Review on Properties and Applications of Grouting Technique

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Abstract

Due to the recent rapid expansion of infrastructure in major cities coupled with a lack of relevant land, the engineers were compelled to improve the soil's quality in order to support the load transferred by the infrastructure, such as buildings, bridges, roadways, railways, etc. These techniques are intended to dramatically reduce settlement and increase soil carrying capacity. One of the helpful methods for treating soils to acquire the necessary technical characteristics and specifications so that structures can be erected securely without experiencing significant settlements is soil stabilization. A common ground improvement technique utilized frequently for foundation and underground construction is grouting technology. Grouting is the process of injecting a liquid-based material into holes or cavities in soil or rock to improve cohesion beneath pre-existing hydraulic structures like dams, regulators, and others, therefore, reducing permeability and increasing shear strength. At present, grouting material is an important element of the connections between prefabricated components. The research on injection grouts used to improve soil and structure is reviewed in this essay. The content of this research is based on reports from researchers and includes the grouting materials and methods. This analysis reveals that several substances have been studied for use as injection grouts and that conservators can currently choose from a wide range of commercial and custom-mixed grouts.

Keywords: grouting, grouting material, chemical grouting, grouting methods.

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مراجعة خصائص وتطبيقات تقنية الحشو

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الخلاصة

نظرًا للتوسع السريع والحاصل في البنية التحتية في المدن الكبرى إضافة إلى قلة الاراضي المناسبة للبناء ، اضطر المهندسون إلى تحسين جودة التربة وتقويتها من أجل القدرة على تحمل الأحمال المنقولة بواسطة البنية التحتية، مثل المباني والجسور والطرق والسكك الحديدية وما إلى ذلك. تهدف هذه التقنيات إلى تقليل الهطول بشكل كبير وزيادة قدرة التربة على التحمل. إحدى الطرق المفيدة لمعالجة التربة للحصول على الخصائص المطلوبة والمواصفات الفنية اللازمة بحيث يمكن إنشاء الهياكل بشكل آمن دون التعرض لهطول كبير هي تثبيت التربة. من تقنيات تحسين الأرض الشائعة المستخدمة بشكل متكرر في الأساسات والبناء تحت الأرض هي تقنية الحشو. الحشو هو عملية حقن مادة ذات أساس سائل في الثقوب أو التجاويف في التربة أو الصخور لتحسين التماسك تحت الهياكل الهيدروليكية الموجودة مسبقًا مثل السدود والنواظم والموانىء وغيرها، وبالتالي تقليل النفاذية وزيادة قوة القص. في الوقت الحاضر، تعد مادة الحشو عنصرًا مهمًا يربط بين المكونات الجاهزة للبناء. تم مراجعة الأبحاث المتعلقة بحقن المواد المستخدمة لتحسين التربة والبنية في هذا البحث. يعتمد محتوى هذا البحث على تقارير الباحثين ويتضمن مواد وطرق الحشو. يكشف هذا التحليل أن العديد من المواد قد تمت دراستها لاستخدامها كمواد للحقن وأن القائمين على عملية الحقن يمكنهم حاليًا الاختيار من بين مجموعة واسعة من مواد الحشو التجارية والمختلطة حسب الطلب وحسب طريقة الحقن .

الكلمات المفتاحية: الحشو، مواد الحشو، الحشو الكيميائي، طرق الحشو.

1. Introduction

Investigating the main causes of cracking and micro cracking is the first step before beginning a repair. Following that, a survey should be conducted to determine the size and locations of cracks. The best method for the given project must be selected after examining the various possible procedures if repairs are required (Langevin, 1993). The foundation treatment plays an important part in maintaining the safety and integrity of any new dam by addressing the seepage problems which that are typically present(Al-Ansari et al., 2015). The characteristics and mechanical behavior of the soil formations that appear in their regions must frequently be improved for the safe building and operation of various technical undertakings(Christodoulou, et al., 2021). Grouting technology is a typical ground improvement method frequently used for underground and foundation construction. The process of grouting involves injecting a liquid-based material into pores or cavities in soil or rock to reduce permeability and increase shear strength by improving cohesion beneath pre-existing hydraulic structures like dams, regulators, and others(“A REVIEW ON GROUTING TECHNIQUE,” 2023). The grouting method, which is frequently used to repair railway tunnel distress, demands a careful selection of materials and technology in order to successfully address issues and produce the perfect grouting result. There are many different types of grout materials available today, which can be loosely split into two categories: Chemical and non-chemical substances, specifically, the nonchemical grout materials principally include cement, clay, bentonite grout, and so on(X. Yang et al., 2020).The process of filling or injecting fluid under pressure into the soil, typically through boreholes, is known as grouting by injecting grout, the soil's permeability will be reduced and the foundation soil's shear strength will be increased. By improving the strength and deformation characteristics of soils, grouting was initially used for ground stabilization. As previously discussed, the two other purposes of grouting are to prevent water from entering and to strengthen rocks(Meng, 2021). Grouting materials are used to fill in soil voids in order to reduce soil permeability. For the purpose of reducing seepage, grouting materials are divided into two categories: I) Grouts of the suspension type; II) Grouts of the solution type. Clay and cement are found in suspension-type grouts, whereas a variety of compounds, including acrylamide, NMethaloacrylamide, acrylate, and colloidal silica, are found in solutions-type grouts(El-latief, et al., 2015). The technique of grouting involves injecting several kinds of grout into the ground at a purposefully controlled pressure and flow rate. Depending on the ground conditions and objectives, different materials, such as cement, silicate, or others, are used to make the grout. A solid soil-grout mass is created when the grout fills in holes and fissures in the ground and seeps into soil pores(El-latief et al., 2015). In civil and geotechnical construction, grouting is injecting a liquid or suspension under pressure into the spaces inside a soil or rock mass or between a soil or rock mass and an existing structure. The grout that was injected into the voids must eventually solidify or gel(Ren et al., 2021). Since grouting is a very economical and effective way to treat some geotechnical engineering issues and disasters, it is currently widely used in a variety of fields, including building lifting and correction, roadway support and foundation pit reinforcement, dam foundation dam seepage control, prevention and control of coal mine water inrush, and other fields (Y. Yang, et al., 2016)(Du ,et al., 2016)(Wu, et al., 2017)(Guo, 2017). It is frequently necessary to modify the soil before to building on unstable soil in order to ensure the safety and security of surrounding constructions. Despite the fact that enormous rock deposits are frequently not solid, they are still referred to as solid rocks. They might have cracks, fissures, or voids that make the deposits unfit for dams, reservoirs, structures, bridge piers, etc. The formation must be made suitable for the planned use by taking corrective measures when subsurface investigations of a site indicate the presence of such structural flaws. It can be necessary to leave the site if the remedy is impossible or expensive, evaluating the reasons for cracking and microcracking is the first step before starting on with a repair. The next step is to conduct a survey to find the locations and size of cracks. Lastly, if repairs are required, the various methods should be investigated and the most appropriate one for the given task should be selected. Grouting has been used on big dam or other structure foundations since it was first used in the 19th century to reduce the amount of leakage through the rock and to reinforce the foundation to withstand the weight of the overlying structure. Therefore, grouting has two possible goals: either to increase a formation's strength and durability or to lessen water flow through it (decrease its permeability)(Langevin, 1993).

The formation under or adjacent to a structure is grouted for several reasons, such as (Langevin, 1993)(Du ,et al., 2016):

1. When the dam's overall integrity has to be strengthened.
2. To increase the formation's ability to support a load by stabilizing and strengthening it.
3. To reduce or prevent the flow of water through a formation, such as tunnel or underneath a dam.
4. To decrease hydrostatic increase beneath a dam.

5. Consolidation and strengthening of weak soil during tunneling excavation
6. curtain grouting for concrete and earth dams
7. ground settlement control
8. waterproofing of existing structures
9. preventing the spreading of hazardous contaminants
10. re-opening of old dams and tunnels
11. When the flow of water causes serious deterioration of the structure by dissolution of the concrete and joint erosion.
12. If freeze-thaw cycles cause the concrete to fracture and disintegrate the concrete.
13. When the volume of water is impacted by the amount of water lost.

2. Mechanism of grouting

The mechanism of grouting can be explained in the process of pressure filtration of grout in which the grout is injected under pressure into the soil and the mix will lose water into the surrounding ground. This loss of water will cause a thickening and reduction in the volume of the mix. As a result of the generation of internal friction, increased viscosity and yield of the grout will finally block the flow or movement of grout into the soil.

3. Classification of Grouting Materials

The choice of materials for grouts typically depends on many elements, such as the required working parameters and performance characteristics; as well as the availability of the materials. Cost could play a significant role, especially for large-scale operations(Biçer-şimşir, et al., 2010).

Although the physical, chemical, or mechanical forms of compatibility evaluated are not always explicitly stated, researchers indicate that they choose a major binder for the grout that is similar to the original material in most situations. Some studies aim to develop compatible grouts by undertaking analysis of the original materials For improving the grout's various attributes, including viscosity, bleeding (stability), setting time, strength, etc., a variety of admixtures may also be used. The super plasticizers, retarders, silica fume, fly ash, blast-furnaced slags, etc. are the most commonly used admixtures(Langevin, 1993).

3.1 Cementitious Grouts

The grouting procedure and application determine the qualities of the grouts that need to be evaluated. For instance, the grouting needs to increase load capacity and decrease soil voids in order to stabilize the soil. It is crucial to assess the injection's consistency and rheology because it is typically administered under high pressure. Grouting should set early in tunneling operations, so determining the setting time and grout's resistance be chemical attack and water seepage erosion are equally crucial.

As is well known, permeability is directly influenced by porosity, an intrinsic property of cementitious materials. When dissolved ionic species (carbonates, sulfates, and chlorides) interact with the matrix, water penetration damages the structure. While the overall porosity decreases as the w/c ratio decreases, fluidity is also hampered. Since the grout's interaction with the environment determines its durability, a high permeability will have a detrimental impact on it. The w/c ratio (The percentage of water mass (w) to cement mass (c) in a concrete mixture) should be as low as feasible for improved durability. Low w/c ratios, however, might reduce the fluidity, which would compromise the injectability of the grout. By adding permeability-reducing admixtures, the permeability can be decreased if a particular application calls for greater w/c ratios(da Rocha Gomes ,et al., 2023).

3.2 Bituminous Grouting

In specific situations, such as when a big leak from a nearby stream or river enters a quarry, asphalt grouts are used to stop water from moving rapidly (Figure 1). At the ground temperature, asphalt is a solid and must be heated over 275 °F (135 °C) to transform it into a flowable, viscous liquid. Pumping hot bitumen into moving water causes it to cool quickly, thicken, and create a low-strength plug. Cementitious grouts are typically used after the water has been stopped or delayed to increase the application's permanence. Hot bitumen and cement grouts can be co-injected as an option to improve the bitumen's resistance to creep and the final product's mechanical strength. The two materials may be concurrently injected into two holes or maybe co-injected into one hole, where mixing takes place at the bottom of the injection pipe. When compared to a two-stage injection, this technique frequently works better. The inflow passage is blocked as more grout is injected because a grout bulb grows at the injection point and combines with grout that sticks to the pathway's sides. An insulated core that is both hot and malleable forms inside this bulb when more hot bitumen is repeatedly injected and the heat exchange slows down(Bruce & Chuaqui, 2012)

The inflow passage is blocked as more grout is injected because a grout bulb grows at the injection point and combines with grout that sticks to the pathway's sides. An insulated core that is both hot and malleable forms inside this bulb when more hot bitumen is repeatedly injected and the heat exchange slows down.

Bitumen emulsion is a practical filler that can be injected into fine sand to create a waterproof barrier. Hot bitumen can also be used as a filler in a unique type called hot bitumen filler. It must be known that hot bitumen cools quickly at the interface and turns from a liquid state to a highly viscous state when injected into a medium saturated with water.

Figure (1): Hot bitumen and HMG from co-injection that escaped to the surface from deep karst.

3.3 Bentonite Grouting

The process of injecting a slurry of bentonite clay and water into the ground to fill in voids, stabilize the soil, and prevent water infiltration is known as bentonite grouting. When combined with water, bentonite swells, making it a useful material for waterproofing and sealing. Drilling holes in the ground and forcing bentonite slurry through them is how bentonite grouting is done. By filling in any holes in the soil, the slurry forms a solid mass that can hold up the structures or stop water from leaking through. In construction projects including dam construction, tunneling, and foundation rehabilitation, bentonite grouting is frequently utilized(Nassef ,et al., 2023) .

3.4 Resin Grouting

Epoxy resins (EP) are among the chemical grouting materials that have sparked a lot of interest because of their strong adhesion to a variety of substrates, excellent thermal and chemical resistance, superior electrical resistance properties, relatively lower shrinkage, and convenient processing characteristics. Usually composed of two components, these grouts are combined only before injection. They are ideal for structural repairs, crack injection, and soil stabilization because of their strong adhesive and compressive strengths(Nomura & Terwilliger, 2019). Epoxy resin grouting material offers good stability, low shrinkage, and strong bonding strength. It serves as the primary reinforcing for structural concrete. Methyl methacrylate grouting material can be injected into tiny fractures, has a low viscosity, strong permeability, high post polymerization strength, and high bond strength. It is frequently used in concrete dams, tubes, docks, and as the foundation for filling and plugging(Pang ,et al., 2017)

Resin fillers have a very low viscosity that allows them to penetrate fine sand. Setting times may vary depending on the type of resin used and the chemical composition of the local water table.

3.5 Chemical Grouting:

A chemical-prepared liquid can be applied to a more subtle gap and alter the setting time as necessary. Inorganic and organic chemical grout are the two categories of chemical grouting material. Chemical grout is mostly made of sodium silicate, which is an inorganic substance. Two fluid methods exist: the single-fluid method and the double-fluid method. The single-fluid approach is used to strengthen loess or soil that resembles loess, while the double-fluid method is used to consolidate and seepage-proof sandy soil with a high permeability coefficient. Various polymer materials, including epoxy resin, methyl methacrylate, and acrylamide, are used as the primary raw components in organic grouting materials.(Pang, et al., 2017).

Chemical grouting, which uses formulations that react after a specific period of time to form a gel to fill cavities in the soil using chemical solutions, is one of the innovative methods in the usage of grouting technologies. Water and other reagents are combined with chemicals, such as sodium silicates. Strength is the main application of sodium silicate. Because the constituents are fluids, they lack particulates that would prevent passage through tiny spaces, like cement.

To strengthen the ground and prevent excessive movement, to reduce the soil's permeability to prevent excessive water inflows, and to support nearby structures and other facilities during tunnel excavation, chemical grouting is frequently used in granular soils with significant fine sand content. Chemical grouting has the benefit of allowing grout to enter soil pores without significantly changing the volume or structure of the original soil. Another benefit is that it makes tunneling easier and allows it to progress without excessive excavation(Shishido, et al., 2018) .

The chemical method has several advantages as compared with other methods, such as the following:

1) It can be pumped into and through narrow apertures because it is a liquid.
2) Lower grout holes are necessary.
3) Compared to other grouting materials, the chemicals typically require less time to be injected.

If the formation to be grouted is particularly porous and has large voids, preliminary grouting should be done using materials like cement, a cement and clay mixture, to limit the rate of water flow to about 10% of the initial rate. After that, the last chemical grouting can be completed.(Shishido, et al., 2018).

As a general rule the grouting fluids can be shared in two classes are insert in Table (1).

Table (1): comparison between Binghamian fluids and Newtonian fluids

	Binghamian fluids	Newtonian fluids
1	Binghamian fluids are cement-based grouts that produce a suspension of granules	Newtonian fluids are solutions produced by grouts based on chemical compounds
2	are subdivided into(Tsingos & Engineer, 1991). -Pure cement mixers, PCM, which combine Cement and water to create an unstable mixture that is therefore not suitable for use as injection grout by most international standards (AFTES). - Admixed cement mixes (ACM), which are Made up of cement, water,plasticizers or superplasticizers, and thixotropy agents or Accelerators at the end. Clays [Bentonite] with an admixed cement mix Compose additive cement mixers, or ADCMs. They may also contain other types of fillers, such as pozzolanic additives [silica fume, fly ashes, etc.] or non-pozzolanic ones [mineral charges]	are subdivided into(Tsingos & Engineer, 1991). -Silicate Gels, also known as SGs, are made by combining sodium silicate in an aqueous solution with a reagent (hardener), typically either inorganic (sodium bicarbonate or sodium aluminate) or organic (carbonic acid esters, glyoxal), to produce a gel (silica snow) with extremely little mechanical Resistance. - Depending on the kind of resin, powerful acidic or alkaline hardeners are used to cure phenolic resins in aqueous Solution. Once a very strong acid serves as the catalyst for the reaction, this type of material Demands careful handling on the jobsite. - Organomineral resins, or OM, are modified Silicates that combine with isocyanate to create a stiff substance with a strong adhesive bond. While some don't, some formulations produce a strong Foamy effect. Although this resin behaves fragilely, It has a low elasticity modulus.

3.5.1 Limits and Advantages of Binghamian and Newtonian

Generally, the main pros and cons for the Binghamian fluids are(Tsingos & Engineer, 1991):

Advantages

- Low cost materials
- Simple to apply
- Have a high E-Modulus

Disadvantages

- Low penetration capacity
- Long setup durations
- Sensitive Conduct

On the side of the Newtonian fluids we have:

Advantages

- High penetration capacity
- Fast setting times
- High capacity of energy absorption (PU)

Disadvantages

- (Types of thixotropy) not washable
- High cost,
- Demand for a trained applicator,
- Low E-Modulus

It is challenging to establish a uniform classification system because there are so many different chemical grouts available. Early methods from the 1960s depended on the grouts' mechanical characteristics. They can also be categorized depending on the chemicals that make them up. The chemical families that make up this later grouping are given below(Langevin, 1993).

1) Sodium silicate formulations

Aqueous (colloidal) solutions are used in the manufacturing of sodium silicate. Whenever a salt (CaCI2) is added. A chemical reaction occurs, leading to the formation of a gel. The two products can be mixed in one or two phases, but the two-phase method—injecting calcium chloride after the sodium silicate solution has been injected into the ground or crack—produces the best results. The major advantage of this procedure is that the grout is weak compared to a cement grout, but hard for a chemical grout. The solution's high viscosity prevents it from penetrating small fissures, and it also prevents a complete reaction between the two injected liquids. A novel method involves mixing a weak acid like sodium bicarbonate with a basic like sodium silicate. After a certain amount of time, silicate precipitates and forms a gel via neutralization when a dilute sodium silicate solution is combined with an acid solution. This imitation has the benefit of having low viscosity, which allows it to penetrate micro cracks. It's extremely low strength, the lengthy setting time (control gel time), and potential shrinking issues are just a few of the disadvantages. Therefore, this chemical grout should only be used to seal fractures rather than consolidate them(Langevin, 1993).

2) Acrylamide grouts

These grouts are a mixture of two organic monomers, 95% acrylamide, which polymerizes at room temperature into long molecular chains, and 5% methylenebisacrylamide, which acts as a cross-linking agent and holds the chains together. The end result is a solid plastic that is strong and long-lasting but has a weak compressive strength. The advantages of these chemical grouts include their low viscosity (near water), resistance to chemical attack, and ability to soak into dry concrete while simultaneously filling cracks and micro cracks. Their high levels of toxicity and flammability, weak strength, inability to be injected into wet cracks (they won't mix with water), and potential for volume variations over time are their main negatives. Therefore, it is not possible to consolidate fractures and microcracks in a concrete structure using this form of grout(Langevin, 1993).

3) Lignosulfonate grouts

The lignosulfonates are a waste product (by-product) of the paper mills that process wood. A hexavalent chromium compound and lignosulfonates make up the intricate chemistry of chrome lignin grout. The concentration of solids used in the mixture affects the viscosity and gel setting 'Lime. The main benefits of lignosulfonate grouts are that they are economical and have a low viscosity. However, they are exceedingly poisonous and lack the compressive strength necessary to consolidate a crack. As with the previous products, ligosulfonates are not recommended to consolidate cracks and micro cracks(Langevin, 1993).

4) Phenoplast grouts

These resins are polycondensates resulting from the phenol-on aldehyde reaction. They only set (are utilized in the oil-well sector) at high temperatures throughout a broad pH range. They require an acid medium to be used at room temperature. If acidity is not preferred, the other choice is to combine resorcinol (another type of phenol) with formaldehyde. While the gel setting time decreases quickly with the concentration of resorcinol, the compressive strength of such a grout increases dramatically. Phenoplast grouts are extremely harmful to the environment, just like many chemical grouts. Phenoplast's low compressive strength prevents it from being regarded as a consolidation agent for cracks(Langevin, 1993).

5) Aminoplast grouts

Formaldehyde and urea, as well as other polymers, are used to create aminoplast resins. The main limitations are that the reaction can only be carried out at high temperatures and that an acid environment, such as phenoplast resins, is necessary for the reaction to be completed. This type of grout is toxic and corrosive and cannot be used in areas with high pH levels. It also provides less strength than a typical cement-based grout (and is therefore not used to consolidate cracks). However, it has a low viscosity that allows it to be injected into fine cracks or soils. The consolidation of cracks is not advised while using these chemical grouts.

6) Water reactive materials

When these substances come into contact with water, they either polymerize, froth, or create a gel. As a result, polymers like polyethylene, polyvinyl, and CCA have very low viscosity values and may fill cracks and micro-cracks in concrete that are as small as 0.05 mm. These foam-type grouts benefit from wide control gel time restrictions and the ability to be used in environments with abundant moisture. However, these materials have the following drawbacks: they require a high level of skill to inject, have a low compressive strength (thus they are employed to seal cracks rather than to consolidate them), and must not dry out while in use(Langevin, 1993).

7) Organic polymers

Organic polymers with outstanding mechanical properties include polyesters, polyurethanes, and epoxy resins. They can be used to consolidate cracks and micro cracks since they have the highest compressive strength of any chemical grout ever produced. Although they have a slightly greater viscosity than the other chemical grouts, they can still be injected into very small fractures (up to 0.05 mm). Finally, these organic polymers are very expensive, difficult to manipulate, have a high coefficient of thermal expansion (compared to concrete), have a problem bonding in a moist environment, and can experience volume changes over time. They also have problems setting at low temperatures (and setting too quickly at high temperatures)(Langevin, 1993).

3.6 Fine mineral grouting material

A new kind of grouting material, fine mineral grouting material achieves breakthroughs in grout performance, consolidation performance, long-term durability, and other critical performance areas by combining various natural minerals, synthetic minerals, and unique functional materials. In terms of key features such as consolidation strength, injection ability, adjusted gelation duration, stability, viscosity, and other grout parameters, certain fine minerals have performed as well as or better than chemical grouting materials. In Wuhan Polytechnic University, for example, powdered slag was utilized in place of cement. They created a novel double-fluid grouting material with a varied gelation period, high compression strength, and 100% stone rate using sodium silicate, and they used it to build the Wuhan Yangtze River. Therefore, the process of making grouting material from industrial waste slag, such as steel slag, fly ash, and so forth, not only helps turn a lot of industrial waste leftover trash into treasure but also lowers environmental pollution and grouting material costs.

In terms of macroscopic characteristics, new fly ash, slag, steel slag, and other solid waste generation are acceptable to meet engineering requirements. However, their early adaptability and long-term durability have not yet been confirmed through experimentation (Pang ,et al., 2017).

4. Process for Selecting Grouting Materials.

a) Grouting method depends on :-

- Type of medium is being grouted (soil, rock, concrete, or combination, e.g., Karst).
- Purpose of the grouting (strengthening or modulus reduction, permeability reduction, or water control) .
- Choose the grouting methods that be used to achieve the purpose.
- How critical is the grout performance.
- How permanent must the grouting be.
- Knowing the rate of flow.
- Choose the grouting method with the environmental considerations.
- Knowledge the cost of grouting.

b) Choosing the principal grouting technique and material will help meet most of the anticipated situations. If more than one material can be utilized to provide the desired enhancements or effects, cost and long-term durability should be considered when making the final decision. The cost of the project that uses the material should be taken into consideration in addition to the material cost when determining the pricing. Materials that are commonly used for grouting include cement, organic polymer polymers, cement-water glass, etc. Because it has exceptional stickiness and can form stable cement, cement is the most stable material. Similarly, high molecular polymers perform rather well. To be used as grout, it must be strong, filling, permeability, aging-resistant, have good adhesion, and have appropriate mechanical properties. The grouting construction effect can only be attained by obtaining these attributes. (P. Wang & Li, 2021)

C) Choosing the secondary grouting material, to achieve the objectives set given for a project, more than one grouting technique or type may be suitable or required. To permeate the rock cracks, for instance, a grouting program in karst terrain might be created employing HMG (High-Mobility Grout) as the main grouting material. LMG (Low- (or Limited-) Mobility Grout (or Grouting)) may be used to treat open or soil-filled solution features, though. The usage of asphalt grouts might be necessary in high-flow situations. A combination of Portland cement and ultrafine cement may be necessary to achieve the low permeability (less than 10-5 cm/sec) performance requirement for the finished curtain.

5. Infectivity analysis of grouting material

The permeability grouting impact of fractured media is influenced by three elements for grouting materials: size effect and rheological effect. The permeability of granular slurry (suspension) is mostly influenced by the size effect, whereas the permeability of slurry solution is primarily influenced by the rheological effect(Guo, 2017).

5.1 Size effect

Since the fracture grouting essentially does not modify the structure of the rock mass medium, the grouting material's particle size must be smaller than that of the rock mass medium's fractures. In other words, the foundation of seepage grouting provides the size effect of grouting material on fracture. The presumption of grout penetration to fracture is $R=D/d>1$, where R is the clearance ratio, assuming that the particle size of the grouting material is d and the crack size of the bottom is D(Katunská & Katunský, 2015). However, under normal conditions, the slurry particles frequently enter the fractures in the form of multiple particles that stick together due to the influence of slurry concentration, obstructing grouting channels and reducing the grouting effect. Therefore, when calculating the size effect, the impact of particle blockage must be included. When the clearance R>3, the collection of particles forms an unstable structure that is quickly destroyed by grouting pressure, and the grouting channel cannot be blocked. R=D/d>3 is therefore typically utilized as the foundation for constructing grouting materials.

5.2 Rheological effect

Rheological characteristics of slurry flow in fissures of a few of the most basic fluid rheological curves shows Figure (2)

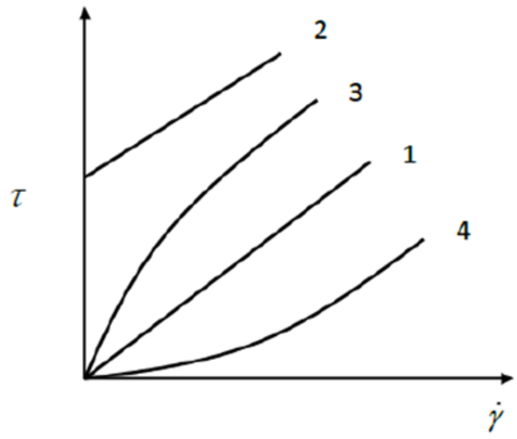

Figure (2): The rheological curve of various fluids

Figure (2) shows the Newton fluid as 1, the Bingham fluid as 2, the shear thinning fluid as 3, and the shear thickening fluid as 4.

Table (2): comparison between Newton fluid and Non-Newtonian fluid.

	Newton fluid	Non-Newtonian fluid
	-The Newton fluid is a single-phase homogeneous system that includes water, the majority of chemical grouts, and cement slurries with water-cement ratios W/C larger than 1	-Non-Newtonian fluid typically has multiple phases, like suspension - non-Newtonian fluid is a cement slurry with a water to cement ratio (W/C) less than 1
	-Newton fluid has a constant viscosity	Non-Newton fluids have variable viscosities that change over time.

Figure (2) demonstrates that the rheological curve of Newton fluid and Bingham fluid, two fluid types that are frequently employed in grouting, is a very straightforward line. This fluid, also known as pseudo plastic fluid or shear thinning fluid, manifests itself as shear thinning during the flow. The apparent viscosity of the fluid indicated by curve 4 increases as the shear rate increases (the curve is convex). It is also known as swelling fluid and is characterized by shear thickening during flow. When it comes to the slurry used in grouting engineering, people usually conceive of it as Newton fluid and Bingham fluid to study. As is common for viscous fluids, the rheological curve of the Newton fluid, represented by curve 1 in Figure 2, is a straight line through the origin. Its constitutive equation is $\mu \frac{\partial u}{\partial y}$ where $u(y)$ the variation of the flow velocity (u) in the cross-flow (transverse) direction. The Bingham fluid is a typical plastic fluid, and unlike curve 2 in Figure, its rheological curve is a straight line away from the origin. Its constitutive formula is $\tau_0=\mu\dot{\gamma}$ where $\tau_{0=}$initial shear stress, μ=at-point plastic viscosity, $\dot{\gamma}$=at point rat ofshear.

Also Slurry viscosity considered as the primary factor influencing the rheological characteristics of slurry is slurry viscosity. Slurries' viscosity is often considered as a constant in engineering applications since the viscosity of standard pulps changes only slightly over time. But as time passes, the slurry's viscosity varies. At various times and with various ratios of water to cement.

6. Preparation for Grouting

The preparation for washing or grouting seams consists of the following

1. Installing a pipe section in the grout hole. Pipe sections are typically (38-50) mm in diameter and (0.45-0.9) m long.
2. The pipe's top end extends a short distance in order to connect to an air tube or a pump.
3. Oakum or another appropriate material is used to seal the area around the pipe's bottom.
4. Cement mortar is used to fill the remaining empty space.
5. Uplift gauges should be set throughout the region to detect any rising of the surface during the grouting operation in order to lessen the risk of weakening the formation through fractures brought on by the application of excessive pressure.

7. Washing the Seams

The seams washing can be summarized as follow

1. It is better to apply the cement in clean seams where any clay or unconsolidated materials have been removed when grouting a formation with neat cement for consolidation reasons. Forcing a mixture of air and water into the seams is the most efficient way to remove such things.
2. Alternating the direction of the air and water flows can improve the efficiency of material removal.
3. By injecting water containing a coloring agent, such as fluorescein dye, it is possible to detect whether a seam is open from one hole to another. If the colored water appears from other holes, this shows open passages through the seam.
4. These steps are taken when washing a formation:

    1. A whole pattern is selected.
    2. To allow the materials that have been washed to drain, some of the holes are sealed with compressed air, others with water, and some without caps.
    3. The pipe caps can be switched to reverse the flow direction.

8. Drilling Injection Holes:

One way to drill holes for grout injection is (Ren ,et al., 2021):

1. Jackhammers.
2. Wagon drills.
3. Diamond drills or shot drills.

The type of drilling machines depends on:

1. The terrain.
2. Class of formation material.
3. Size and depth of holes.

Diamond drills usually give holes that are uniform in shape and size, which are more satisfactory than holes drilled by other equipment. Wagon drills are satisfactory for holes whose depths do not exceed (12 m).

9. Grouting Methods

Grouting is a useful tool in the field of construction, and the kind of grouting used should be chosen by evaluating all the factors involved in a problem, such as the engineering requirements, the subsurface conditions, the materials available, and the economic factors. Some of the grouting techniques used include Penetration grouting, Vacuum grouting, Compaction grouting, Jet grouting, Fracture grouting and Fissure or rock grouting and below is an explanation of these methods.

9.1 Penetration grouting:

A type of grouting also known as permeation grouting involves filling the soil's pores and seams with grout without changing the soil's volume or structure. It penetrates granular and coarse soils as a result, creating a cemented mass. When using of this grouting technique, the choice of binders is mostly determined by the soil's permeability. It's also known as cement grouting or pressure grouting. When the coefficient of permeability is greater than 10-2 cm/sec, water-cement mixes are used; when it is less than 10-5 cm/sec, costly resin-based grouts are used. Using the permeation approach, grouting is frequently not possible in soils with K values less than 10-6 cm/sec (“A REVIEW ON GROUTING TECHNIQUE,” 2023).

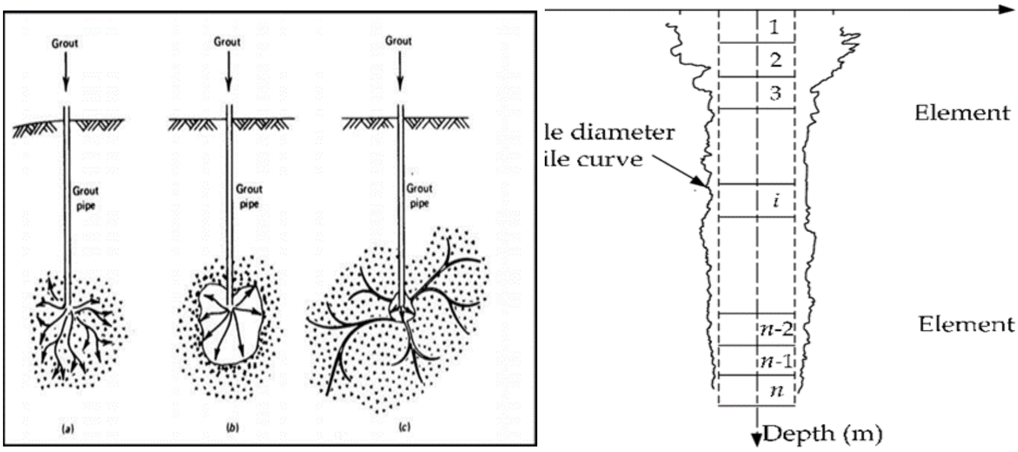

Figure (3): Penetration grouting

9.2 Vacuum grouting:

In geotechnical engineering, vacuum grouting is a new grouting technique that is frequently applied in layers where penetration grouting is difficult because of the anticipated slurry diffusion radius, such as sand and silt strata. Vacuum grouting is the process of 'sucking' grout into a void under pressure, despite the fact that grout is generally driven by pressure. The vacuum grouting device is made up of four components: a test box, a vacuum monitoring system, a grouting system, and a vacuum generation system. The rubber tube connects the components of the vacuum generation system, which also includes an air compressor, a vacuum generator, a vacuum well, a vacuum gauge, and a pressure-regulating valve. Similar to a jet pump, it operates on the same principal. The compressed air that the air compressor produces flows into the vacuum generator's bottom end. The air surrounding the neck's exit is continuously drawn away, creating a negative pressure in the vacuum well that is connected to the throat. The air pulls the dust from the test box into the vacuum well. At this stage, there is a certain amount of vacuum in the soil, and a vacuum field forms around the vacuum well (Li et al., 2020).

9.2.1 Main technical advantages

The advantages of the vacuum packing method can be summarized as:

1. The air, water, and bubbles established with the cement slurry are removed in the vacuum state, which reduces porosity and bleeding.

2. The channel shows good sealing properties during the grouting procedure, ensuring that the slurry fills the whole channel under pressure.
3. The technique and slurry are optimized to prevent cracks from developing and to ensure the strength and fullness of the grouting.
4. The grouting period is shortened by the vacuum grouting procedure, which is continuous and quick.
5. Structures can be corrected using this technique (Liu et al., 2020)

9.3 Compaction grouting:

Is a technology that is more cost-effective than traditional methods for re-compacting and stabilizing sub soils at deeper levels 7-23.3m (25–75 ft) of depth is not unusual as show in figure (4). Poorly compacted fill, loose soils, water infiltration, and poor over-excavation and re-compaction of a building site are frequently to blame for soil issues. Compaction it has been shown that grouting may reduce the potential damage caused by soil liquefaction during seismic occurrences. In order to densify and re-compact the soils, this approach uses a clear, low-slump grout that can be poured into the soils slowly and under high pressure.

This type of grouting involves injecting a thick grout made of soil cement under pressure into the soil mass, stabilizing the surrounding soils as the grout consolidates. Because of the way the grout mixture is made, it cannot mix with the soil or fill in voids in the soil. However, it moves the soil into which it is injected (“A REVIEW ON GROUTING TECHNIQUE,” 2023).

9.3.1 Advantages of Compaction Grouting:

The advantages of the Compaction Grouting method can be summarized as:

1. Compaction grouting is appropriate in places with limited space and restricted access.
2. Quick installation is possible.
3. Produces little site vibration.
4. No spoils are brought on.
5. There aren't any connections to a built-in foundation.
6. Significantly lessens current foundation settling.
7. Reduces the risk of soil liquefaction brought on by earthquakes.
8. Offers precise aggregate grout structure placement and pressure.

9. The ideal cure for sinkholes.
10. More affordable than some other ground-shoring and soil stabilization techniques.

9.3.2 Limitation

- Compaction technique It should not be used in circumstances when the overburden above the grouting zone is little or nonexistent since it may cause the ground to heave around the bulb column. Usually, an overburden of at least five feet is necessary.
- Clays and other low-permeability soils are inappropriate for use in the compaction process.

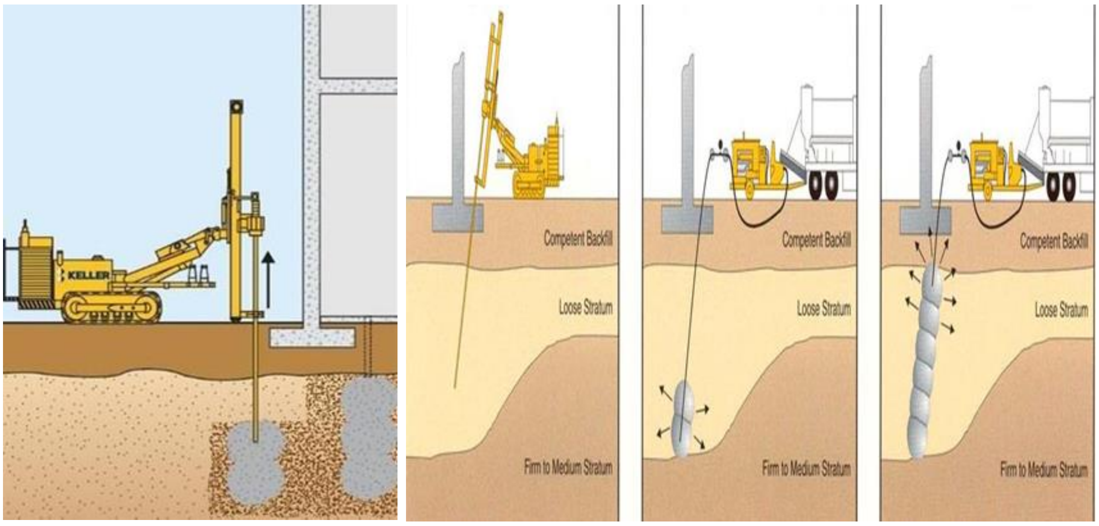

Figure (4): Compaction grouting

9.4 Jet grouting

Pressure grouting or jet grouting Considering jet grouting may be applied to almost any type of soil, it is one of the most widely used ground improvement procedures. By mixing in-situ soil and cement slurry, jet grouting is a soil treatment method for stabilizing fragile ground. Jet grouting has been extensively utilized in numerous subterranean projects for soft ground modification, including base seals and buried grout struts for deep excavations, structural support surrounding tunnel eyes at the tunnel boring machine's departure and entrance sites, and sealing diaphragm wall leaks. In jet grouting, a nozzle mounted on a spinning monitor is used to spray cement slurry into the ground at high pressure. In order to create a soil-cement column, the ensuing high-speed fluid jet both erodes the in-situ soil and simultaneously mixes it with cement slurry as showed in figure (5). According to some applications, the soil-cement column's shear strength may approach several megapascals. The soil is improved during the eroding and mixing of grout with the dirt. It costs more than Penetration grouting(Z. F. Wang et al., 2013).

The main operational parameters for jet grouting that control the jetting performance are

(Z. F. Wang et al., 2013)

1. Features of the jetting fluid (i.e., the grout's water-to-cement ratio.
2. Pressure and flow rate of the jetting fluid.
3. Jetting time (which depends on the nozzle's traverse velocity and, consequently, the rate of withdrawal and rotation speed.
4. Nozzle characteristics (i.e., nozzle diameter, number of nozzles, and nozzle shape).

9.4.1 Advantages

The advantages of the Jet Grouting method can be summarized as:

1. The ability to produce soil Crete in confined places and around subsurface barriers like utilities.
2. The ability to be effective over the broadest variety of soil types of any grouting technology, including silts and most clays
3. Low headroom machinery makes it possible to build in small locations, such as basements.
4. Can treat soils below a particular layer of soil without treating soils above.
5. Regular facility operations may typically be carried out without interruption
6. When using jet grouting in combination with other geotechnical techniques.
7. Containerized, highly mobile support equipment decreases the cost and duration of mobilization and demobilization.

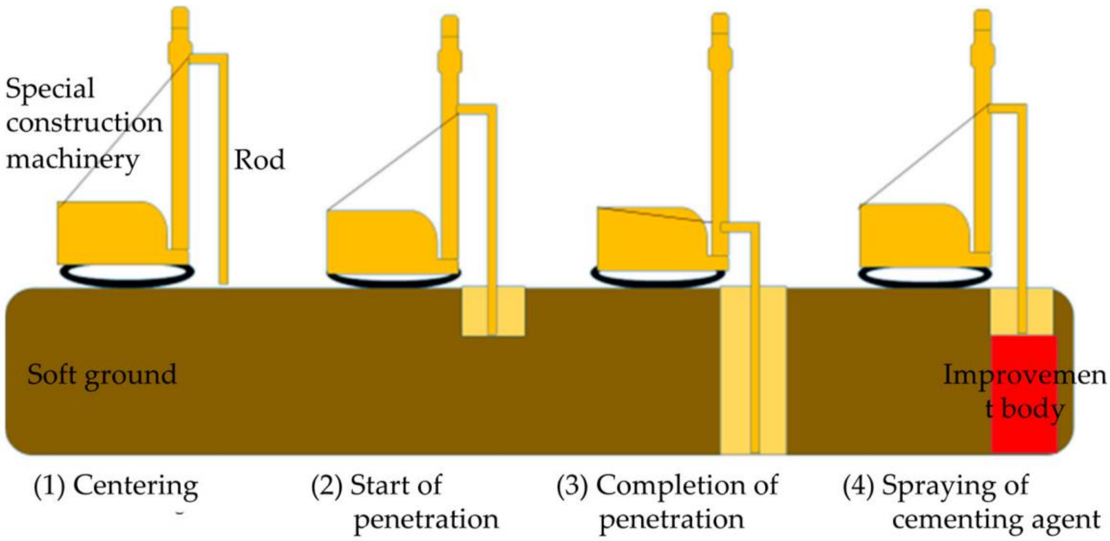

Figure (5): Jet grouting system construction process.

9.5 Fracture grouting

Figure (6) show the Fracture grouting and the other name for it is compensation grouting. In order to create root-like or thin lenses inside the soil mass, a cement slurry grout is injected into the soil at a high pressure. The compacted soil is raised above the surrounding soil by the root-like lenses. It significantly boosts the soil mass's density and macroscopic strength. The idea behind hydro fracture grouting, or "frac" grouting as it is more often known, is to inject grout under pressure to break the soil's tensile strength, which then causes grout lenses to be injected into the soil. Due to the higher strength of the grout compared to the soil (grout strength is typically measured in psi versus soil strength, a difference of two orders of magnitude), these pressurized lenses of grout densify the soil by plastic deformation in the vicinity of the lenses and also reinforce the soil mass. In clay soils, the grout may also undergo a chemical reaction (cation exchange) with the clay minerals in close proximity to the lenses, increasing the strength. Fracture grouting applies stable grouts to prevent further deformations brought on by bleed water dissipation. The vertical effective stress is greater than the horizontal effective stress in an under consolidated or typically consolidated soil in this method.

Therefore, in an underconsolidated or normally consolidated soil mass, the first crack in frac grouting propagates vertically. With several re-injections at the same location, the soil's stress state changes and the fractures' angle changes from vertical to horizontal. Until the fracture is horizontal and the greatest amount of deformation possible within the soil mass is reached, the process is repeated. At this point, the injection stops, and the bulk starts to lift or heave. The intended result of the repeated injection method, under ideal circumstances, is a network of grout lenses in all directions that have individually led to densification and left behind a skeleton of a stronger material that is more resistant to future settlement.

The greatest level of densification for both compaction and fracture grouting is controlled by surface heave, which occurs when pressures applied to the soil during application surpass the overburden pressure at that moment. Estimating the degree of the deformations is difficult because fracture grouting does not reveal the length of the produced fracture. The grout lens matrix's benefit is easy to envision, but it's impossible to quantify in technical terms. Consequently, even though successful fracture grouting projects have been documented, there are no defined procedures for developing such a program. Another common usage for fracture grouting is compensation grouting, where the grout is started to make up for settling. The tunneling industry widely uses compensatory grouting to rectify the settlement of structures caused by tunnel excavation in soils. When grouting is used to reinforce a fractured rock mass, the shattered surface is the process' immediate target. The mechanical properties of the fractured surface are directly altered by grouting reinforcement. A crack is the primary building block of grouting. Understanding the grouting mechanism for fractured rock masses requires investigating how grouting affects the mechanical properties of fractured surfaces(Liu et al., 2020). This kind of grouting can be used for a variety of tasks, including:

- releveling structures.
- Controlling settlement and bearing capacity.
- Mine void filling and stability

9.5.1 Advantages

The advantages of the fracture Grouting method can be summarized as:

1. Can be carried out without entering the impacted building from shafts or tunnels below the structure.
2. Real-time observation of soil and structural displacements during the grouting process.

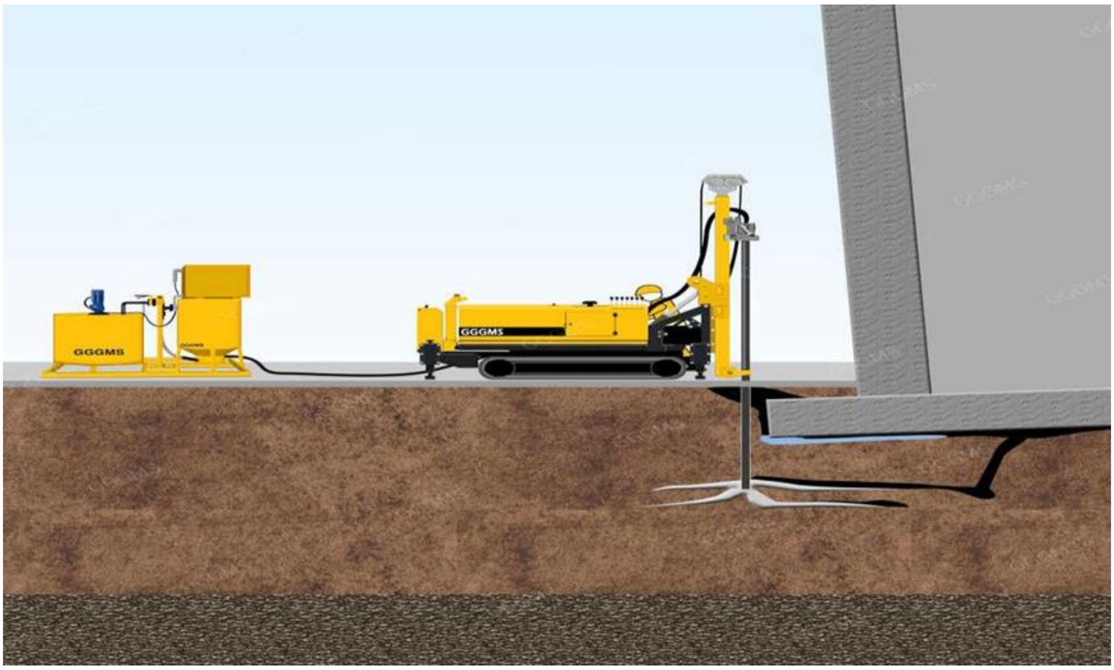

Figure (6): Fracture grouting

9.6 Fissure or rock grouting

Rock grouting is the practice of injecting grout into fissures, fractures, or joints in a rock mass to fill them entirely or partially without producing new cracks or enlarging existing ones. Drilling a hole in the rock mass and injecting grout through it under pressure is the treatment method. This type of grouting is frequently employed in fissured rock to prevent water from flowing along the joints as show in figure (7)("A REVIEW ON GROUTING TECHNIQUE," 2023).

9.6.1 Advantages

The advantages of the rock Grouting method can be summarized as

1. Minimizes groundwater flow rates.
2. Minimizes deformation of rocks.
3. Lowers transmissivity through aquifers' linked porous zones.
4. Reduces the cost of pumping during basement excavation.
5. Assists in lowering groundwater levels away from the excavation.

Figure (7): Rock grouting

10. Advantages of Grouting

The benefits of many different kinds of grouting have already been covered above:

1. The benefits include the fact that it may be done on practically any type of ground.
2. It can be controlled to prevent structural damage and doesn't vibrate.
3. Ground improvements are quantifiable.
4. May be working in confined or difficult-to-access areas.
5. Can be built close to existing walls.
6. Very helpful for slab jacking to lift or level crooked foundations.

11. Determining the Effectiveness of Grouting:

Additional exploratory holes may be drilled at various points inside the grouted region before the grouting procedure is finished in order to collect formation cores. If these cores reveal that there is enough grout present to create satisfactory consolidation where voids previously existed, the grout process was successful.

By injecting water or grout into the holes where the cores were taken, the effectiveness of the grouting operation can be evaluated. The test shows that the formation has been effectively consolidated by prior injections if these holes refuse to accept grout.

12. Application of Grouting

The following are examples of how various types of grouting are applied(“A REVIEW ON GROUTING TECHNIQUE,” 2023):

1. Reducing water flow in underground constructions such as dams, parkades, tunnels, and mines
2. Stabilizing the soil.
3. Mining applications and structural support.
4. Enhanced bearing capacity.
5. Minimizing and adjusting settlement.
6. Grounds maintenance.
7. To offer assistance with excavating.
8. When tunneling, filling the space between the liner and the rock face.
9. Strange and challenging geotechnical and structural issues.

13. Conclusions

1) The general goal of injections is to either raise the soil's shear strength, density, and stiffness or decrease its compressibility and permeability.
2) Several grouting kinds used in construction have been covered in this research. It is technically and financially viable to use ground improvement techniques to fix unstable soils so they may be used for construction, according to the study's findings.
3) We have covered many grouting kinds used in construction in this article. According to the study, fixing weak soils to make them suitable for development using ground improvement techniques is both technically possible and advantageous from an economic standpoint. For a variety of projects, including highways, ports, runways, industrial buildings, railroads, dams, slope stabilization, excavations, and other infrastructure developments, the effectiveness of many solutions has lately been proven .
4) Varying grouting materials have varying application scopes and levels of localization. Their performances differ greatly in terms of mobility, gelation time, stability, toxicity, compressive strength, reinforcing, extension alrigidity, anti-permeability, corrosion resistance, and aging resistance. Therefore, in order to fully understand how different types of grouting material work, extensive comparison and experimental investigation are required.
5) By carrying out a suitable injection program, the characteristics and mechanical behavior of soil formations can be improved immediately. The injection program may be carried out as part of the preliminary field work before the main project's construction begins, as part

of the main project's construction, or as a "treatment" when unforeseen circumstances occur while a project is being built.

6) In finer-grained formations, chemical solutions can pass through to fine grained sands or coarse-grained sludges with satisfactory ease.
7) In constructed concrete structures today, the primary grouting substance is still classic cement-based grout. Since there are still malpractices, we must work harder to investigate and create novel grouting materials with low costs, abundant raw resources, and flawless performance.
8) All across the world, a variety of soil types, including loose sand, silt, clay, and weak rocks, have been stabilized using these approaches.

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