly encountered in construction projects requiring foundation grouting or seepage remediation.

2.3.2. Experimental Variable Design

The selection of value ranges for the three primary mix design factors-Silicate-to-Cement ratio (S/C), Water-to-Cement ratio (W/C), and the Silicate-Cement solution to Sand ratio (S-S-C/Sand)-was based on a combination of scientific reasoning, field construc-tion experience, and references to international guidelines, including Karol (2003) [7] and the technical manual by the U.S. Army Corps of Engineers (1995) [1]. The experimental levels were arranged in linear or semi-linear sequences to adequately capture significant response trends and identify optimal ranges for each targeted performance criterion.

For the Silicate-to-Cement ratio (S/C), values ranging from 10% to 50 % were selected to capture the full spectrum of silicate influ-ence on gelation rate and gel formation behavior. Ratios below 10 % typically result in excessively slow setting, making them unsuitable for emergency seepage treatment. Conversely, ratios above 50 % may cause immediate gelation, reducing grout spreadability and potentially clog-ging pumping equipment. Thus, test levels of 10 %, 20 %, 30 %, 40 %, and 50 % were evenly distributed to evaluate gelation trends, particular-ly in the mid-range (30-40 %), which is hypothesized to offer optimal control.

For the Water-to-Cement ratio (W/C), values were varied from 0.4 to 1.2 to assess the impact of slurry fluidity on workability and post-curing compressive strength. Ratios below 0.4 tend to yield mixtures that are too viscous for practical pumping, while ratios above 1.0 often result in significant strength reduction. This range allows for the identification of an optimal threshold-likely between 0.5 and 0.6-that balances grout fluidity and structural integrity after 28 days of curing.

In terms of the Silicate-Cement solution to Sand ratio (S-S-C/Sand), the mass ratios of 30 %, 40 %, 50 %, 60 %, and 70 % were designed to evaluate the compatibility between grout volume and soil matrix. Prior studies indicate that ratios below 30 % generally fail to form a continuous gel network within the sand, whereas values above 70 % may produce excessively thick mixtures that hinder penetration and uni-form distribution in loose sandy soils.

Table 2. Experimental Variables and Investigation Objectives.

Factor	Test Levels	Investigation Objectives
S/C (Silicate/Cement)	10 %, 20 %, 30 %, 40 %, 50 %	Effect on gelation rate and gel formation
W/C (Water/Cement)	0.4; 0.5; 0.6; 0.8; 1.0; 1.2	Mixture consistency and compressive strength after curing
S-S-C/Sand (Solution/Sand)	30 %, 40 %, 50 %, 60 %, 70 %	Grout penetration and homogeneity in sandy soil matrix

This systematic experimental design forms the basis for analyzing the performance characteristics of the silicate-cement grout under varying field-relevant conditions.

2.3.3. Experimental Procedure

The testing procedure for the silicate-cement grout was structured to evaluate the key performance characteristics of the material mixture in terms of setting behavior, mechanical strength, and permeability. The process involved sequential stages to ensure repeatability and standard compliance.

1. Grout Preparation

The silicate solution was first diluted with the appropriate amount of water, followed by the gradual addition of Portland cement. The mixture was stirred using a U-blade mechanical mixer at medium speed for 3-5 minutes until uniform consistency was achieved. If applicable, river sand was added at the final stage to avoid premature thickening and to ensure homogeneous dispersion within the mix.

2. Gelation Time Measurement

Gelation time was determined using the visual flow test method as described by Karol (2003) [7]. The test aimed to identify the transition point at which the mixture changed from a flowable state to a viscous, plastic state. This parameter reflects the working time available for field application and is critical in high-seepage conditions.

3. Compressive Strength Testing

Cylindrical specimens (Ø50 mm × 100 mm) were cast and cured in a controlled environment at 25 ± 2 °C and relative humidity > 95 %. Curing periods of 7 and 28 days were adopted to monitor strength development over time. After curing, specimens were subjected to unconfined compressive strength (UCS) testing using a compression testing machine with a calibrated load cell of ±1 kN. The average UCS value from at least three specimens was recorded for each mix.

4. Permeability Test

Vertical permeability was assessed in accordance with Vietnamese Standard TCVN 8664:2011. Fully saturated specimens were prepared and subjected to a constant head permeability test under a standard atmospheric pressure (1 atm) for 24 hours. The coefficient of permeability (K) was calculated based on flow rate, sample dimensions, and head loss, providing insights into the material's effectiveness in seepage control.

This experimental protocol ensures a comprehensive understanding of the grout's physical performance, supporting its evaluation as a candidate material for emergency seepage treatment in sandy foundations.

3. Experimental Results

Based on the experimental findings presented in the previous sections, it is evident that the performance of the silicate-cement grout mixture is governed by the complex interaction among three key factors: the Silicate-to-Cement ratio (S/C), the Water-to-Cement ratio (W/C), and the Silicate-Cement solution to Sand ratio (S-S-C/Sand). A detailed analysis of the interrelationships among these variables allows for the development of mix designs tailored to specific field objectives-particularly in emergency seepage control scenarios.

The experimental outcomes were systematically categorized and analyzed according to three primary technical indicators:(i) Gelation time; (ii) Compressive strength; (iii) Permeability coefficient (K). Each parameter was individually assessed in relation to the three experimental variables (S/C, W/C, and S-S-C/Sand). This structured analysis enabled the identification of optimal mix regions corresponding to different performance priorities, such as rapid setting, mechanical stability, or seepage resistance.

The results form a data-driven foundation for recommending practical mix proportions and operational guidelines in real-world applications, particularly for hydraulic structures requiring urgent foundation treatment under adverse seepage conditions.

3.1. Effect of Silicate-to-Cement Ratio (S/C)

Adjusting the gelation time of the Portland cement (PCB40) grout mixture is a crucial factor in foundation construction and soil stabilization. This experiment aimed to evaluate the influence of the Silicate-to-Cement ratio (S/C) on the gelation time, thereby determining the optimal mix ratio for efficient grouting material performance.

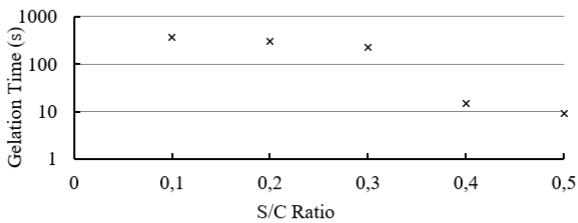

Figure 1. Relationship between gelation time and different S/C ratios (W/C = 0.5:1; PCB40).

The results show that gelation time decreases significantly as the S/C ratio increases, especially beyond the threshold of S/C = 0.4. Specifically, when the S/C ratio increases from 0.1 to 0.3, the gelation time remains relatively high, fluctuating above 100 seconds. However, once the S/C ratio exceeds 0.4, the gelation time drops sharply to approximately 10 seconds. This indicates that sodium silicate, as the primary component in liquid glass, acts as a catalyst for the gelation process, enabling precise control of the gelation time to meet the design requirements of the grouting material.

Table 3. Impact of S/C Ratio on Gelation Tim.

S/C Ratio (%)	Gelation Time (seconds)	Comments
10 %	> 300	Too slow, difficult to apply in the field
20 %	~180	Gelation starts to stabilize
30 %	~120	Suitable gelation time for seepage conditions
40 %	~90	Fast gelation, smaller spread radius
50 %	< 60	Very fast gelation, may cause pump blockages

The notable change in gelation time has practical significance in controlling the setting process of the silicate-cement grout system, particularly in applications involving soil stabilization, where rapid setting or adjustment to specific geological conditions is required.

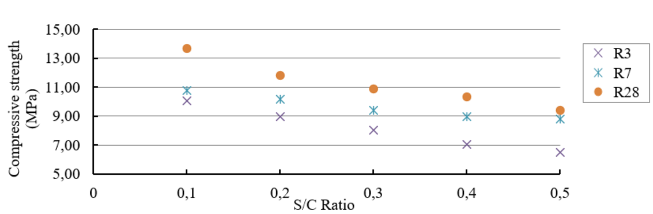

Figure 2. Relationship between compressive strength and different S/C ratios (W/C = 0.5:1; PCB40).

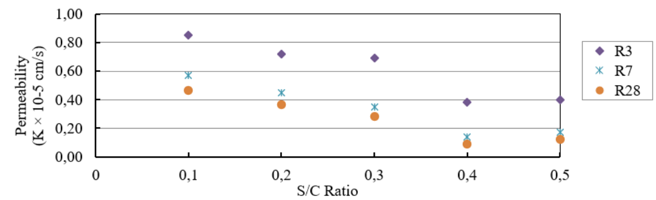

Figure 3. Relationship between permeability coefficient and different S/C ratios (W/C = 0.5:1; PCB40).

3.2. Effect of Water-to-Cement Ratio (W/C)

The variation of the Water-to-Cement ratio (W/C) has a significant impact on the consistency, workability, and compressive strength of the grout after curing. The specimens were tested for compressive strength at 7 and 28 days, and the results are presented in the following table:

Table 4. Impact of W/C on Compressive Strength of Grout.

W/C	Compressive Strength (MPa)		Comments
	7 days	28 days	
0.4	6.8	9.4	Difficult to apply, high strength
0.5	6.3	8.7	Ideal, best performance
0.6	5.5	7.9	Acceptable
0.8	4.1	6.5	Noticeable strength reduction
1.0	3.2	5.3	Noticeable strength reduction
1.2	2.7	4.6	Not recommended

The modification of the Water-to-Cement ratio (W/C) notably affects the viscosity, workability, and compressive strength after setting of the Portland cement grout mixture (PCB40). Compressive strength tests conducted at 7 and 28 days show a clear trend: as the W/C ratio increases, the compressive strength tends to decrease. Specifically, the mixture with a W/C ratio of 0.4 achieved the highest compressive strength but was difficult to apply in the field. In contrast, mixtures with W/C ≥ 1.0 had excessive liquidity and low strength, which failed to meet the technical requirements. The ideal W/C ratio was found to be in the range of 0.5-0.6, balancing a minimum compressive strength of 7-9 MPa after 28 days and good workability.

3.3. Effect of Silicate-Cement Solution to Sand Ratio (S-S-C/Sand)

This factor evaluates the practical effectiveness of the grout when injected into sandy foundations under seepage conditions. The results are summarized in the following table 5:

Table 5. Effect of S-S-C/Sand Ratio on Seepage Resistance.

S-S-C/ Sand Ratio (%)	Permeability Coefficient (K) (cm/s)	Gel Membrane Uniformity	Comments
30 %	4.3×10^{-5}	Discontinuous	Not satisfactory
40 %	2.8×10^{-5}	Average	Weak
50 %	1.6×10^{-5}	Good	Recommended
60 %	1.1×10^{-5}	Good	Suitable
70 %	0.9×10^{-5}	Difficult to apply, loss of permeability	Limited

In the study of the S-S-C (Silicate-Cement-Water and Sand) mix ratio for grouting sandy foundations with seepage flow, the experimental results revealed a clear relationship between the component ratios and the material's seepage resistance. As the S-S-C ratio increases, the permeability coefficient (K) significantly decreases, indicating enhanced water resistance. Particularly, the S-S-C/Sand ratio in the range of 50-60 % yielded optimal performance, with permeability coefficients of $K < 1.6 \times 10^{-5}$ cm/s and significantly improved uniformity of the gel membrane. However, when the S-S-C/Sand ratio exceeded 60 %, the mixture became difficult to apply, and the permeability resistance was reduced.

Other mix ratios, such as Silicate-to-Cement (S/C) between 30-40 % and Water-to-Cement (W/C) in the range of 0.5-0.6, were also found to be suitable to ensure good workability and high-quality grout. These proportions helped maintain the stability of the gel membrane after application without compromising the material's seepage resistance.

The results provide essential technical parameters to optimize the grouting material production process for sandy foundations in construction projects, particularly in seepage-prone conditions.

3.4. Mix Proportion Selection Based on Technical Objectives

Based on the experimental results, the research team has developed guidelines for selecting the appropriate Silicate-Cement mix ratios tailored to specific technical objectives in seepage control applications.

For rapid seepage control in emergency situations, a Silicate-to-Cement (S/C) ratio between 40-50 %, a Water-to-Cement (W/C) ratio of approximately 0.5, and an S-S-C/Sand ratio of about 60 % are recommended. This mix proportion provides fast gelation time and excellent water resistance; however, caution must be taken to avoid pump clogging and challenges with workability.

For situations requiring sand foundation reinforcement, a S/C ratio of 30 %, W/C = 0.6, and S-S-C/Sand = 50 % is considered optimal, offering good penetration ability and high compressive strength after curing, even though the gelation time may be slower.

When the objective is to seal fine voids, a S/C ratio of 35 %, W/C = 0.5, and S-S-C/Sand between 50-55 % is a suitable option. This formulation ensures uniform spread and gel stability, but the pumping rate must be carefully controlled to avoid inconsistencies in gel formation.

Based on the synthesis of technical performance indicators and workability considerations, the research team proposes a general-purpose mix proportion for sand foundation seepage control as follows: Sodium Silicate constitutes approximately 12 % by weight of the mixture; Portland Cement (PCB40) accounts for 40 %; Water makes up 20-25 %, corresponding to W/C ≈ 0.5-0.6; and the remainder is yellow sand, constituting 25-30 %. This mix ratio has shown significant effectiveness through experiments, with a gelation time ranging from 90 to 120 seconds, compressive strength after 28 days exceeding 8 MPa, and a permeability coefficient smaller than 1.5×10^{-5} cm/s. This is considered the optimal formulation for broad application in construction projects requiring seepage control, deep penetration, and high mechanical strength.

4. Discussion on the Practical Application Potential

Given the serious deterioration of many hydraulic structures in Vietnam, particularly small to medium-sized earth dams built before 2000, the search for and implementation of effective and rapid seepage treatment solutions has become an urgent requirement. Key regions such as the Mekong Delta, Central Coastal Region, and Northern Midlands are encountering leakage issues, internal erosion through the dam body or foundation, posing significant safety risks and causing severe damage to people and property, especially during the rainy season.

In this context, research into Silicate-Cement materials applied in jet grouting technology has introduced a promising new approach. Laboratory experiments have demonstrated the feasibility of this material system for treating seepage in sandy foundations at hydraulic projects. The Silicate-Cement mixture shows several significant advantages over traditional jet grouting materials such as regular cement and Jet Grouting. Specifically, its fast and controllable gelation time (60-120 seconds) is a standout advantage, allowing the material to penetrate effectively into weak soils or loose sands without being washed away, while also meeting emergency treatment requirements under challenging construction conditions. Moreover, the mixture ensures a compressive strength of over 8 MPa after 28 days, which is sufficient to meet the demands of foundation reinforcement in complex hydraulic conditions.

Table 6. Mix Proportion Selection Based on Technical Objectives.

Technical Objective	S/C (%)	W/C	S-S-C/ Sand (%)	Main Advantages	Limitations
Rapid seepage control (emergency)	40-50	0.5	60	Fast gelation, good water resistance	Risk of pump clogging, difficult to apply
Sand foundation reinforcement	30	0.6	50	High compressive strength, good penetration	Slower gelation time
Sealing fine voids	35	0.5	50-55	Uniform spread, stable gel	Requires precise control of pumping rate

Table 7. Comparison of Technical and Construction Properties of Three Common Jet Grouting Materials.

Criteria	Silicate-Cement	Regular Cement	Jet Grouting
Gelation time	60-120 seconds (controllable)	> 3 giờ	Uncontrollable
Penetrability in sand	Excellent	Poor	Average
Compressive strength after 28 days	> 8 MPa	10-15 MPa	> 12 MPa
Emergency application	Highly suitable	Not suitable	Complex application
Environmental friendlines	High	High	Average
Cost	Moderate	Low	High

As shown in the table, although the compressive strength of Silicate-Cement does not surpass Jet Grouting, other properties such as penetrability, gelation time, and emergency application suitability clearly demonstrate its advantages. The Silicate-Cement system allows for rapid penetration into weak soils or loose sands without being washed away, with gelation time controllable within 60-120 seconds. This helps save construction time and ensures effective seepage treatment in emergency situations. The flexibility in application, especially in regions with weak soil foundations or strong seepage, enables this material to meet emergency reinforcement and rapid soil stabilization re-quirements, ensuring the safety of the structure.

In addition to the technical factors, the environmental friendliness of the Silicate-Cement material system is another highlight. Un-like traditional jet grouting materials, it does not involve the use of harmful chemicals or heavy metals, making it a much safer alternative. This is particularly important in hydraulic construction projects, where environmental protection and adherence to strict legal regulations are critical. Furthermore, the moderate material cost reduces financial burdens on investors, and its integration into existing grouting procedures reduces investment costs and training time.

This material system can be effectively applied in many hydraulic construction projects, such as seepage treatment in earth dam bodies, reinforcement of culverts, sealing leaks at weak structural points, foundation stabilization in urban flood-prone areas, or emergency intervention in flood-control systems during the rainy season. Especially in regions with complex soil conditions or high seep-age rates, the Silicate-Cement material shows excellent adaptability and superior performance in speed and treatment efficacy.

However, its practical application faces several barriers. First, there is currently no national standard system (TCVN) for Silicate-Cement materials and their corresponding construction procedures, making it difficult to approve and validate the quality. Second, there is a lack of field data, particularly long-term post-treatment studies, which are crucial for assessing the durability and effectiveness of the material. Third, some technical staff and investors are hesitant to use "chemical materials" in hydraulic projects, which remains a significant barrier.

To overcome these obstacles, the research team proposes the following specific approaches:

- Pilot Projects: Implementing pilot projects at critical sites with known seepage issues can provide valuable data for assessing real-world performance and fine-tuning the mix proportions.

- Collaboration with Regulatory Bodies: The development of national standards and technical guidelines in collaboration with re-search institutes and regulatory bodies is crucial to enable the broad acceptance of the material system in Vietnam.

- Field Studies and Long-term Monitoring: Conducting additional field studies, particularly those involving long-term monitoring, will be vital in establishing the long-term reliability and efficacy of the Silicate-Cement material system.

- Training and Awareness: Enhanced technical communication and training programs for engineers, construction managers, and stakeholders will help raise awareness of the material’s benefits and increase its adoption in practical applications.

In conclusion, the Silicate-Cement material system presents an innovative and adaptable solution for seepage control and soil stabi-lization in hydraulic engineering. With its fast-setting capabilities, ease of use, and environmental safety, it offers a sustainable alternative to traditional grouting methods. However, further research, field studies, and the establishment of formal standards are essential to fully realize its potential and enable widespread implementation in future hydraulic projects in Vietnam.

5. Conclusion

This study conducted a series of laboratory experiments to evaluate the impact of key mix ratios-Silicate-to-Cement (S/C), Water-to-Cement (W/C), and Silicate-Cement solution to Sand (S-S-C/Sand)-on three core technical parameters: gelation time, compressive strength, and permeability coefficient. The results indicate that each factor plays a critical role in determining the material's effectiveness in seepage control and field workability. Based on the findings, the research team established the optimal mix ratios corresponding to specific technical objectives, including emergency seepage control, reinforcement of loose sand foundations, and sealing fine voids. The mix proportion selection based on these objectives helps optimize material performance under diverse geological and hydraulic conditions. This study provides an important foundation not only for applications in hydraulic engineering but also for potential deployment in other infrastructure projects, such as transportation, public works, and civil engineering, where weak soils and complex seepage conditions are present.

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References

[1]. US Army Corps of Engineers, “Chemical Grouting,” *Washington, USA*, 1995.

[2]. W. Clifton, “CHEMICAL GROUTS FOR POTENTIAL USE IN BUREAU OF RECLAMATION PROJECTS,” *US Dep. Inter. Bur. Reclam. Div. Res. Lab. Serv. Appl. Sci. Brance*.

[3]. M. Mollamahmutoglu, E. Avci, and E. Deveci, “Strength and permeability properties of sodium silicate-sodium dihydrogen phosphate grouted sand Strength and permeability properties of sodium silicate-sodium dihydrogen phosphate grouted sand,” no. January 2022, 2021, doi: 10.1007/s12517-021-08427-y.

[4]. E. Avci, E. Deveci, and A. Gokce, “Effect of Sodium Silicate on the Strength and Permeability Properties of Ultrafine Cement Grouted Sands,” *J. Mater. Civ. Eng.*, no. January, 2022.

[5]. S. Kazemian, A. Prasad, B. B. K. Huat, T. A. Mohammed, and F. N. A. Abdul Aziz, “Effect of cement, sodium silicate, kaolinite and water on the viscosity of the grout,” *Sci. Res. Essays*, vol. 5, no. 22, pp. 3434-3442, 2010.

[6]. Zhao Peng, “An Introduction to Chemicals for Grouting of Soils,” in *Continuing Education and Development*, Inc. 9 Greyridge Farm Court Stony Point, 2016.

[7]. R. H. Karol, *Chemical Grouting And Soil Stabilization*. Marcel Dekker, 2003.