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An Overview of Soil Improvement through Ground Grouting

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Abstract

Soil is an essential component of what surrounds us in nature, providing as the basis for our infrastructure and construction. However, soil is not always suitable for construction due to a variety of geotechnical issues such as inadequate bearing capacity, excessive settlement, and liquefaction susceptibility. Through improving the engineering qualities of soil, such as strength, permeability, and stability, ground grouting is a specific geotechnical method used. Using a fluid grout mixture injected into the subsurface, holes are filled and weak or loose strata are solidified as the material seeps into the soil matrix. The approach's adaptability in addressing soil-related issues has made it more well-known in the fields of civil engineering and construction. In the end, this has improved groundwater management, foundation support, and overall geotechnical performance.

Keywords

Grouting, Soil Improvement, Permeation Grouting, Compaction Grouting and Jet Grouting

1. Introduction

Soil improvement techniques are critical in the domains of geotechnical engineering and construction because they allow for the upgrading of soil qualities to satisfy the needs of diverse infrastructure projects. Grouting is the process of ground improvement attained by injection of a fluid like material that is capable of forming a gel and binding the soil particles (Dayakar et al., 2012). Ground grouting stands out as a flexible and successful approach for hardening and stabilizing soil among various procedures. Grouting is the most commonly used method in underground engineering projects to prevent water inrush and ensure the stability of the surrounding rock (Bahrani & Hadjigeorgiou, 2017; Chepurnova, 2014; Wang et al., 2016; Jafarpour et al., 2020; Mu et al., 2021; Thenevin et al., 2017; Vlachopoulos et al., 2018). Ground grouting is the injection of grout materials into the ground to change its physical and mechanical properties, making it more suited for supporting structures, minimizing settling, and dealing with soil-related issues. This study article goes into the vast field of ground grouting, investigating its concepts, methodology, applications, and relevance in soil development.

Ground grouting has gained popularity because to its versatility and efficacy in a variety of geotechnical settings, including foundation underpinning, excavation support, liquefaction mitigation, and ground improvement in tunneling and mining operations. As an inventive and expanding topic, ground grouting research is critical for understanding its subtleties and exploring the most recent breakthroughs in grout materials, injection techniques, and quality control systems. This study aims to offer a complete review of the fundamental ideas and practical applications of ground grouting, throwing light on its potential as a sustainable and economically feasible solution to soil improvement concerns. However, grouting does provide the benefits of a permanent, or at least semi-permanent, ground treatment and the bonus of increased stability in some situations, as compared with purely temporary expedients such as dewatering and ground freezing (Daw & Pollard, 1986).

2. Grouting Methods

Grouting methods are further classified depending on their implementation techniques. Grouting is only one of several methods of ground treatment for excluding water which have to be assessed on their respective merits for each situation (Daw & Pollard, 1986). The method consists of soil injection of a mixed fluid at high pressure forming jets that erode and replace the existing soil with the injection mixture (Chernyakov, 2009). Nowadays, grouts can be employed in several different applications and the grouting methods (permeation, compaction, jet, compensation, backfill, injection grouting) vary according to the grout type, its mechanisms and field of application (Patel (Ed.), 2019), Here methods are Permeation grouting, Compaction grouting and Jet grouting.

2.1. Permeation Grouting

The permeation grouting is a commonly used technique to improve the engineering geology condition of the soft ground (Wang et al., 2020). A popular geotechnical method for enhancing the qualities of soil for building and infrastructure projects is permeation grouting. In **Figure 1** shows by injecting a specific grout mixture into the soil, this technique modifies the soil's properties and increases its strength, stability, and durability. Drilling properly spaced boreholes into the desired soil mass to cover the whole region of interest is the first step in the procedure. After the boreholes are drilled, the earth is forced to accept a fluid grout mixture, usually made of cement, water, and additives.

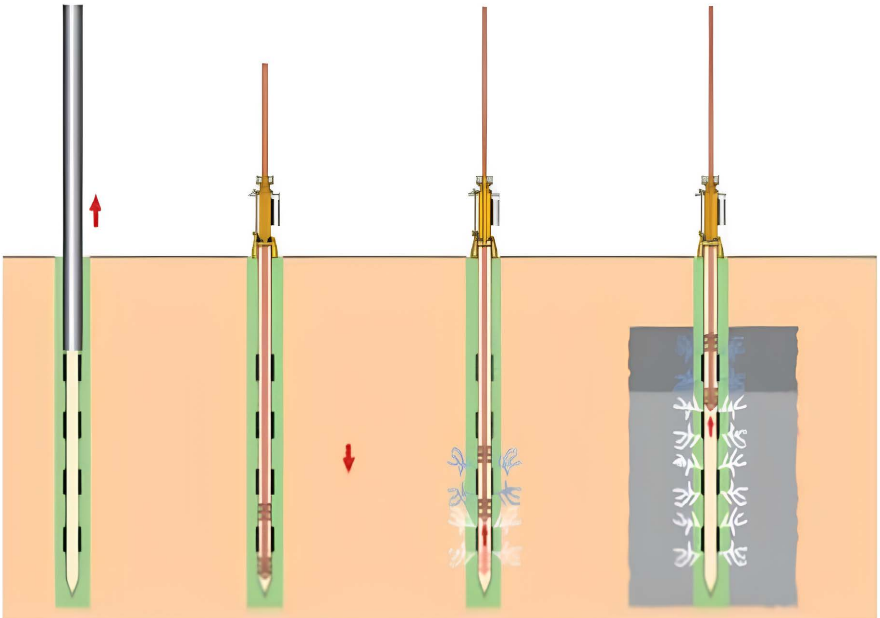

Figure 1. Diagram showing permeation grouting (Sarker & Abedin, 2015).

Through permeating the soil matrix, the injected grout fills up gaps, compacts loose particles, and binds soil particles together. As a result, there is a general increase in the soil's ability to support weight, which lowers settlement and boosts ground stability.

In situations when the current soil is not strong or stable enough to support structures, permeation grouting is very helpful. Ground improvement, underpinning, and foundation restoration operations frequently use it. The method's versatility for a range of applications stems from its ability to be customized to fit particular soil conditions. Permeation grouting is also an adaptable option for a variety of geological contexts since it may be used in cohesive and non-cohesive soils. Permeation grouting works by efficiently changes the soil's structure, improving its technical qualities, and guaranteeing a strong base for building projects.

2.2. Compaction Grouting

Compaction grouting as a ground improvement technique involves the injection of very stiff grout material to densify the treated soils by radially displacing the soil particles into a closer spacing (El-Kelesh & Matsui, 2002). **Figure 2** showing the diagram, compaction grouting is a highly successful soil improvement method, particularly when the soil lacks the required density or stability. This procedure entails injecting a particular grout mixture into the ground at appropriate areas in order to improve the overall soil structure. The grout employed is usually a cementitious or polyurethane substance that hardens after being injected into the soil, resulting in a more compact and stable subsurface. The grouting pressure compacts the fractured and bulking rock masses below the key strata in advance, and the injection fill replaces the potential sinking space

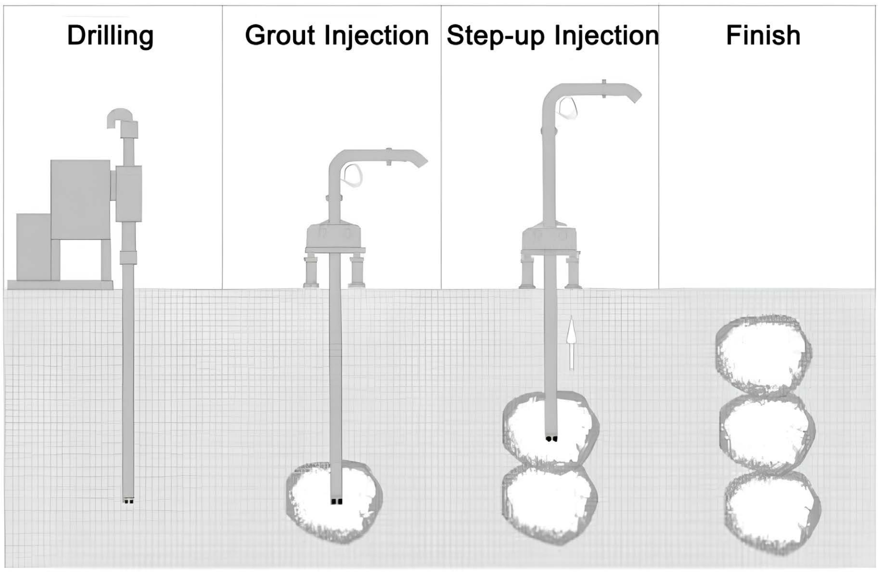

Figure 2. Implementation of compaction grouting (Sarker & Abedin, 2015).

associated with rock layers, thus controlling surface subsidence (Xuan et al., 2016). Compaction grouting is very useful for treating soil settlement difficulties, reducing the danger of foundation settling, and providing structural support on soft or loose soils.

One of the primary benefits of compaction grouting is its ability to enhance soil density and load-bearing capability. The injected grout displaces and densifies the underlying soil, filling gaps and making the foundation more secure. This method is especially useful in places with loose or unconsolidated soils that are prone to settling. Compaction grouting is often utilized in structural stabilization projects such as construction, bridges, and retaining walls. This procedure helps avoid future settling concerns and assures the long-term stability of the erected elements by enhancing the compaction and load-bearing qualities of the soil.

Furthermore, Compaction grouting is an important soil improvement and underpinning technique that involves injection of a very stiff grout material into the soil (El-Kelesh & Matsui, 2002). Compaction grouting is a versatile solution that can be tailored to different soil conditions and project specifications. The injection process may be precisely managed to target specific areas of concern, allowing engineers to personalize the treatment to the site's individual features. Furthermore, compaction grouting is a low-impact method that causes little damage to existing construction and landscapes. This makes it an excellent alternative for soil improvement in urban areas or areas with restricted access. Overall, compaction grouting stands out as a dependable and effective approach for improving soil stability, laying a firm foundation for building projects, and extending the life of structures erected on difficult soil types.

2.3. Jet-Grouting

Jet-grouting is an effective way to improve the strength and stiffness of the ground so as to reduce the ground settlement. Also, deep foundations, such as the rotary grouting pile, are necessary if grouting in surface layer is unable to sustain the superstructures (Jalili et al., 2019). Jet grouting is a creative and successful soil enhancement technology that helps to stabilize and fortify the ground for a variety of building projects. This process includes injecting a high-pressure stream of grout into the soil, resulting in a cemented mass that improves the engineering qualities of the soil. The procedure begins with the drilling of a borehole into the ground, followed by the injection of a high-velocity jet of grout as the drill is progressively withdrawn, resulting in a column or curtain of treated soil. To obtain the necessary qualities, the grout mixture normally includes of cement, water, and occasionally extra additives. The resultant treated soil mass has improved stability, bearing capacity, and permeability, making it appropriate for a variety of geotechnical applications.

The ability of jet grouting to handle a variety of soil conditions is one of its main benefits. Conditions of development are shown in **Figure 3**. Jet grouting may be tailored to the unique demands of the site, whether it is working with loose, cohesionless soils or cohesive soils with significant water content. The jet grouting is found to be the most feasible solution for mitigating the anticipated liquefaction hazard and for an improved bearing support for shallow foundations considering the locally available technologies and encountered ground conditions (Durgunoglu et al., 2003). Because of its versatility, it is an excellent choice for foundation improvement, excavation support, and ground reinforcement in difficult geotechnical situations. Furthermore, when compared to traditional approaches like as deep foundation systems or soil replacement, jet grouting is a more cost-effective alternative. It reduces the need for soil extraction and disposal, lowering total project costs and environmental effect.

Jet grouting, with its capacity to generate a continuous, homogeneous treated soil mass, offers engineers and builders with a dependable technology for soil improvement that assures the long-term stability and safety of building projects. Finally, jet grouting is a versatile and effective technology for improving soil qualities, providing a long-term solution to a wide range of geotechnical difficulties in building and infrastructure development.

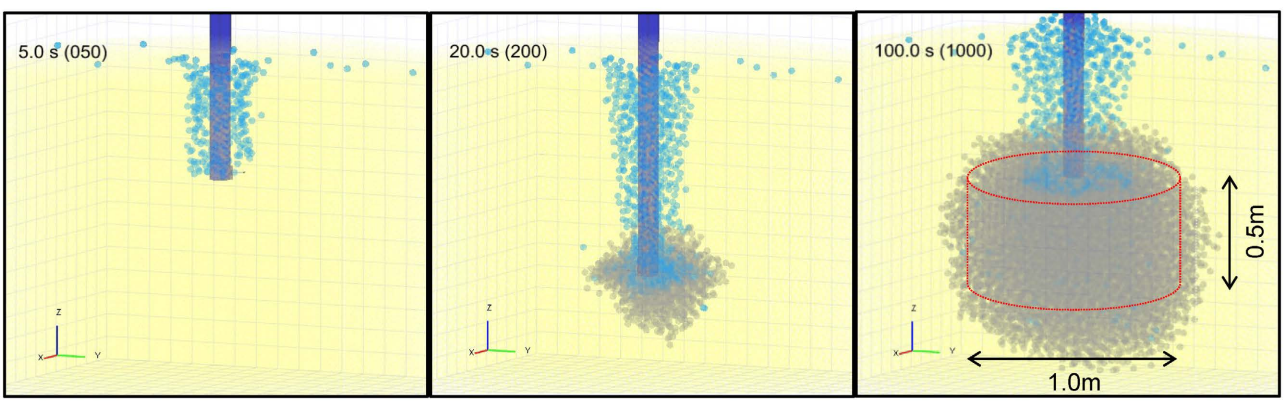

Figure 3. Conditions of development of columnar soil-improved body by jet grouting type method (Inazumi et al., 2021).

3. Applications of Grouting

The soft ground may experience great settlement under the load transferred from the superstructures constructed over it (Cai et al., 2006). Grouting is a flexible and frequently utilized ground modification method in civil engineering and geotechnical applications. It entails injecting a grout substance into the ground to increase its characteristics or stability, which is commonly a combination of cement, water, and occasionally additives. Grouting has a wide range of uses, the most of which are targeted at reinforcing and stabilizing soil and rock formations, as well as alleviating ground-related issues.

Grouting is commonly used in the building and maintenance of tunnels, subterranean structures, and deep excavations. Engineers can build a grout curtain or ground improvement zone by injecting grout into the surrounding soil or rock, which serves to shut off water intrusion and fortify the surrounding ground. This is critical for preventing ground subsidence, preventing water penetration, and ensuring the safety and lifespan of subterranean systems. In mining operations, grouting is used to fortify the ground and manage water flow. In addition to infrastructure projects, grouting aids in the prevention of sinkholes and the stabilization of soil or rock slopes, giving practical solutions to geological dangers. Furthermore, grouting has environmental implications, such as sealing underground storage tanks or regulating pollutants' subsurface movement. Overall, ground modification by grouting is a flexible technique that may be used in a variety of civil engineering and geotechnical projects to improve the stability and performance of the ground and the structures erected on it.

4. Soil Improvement

Ground improvement options including dynamic compaction, preloading, vibro-stone columns, jet grout columns, deep soil mixing, excavation replacement are evaluated and compared in terms of applicability, effectiveness considering the ground conditions and; cost and local availability of the related experience (Durgunoglu et al., 2003). Grouting is a geotechnical engineering method used to improve the qualities of soil, making it more stable and appropriate for construction projects. Grouting is the process of injecting a fluid ingredient into the soil, often cementitious grout, to fill voids, promote cohesion, and improve overall strength, in addition to the effects of natural disasters such as over-level floods and earthquakes (Pang et al., 2020). This procedure is especially useful for treating soil characteristics that may provide building issues, such as loose or poorly compacted soil, floods and earthquakes sinkholes, and subsurface voids. One of the key advantages of grouting is its ability to boost the soil's bearing capacity. Engineers may efficiently fortify the soil and decrease settling by injecting grout into the ground, creating a sturdy foundation for construction. This is especially important in places with soft or compressible soil, where traditional foundation approaches may be insufficient. Grout bridges gaps between soil particles, resulting in a more homogenous and compacted foundation.

Grouting is also commonly utilized in soil to restrict groundwater movement. Water penetration in permeable soils can cause instability and erosion, posing a hazard to construction. Grouting contributes to the formation of an impermeable barrier, preventing water from penetrating the soil. This is especially critical in tunneling and subterranean construction, where water penetration can jeopardize excavation structural integrity. Engineers can successfully regulate groundwater and improve the stability of subterranean construction by sealing the soil with grout. Grouting is also useful in minimizing the consequences of subsurface voids and sinkholes. Voids beneath the surface can cause sudden collapses, putting infrastructure and safety at risk. Grouting fills these spaces, adding strength and preventing future settling. In sinkhole-prone areas, grouting can stabilize the soil and reduce the danger of rapid ground subsidence. Grouting's flexibility extends to soil consolidation, where it is used to increase the density and strength of loose or cohesionless soils. Loose soil presents building issues because it lacks the essential strength to support high loads. Engineers can strengthen the cohesiveness between soil particles by injecting grout, resulting in a more solid and load-bearing foundation. This is especially useful in coastal areas with loose, sandy soils, where erosion and instability are more likely.

Grouting, in addition to its technical benefits, provides a cost-effective and efficient alternative for soil improvement. Grouting is less disruptive than traditional procedures such as excavation and replacement of soil or the use of deep foundations and may be executed with minimum impact on existing structures and the environment. Because the procedure may be adjusted to unique site circumstances, it is a versatile alternative for a wide range of geotechnical difficulties.

Fundamental Ideas and Objectives, Grouting is a civil engineering practice that includes injecting a cementitious or chemical combination into the ground in order to enhance its characteristics and stability. The basic idea of grouting is to improve the mechanical properties of the soil or rock while decreasing permeability, making it more suited for building, infrastructure, or environmental remediation operations. The basic goals of grouting are to increase the earth's load-bearing capacity, regulate water infiltration, and reduce soil settling, assuring the long-term integrity and safety of construction erected on or near the treated ground.

Grouting is used in a range of applications, from constructing foundations and bridges to sealing subterranean tunnels and dams. The procedure normally entails drilling specified holes in the ground and inserting grout ingredients under pressure. Different types of grouting procedures, including as cement grouting, chemical grouting, and compaction grouting, can be utilized depending on the unique project needs and ground conditions.

5. The Objectives of Grouting

5.1. Increased Load-Bearing Capacity and Water Infiltration Control

One of the fundamental purposes of ground alteration via grouting is to enhance the load-bearing capacity of the soil or rock. Engineers can fill cavities, gaps, and cracks in the ground by injecting grout material into them, significantly enhancing the cohesion and friction between soil particles. This results in a stronger and more solid foundation for structures such as construction, bridges, and retaining walls. Improved load-bearing capacity guarantees that these constructions can endure the stresses and pressures that they will face during their lifetime.

Grouting is frequently used to control water infiltration into the ground. Grouting can reduce the risk of soil erosion, prevent the formation of sinkholes, and stabilize the groundwater table by sealing underground pathways and voids. Grouting is the most commonly used method in underground engineering projects to prevent water inrush and ensure the stability of the surrounding rock (Bahrani & Hadjigeorgiou, 2017; Chepurnova, 2014; Wang et al., 2016; Jafarpour et al., 2020; Mu et al., 2021; Thenevin et al., 2017; Vlachopoulos et al., 2018). This is especially important for infrastructure projects that include tunnels, dams, and underground storage facilities. It aids in the protection of structures and their surroundings from water-related issues and potential disasters.

5.2. Settlement Mitigation and Protection of the Environment

Grouting can be used to reduce soil settlement, particularly in areas with loose or compressible soils. Injecting grout material into these soils can fill voids and improve overall density and stability. This reduces the possibility of settlement, which is critical for avoiding structural damage and maintaining the functionality of infrastructure such as roads, pipelines, and industrial facilities.

In certain circumstances, grouting is used to confine and immobilize contaminants in the ground, such as toxic chemicals or pollutants. This approach, known as chemical grouting, aids in the prevention of toxins from entering groundwater and surrounding ecosystems. It is critical in environmental cleanup activities.

5.3. Increase Ground Stability

Grouting can increase the stability of slopes and embankments, lowering the danger of landslides and erosion. This is critical for infrastructure projects in hilly or mountainous areas where ground stability is an issue.

To summarize, ground modification via grouting is a versatile and successful civil engineering technology utilized to handle a wide variety of geotechnical difficulties. It is a vital instrument for enhancing the characteristics and stability of the ground, assuring safe and sustainable infrastructure building, and environmental protection. Grouting has become an integral aspect of current construction and geotechnical engineering procedures by attaining goals such as greater load-bearing capacity, control of water infiltration, settlement reduction, and enhanced ground stability.

6. Materials and Properties of Grout

Ground modification via grouting is a frequently used geotechnical engineering technique for improving the mechanical and hydraulic qualities of soil or rock formations. Grouting is the process of injecting a specifically prepared substance known as grout into the subsurface to change its characteristics. Grout materials and their qualities are critical to the success of such undertakings.

Grout materials vary greatly and are chosen to meet the specific goals of the ground alteration project. The grout must ensure the stability of surrounding strata and the tunnel by distributing the constraints. Most grouts used are cement-based as cement is readily available and inexpensive (André et al., 2022). Cement-based grouts, such as Portland cement and microfine cement, are common grout materials that are used for soil stabilization and permeation grouting. Curing of concrete is the process of maintaining proper moisture and temperature conditions within the concrete after it has been placed and finished (Bhuiyan et al., 2023). Chemical grouts such as polyurethane and epoxy resins are also used because of their ability to enter small cracks and gaps in the ground, making them excellent for sealing and waterproofing purposes. The geology of the site, the anticipated improvement in soil or rock qualities, and the environmental limitations of the project all influence the selection of grout material.

Grout qualities must be considered for the effectiveness of a ground alteration project. These characteristics include the compressive strength, permeability, viscosity, and setting time of the grout. Compressive strength is essential for ensuring that the grout can hold the appropriate loads or offer structural stability to the ground. The capacity of the grout to seal fractures and prevent water infiltration is critical for waterproofing and environmental protection. The flowability of the grout during injection is affected by viscosity, which might affect its distribution and efficacy in filling voids and cracks. Setting time is the amount of time it takes for the grout to harden, and it affects the amount of time available for effective injection and consolidation.

Furthermore, grout's rheological qualities, such as thixotropy, shear-thinning tendency, and yield stress, influence its performance. These characteristics govern how the grout moves and interacts with the surrounding ground, influencing its capacity to enter cracks and fractures, displace air or water, and efficiently fill gaps. Grout should be designed to match the site's unique circumstances and suit the project's needs. For more clearance **Figure 4** has been added.

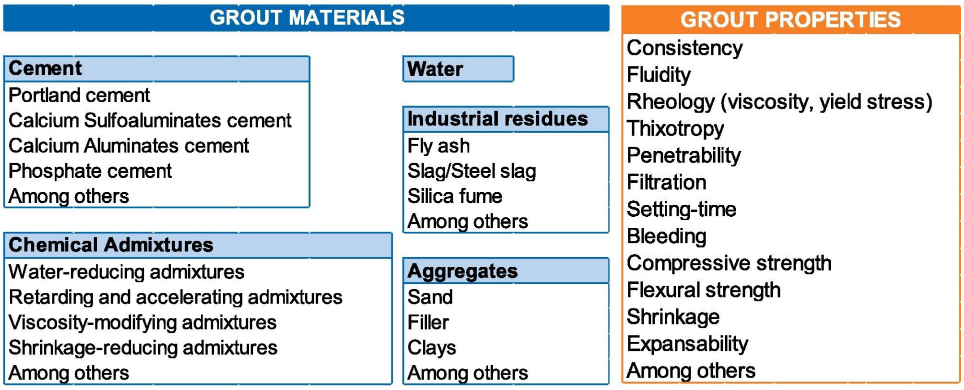

Figure 4. Grout materials and properties (da Rocha Gomes et al., 2023).

In conclusion, ground modification by grouting is a diverse approach that is dependent on the precise selection and formulation of grout ingredients and their qualities. Engineers and geotechnical professionals must evaluate geology, project goals, and environmental limitations while selecting the best grout material. Furthermore, the properties of grout, such as compressive strength, permeability, viscosity, setting time, and rheological behavior, must be tailored to the project's specific requirements in order to successfully improve soil or rock properties and overall ground modification success.

7. Techniques, Technology, and Control

Grouting is a flexible and successful geotechnical engineering method used to enhance the characteristics of soil or rock masses for a variety of building and infrastructure projects. This technology is useful to underpinnings of existing foundations, to support excavations in cohesiveless soils, to control the groundwater migration and to improve the strength of liquefiable soil (Sun & Wang, 2006). Grouting is injecting a specific substance into the ground, often a cement-based or chemical grout, to fill gaps, consolidate loose soils, enhance soil density, and control groundwater movement. This procedure may improve the ground's load-bearing capacity, minimize settlement, and reduce the permeability of soil or rock, making it an important technology in the building and maintenance of tunnels, dams, foundations, and other civil engineering projects.

There are various ways for ground alteration via grouting, each adapted to unique ground conditions and project needs. Permeation grouting, also known as chemical grouting, is used to stabilize fine-grained soils by injecting a chemical grout into the ground, where it solidifies and forms a solid mass. In permeation grouting the grout material penetrates the inter connected porous structure of the soil or rock which may comprise both the inter granular voids and the fissure network (Wang et al., 2016). Compaction grouting is the process of injecting a low-mobility grout into granular soils in order to displace and compact the surrounding soil, hence increasing its density. Jet grouting uses a high-velocity grout stream to erode and mix the in-situ soil, resulting in a homogeneous cementitious column. Contact grouting is a method of strengthening the structural integrity of rock or soil by filling voids or cracks. Furthermore, curtain grouting creates a barrier in the ground to manage water flow and prevent groundwater penetration into excavation sites. The grouting technique used is determined by elements such as ground conditions, project objectives, and environmental considerations.

Modern technology and equipment are critical to the effectiveness of grouting ground alteration. Grout pumps, mixers, and injection tools are common pieces of grouting equipment that are used to mix grout ingredients and transport them to injection locations. Computer-controlled system advancements have increased the precision and efficiency of grouting operations, enabling real-time monitoring and modification of grout injection settings. This method guarantees that grout is injected at the appropriate pressure, volume, and pace, therefore improving the ground modification process. For site inspection and monitoring, ground-penetrating radar (GPR) and other geophysical methods are used to analyze the efficiency of grouting, verify the distribution of grout in the ground, and discover any voids or abnormalities.

Control and quality assurance are key parts of grouting ground modification to guarantee that the desired improvements in ground characteristics are realized. Material testing, grout mix design, and monitoring of injection pressures and volumes are all examples of quality control procedures. To measure the efficacy of grouting in satisfying project objectives, site-specific performance criteria are devised. Post-grouting evaluation is carried out by geotechnical testing and inspections to ensure the anticipated ground improvement. In some circumstances, remotely operated vehicles (ROVs) or borehole cameras may be used to check the inside of grouted columns or ground voids.

Finally, ground modification using grouting is an important geotechnical method used to improve the qualities of soil and rock masses for a variety of building and infrastructure projects. Permeation grouting, compaction grouting, jet grouting, contact grouting, and curtain grouting are some of the grouting techniques that may be used to handle differing ground conditions and project needs. Computer-controlled systems and geophysical approaches, for example, have enhanced the precision and efficiency of grouting operations. Quality management and monitoring are critical to the success of grouting projects because they assist to verify the intended ground improvement and avoid hazards associated with ground alteration. Overall, ground modification by grouting remains a vital instrument in the construction sector, helping to ensure the safe and efficient development of numerous civil engineering projects.

Finally, Grouting is adaptable and may be customized to individual soil conditions and project needs. Engineers have a variety of grouting techniques to choose from, including as permeation grouting, compaction grouting, and jet grouting, to address a variety of soil issues. The success of grouting projects is dependent on a thorough understanding of the geology of the site and careful planning of the grouting procedure. Grouting, when done correctly, may increase the life of structures, save maintenance costs, and improve the overall resilience of the built environment. Overall, grouting is a vital and well-proven geotechnical solution that gives engineers a powerful tool for improving soil conditions and ensuring the long-term stability and performance of civil infrastructure projects.

8. Conclusion

This research focused for resolving a range of geotechnical issues related to soil conditions, ground grouting is a flexible and effective option. Whether used for permeability reduction, settlement control, or foundation stabilization, this method provides an affordable way to improve the subsurface's engineering qualities. Ground grouting is a useful technique in infrastructure and building projects because of its versatility, which allows engineers to guarantee the long-term performance and safety of structures while also optimizing site conditions. The efficiency and application of ground grouting are anticipated to substantially increase as grouting materials and injection technologies continue to progress, offering dependable and sustainable solutions for a variety of geotechnical problems.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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