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Review paper

Applying different soil stabilization mechanisms: a review

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Abstract: To guarantee a durable pavement construction that only needs a little care, it is crucial to manage problematic soil conditions properly and prepare the foundation. Some organizations remove soils since they have realized they do not function as well as other materials (for example, a state specification dictating that frost susceptible loess could not be present in the frost penetration zone). Nevertheless, there are more advantageous or desirable courses of action than this (e.g., excavation might create a disturbance, plus additional issues of disposal and removal). The subgrade conditions described in the preceding section may be improved by stabilization, offering an alternative solution. It is impossible to overstate the importance of ensuring a homogeneous soil profile in terms of density, moisture content, and textural categorization in the top section of the subgrade. Thru soil sub-cutting or other stabilizing methods, this consistency may be attained. Additionally, stabilization may be utilized to prevent swelling in expansive materials, create a weather-resistant work platform, enhance soil workability, and limit issues with frost heave. Alternative stabilizing techniques will be discussed in this part, and advice for choosing the best technique will be adequately provided. The current review paper aims to identify bridge issues related to soft soil and takes two ways of soft soil stabilization: chemical and mechanical. The finding of both methods show that the compressive strength and settlement have been improved after using waste materials; therefore, using waste materials as a cement replacement is considered one of the expansive utilized methods in most construction applications and bridges of that applications.

Keywords: soil stabilization, bridge, chemical stabilization, geogrids, fly ash, mechanical stabilization

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1. Introduction

Stabilization is the act of combining and mixing different elements with soil to enhance certain soil qualities. The procedure could include combining commercially available additives to change the soil's plasticity, texture, or gradation or serve as a binder for cementing the soil. Alternatively, it might involve blending soils to produce the appropriate gradation [1].

Modification is the process of decreasing plasticity and enhancing soil texture. In subgrade soil, monovalent cations like potassium and sodium are often present. These cations may be exchanged for greater valencies, such as calcium, which is present in limestone and fly ashes. Within a few hours, this ion exchange process is completed practically instantly. Clay particles may flocculate because the calcium cations surrounding them take the place of the sodium cations and reduce the thickness of the bound water layer. The flocculation transforms cohesive soil into more granular, sand-like soil while decreasing flexibility and improving the shear strength of subgrade soil. The altered structure makes the soil more workable and constructive while reducing its susceptibility to moisture. The impact of alteration with a considerable increase in strength is included in soil stabilization [2].

The current study aims to identify the bridge issues that related to soft soil issues and ways of reduction, where firstly the review focuses on bridge foundation issues and ways of reductions these issues specially the issues that related soft soils. Furthermore, the review takes into consideration two methods to stabilized soil by waste materials and geo-grid that mostly used when construct bridges to identify the differences in compressive strength.

2. Common causes of bridge foundation issues

Due to natural and manufactured factors, weak soils may develop under bridge abutments and approach/departure ramps. The original soil composition had components that were not tightly packed before building or that adjacent drilling or excavation lowered the soil quality. Strong soils often produce subsidence that frequently causes the creation of voids under the surface in sub-base and base soils, regardless of the reason. Subsidence may harm bridge abutments and the entry and exit ramps if unchecked. A bumpy ride while approaching or leaving the bridge, fractures in the heaves, dips, and slabs, and signs of soil subsidence close to the bridge are all signs of unstable soils [3–7].

Fortunately, bridge failures are uncommon, but each year reports provide information on a few bridge collapses that have happened somewhere in the globe. The eroding of foundations owing to bed scour is one form of failure that sometimes results in a sudden, catastrophic collapse of bridges.

Engineers and academics have been interested in scouring bridge piers and abutments because it may cause significant failure and bridge collapse. The many research conducted to comprehend the aphenomena and gauge the scour depth is evidence of its significance. Nevertheless, there are still a lot of significant uncertainties around the forecasts made by the current formulations. Figure 1 shows many failures modes in bridge structure and substructure.

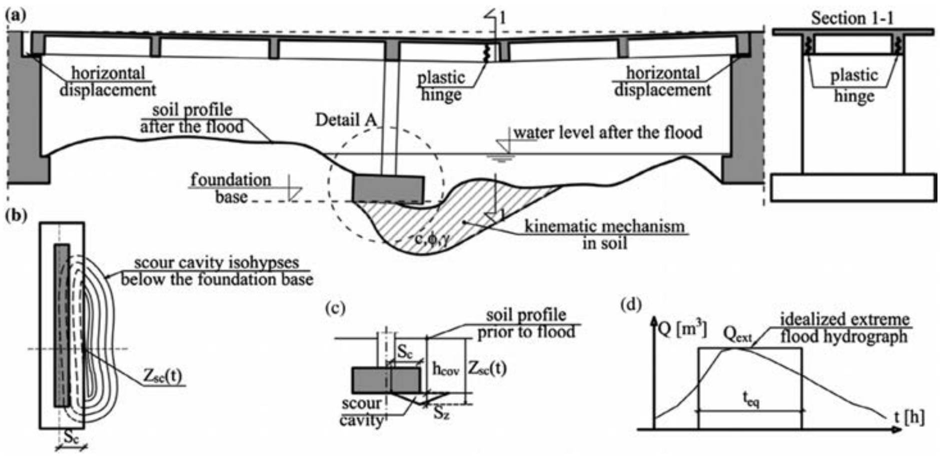

Fig. 1. (a) Bridge failure mode in the longitudinal direction; (b) a local scour cavity at the affected pier foundation; (c) detail a – the cavity approximation; (d) an idealized extreme flood hydrograph [8]

2.1. Settled bridge approach and departure slabs endanger drivers

An approach slab is a transitional system between a bridge and an approach road. The approach slab's primary purpose is to reduce the difference in settling between a bridge abutment and a filled embankment as shown in Figure 2. When driving through a bridge abutment, a vehicle might encounter a bump when the approach slab is not functioning correctly. A "bump at the end of the bridge" caused by an approach slab settlement may

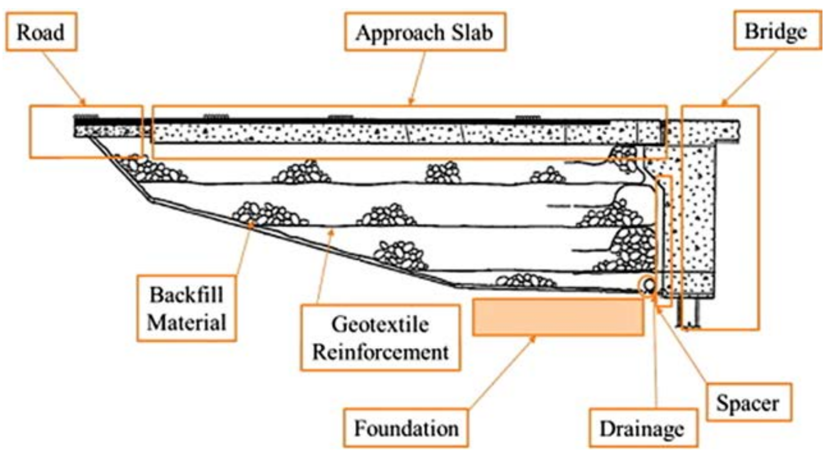

Fig. 2. Approach and Departure Slabs Endanger Drivers [12]

have detrimental consequences on how well roadways perform, influence road structures and bridges, and raise maintenance costs. A few adverse outcomes related to the operation of roads include uncomfortable and risky driving conditions, traffic accidents, car deterioration, and harm to delicately carried items. The dynamic effect of moving vehicles on road structures and bridges results in repeated and increasing impact loads, which shortens the lifespan of the structures [9, 10].

Despite the fact that there has been a lot of study on approach slabs during America, as Yasrobi [11] has found that settlement issues impact the approach slabs performance still exist. Since roughly 20 years ago, the Wyoming Department of Transportation (WYDOT) [12] in the state of Wyoming is employing an approach slab system that consists of a concrete approach slab, geotextile-reinforced backfill, and both. According to a study that was done by Edgar et al., [13] this approach slab system was created. WYDOT engineers and site staff are seeing settlements of the backfill and concrete approach slab at both new bridges that were opened to traffic as well as at older bridges for a number of years.

For drivers, an early settlement at a bridge approach might manifest as a pronounced "bump" upon entering the bridge [14]. A song might skip, or a little coffee gets spilled. Nevertheless, as the settlement progresses, serious safety issues are presented for drivers, who are entirely unprepared for the adrenaline rush accompanying the temporary loss of control upon entering or exiting a seriously settled bridge abutment [15]. Bridges like these present a serious safety issue, and the only ones who do not mind are probably the owners of the local front-end alignment shop [16].

The severity of the elevation difference between the bridge approach and the deck determines the degree of danger for drivers. From a transportation department's point of view, bridge settlement issues can face larger public perception challenges, with citizens pointing to dangerous bridge ramps as an indication of overall department effectiveness. In some cases, faulty bridge approaches and departure ramps have resulted in costly litigation that has seriously compromised already-tight budgets [17].

Therefore, the solution to bridge settlement problems must always seek to reduce the size of the "bump" at approach and departure ramps. It must do this economically, providing enough flexibility to address a wide variety of site-specific variables [18].

2.2. Providing a safe transition between road and bridge

The approach slab transitions between the roadway pavement system and the bridge. In this capacity, the approach slab acts as an intermediate bridge to span the embankment portion directly behind the bridge abutment excavated during the abutment construction. It is understood that this area is traditionally challenging to compact during construction and is, therefore, prone to settlement [19].

The approach slab bridges the gap between the rigid abutment and the undisturbed embankment beyond the area excavated during construction. Even on new construction projects, it is typical for there to be some settlement below the bridge ramp, even with dynamic compaction. In these cases, just like in older bridge installations, the pavement end of the approach slab may settle, creating an uneven transition onto the bridge [20].

2.3. Weak soil issues

Generally, soft soil is not ideal for employing in building engineering because of its high-water content, poor strength, and significant deformation. Soft soil was a specific kind of under-consolidated soil that is often found in coastal locations. Since the fortification intensity was equal to or higher than 7 degrees, it is required by the standards for geotechnical study in soft clay regions to make a distinction between places with distributions of thick soft soil and those without [21].

If adequate planning and site management are not implemented at an early stage of any planned construction, slope and embankment collapses on unstable terrain during construction would undoubtedly become worse given the faster pace of growth [22]. Research was started to look at potential technical and geological reasons that may have led to earthwork issues to aid effective planning.

For designers and builders of projects related to the building of new and modernizing existing sections of road networks, motorways, and bridge structures, providing a suitable land transport infrastructure foundation represents a significant challenge [23]. Extensive testing of the load capacity, robustness, bridge structures and road structures sensitivity are conducted both during the design stage and the performance stage. However, damage and devastation to these buildings frequently happens after building is finished, and sometimes even while it is still going on. This is due to excessive settlements and road embankments' deformations, that in the worst situations take the shape of landslides. The intersection of the bridge structure and the road embankment is the most delicate part of a road sequence.

In addition to that scouring happened in soft soils, it is the product of rushing water's erosive activity, which excavates and carries away debris from stream banks and beds. Different substances scour at various rates. Cohesive or cemented soils are more resistant to scouring, but loose granular soils quickly disintegrate underwater. However, the final scour in cohesive or cemented soils may reach depths comparable to those in sand bed streams. In cohesive bed materials, the scour will get its maximum depth in days, hard, thick, and cemented sandstone or shales, years, and granites in millennia. Throughout the lifespan of a typical bridge, massive rock formations with minimal discontinuities may withstand scour and erosion quite well [24].

Scouring a bridge involves clearing the area surrounding its piers or abutments of any debris. A structure's stability may be compromised by scour produced by quickly flowing water [25]. Scour might be caused by human action, such as dredging or erecting buildings in the channel, natural changes in the channel's flow, or longer-term morphological development [26]. The foundations of bridge abutments or piers may disintegrate due to scour.

3. Soil stabilization

Once paired with truck traffic, soils extremely vulnerable to volume and strength changes may exacerbate roughness, hasten the degradation of the pavement structure via increased cracking, and reduce ride quality. Generally, moisture content and stress conditions significantly impact certain soils' stiffness (measured in terms of the resilient modulus) [27]. The subgrade soil may be treated with various substances to enhance its stiffness and strength properties in certain circumstances. Three factors are often considered while stabilizing soils [28]:

1. As a building platform to assist compaction of the higher layers and dry out excessively damp soils, in this situation, stabilized soil often needs to be considered when designing a pavement's structural layers.
2. In this situation, the changed soil is often given some structural value or credit during the pavement design process to reinforce weak soil and limit the volume-changing potential of highly compressible or plastic soil.
3. To decrease fine-grain soils' sensitivity to water.

3.1. Soil structure

The term "soil structure" describes the general grouping of soil particles into aggregates. A soil's structure might be either simple or complex. Regarding cohesion, flexibility, and consistency – measures of the soil particles' resistance to segregation – sands and gravels, two examples of simple-structured soils, are quite weak. Simple-structured soils are often made of substances like quartz sand that are deterioration-resistant. It is also said that they are single grain in structure. The soil may be categorized as fine-grained soil when a liquid limit is more than 35 and less than 50 with medium compressibility; that soil type falls under inorganic clay (CI) [29].

3.2. Uses of stabilization

The foundation of pavement design assumes that every layer of material in the pavement system would meet a minimum level of specified structural quality. Every layer should be able to withstand shearing, stay clear of severe deflections that might lead to fatigue cracking either inside the layer or in layers above it, and limit the amount of irreversible through-densification. The capacity of a soil layer to distribute the load over a larger area often increases with soil quality, allowing for a decrease in the necessary thickness of the soil and surface layers [30].

The most frequent gains made by stabilization are improved soil gradation, decreased swelling potential and plasticity index, and gains in toughness and durability. Stabilization might also be employed in damp conditions to give building projects a working surface. These methods of soil modification are used to enhance the soil's quality [31].

3.3. Mechanism

The long-term strength increase for soil stabilization with lime depends significantly on the soil characteristics and mineralogical characteristics. The soil particles and Ca from the lime may create a cemented structure by a pozzolanic reaction between alumina and silica, enhancing the strength of the stabilized soil. To keep the pH sufficient to sustain the pozzolanic reaction, residual calcium must continue in the system, where it may mix with the accessible silica or alumina. The soil should be considered for lime remediation if its PI is more than 10 and 25 percent of it passes the #200 sieve [32].

During lime stabilization, the soil's liquid limit often declines while its plastic limit rises. As a result, the soil's plasticity index drops. In general, soil that has been stabilized with lime is more vital. The creation of cement material is partially to blame. The unconfined compressive strength may increase by up to 60 times. Additionally, the soil's modulus of elasticity rises significantly [33].

Calcium ions are highly concentrated in the double layer due to lime addition. Water's propensity to attract is reduced as a result. As a result, there is a significant improvement in the soil's resistance to water absorption, capillary rise, and volume changes caused by drying or wetting. Rainwater cannot penetrate the lime-stabilized subbases or bases because they provide a water-resistant barrier. The maximum density decreases as the ideal moisture content rises. Application of lime to the soil aids in soil drying in marshy places when the water content is over the ideal level. Cycles of freezing and thawing may result in a brief loss of strength, but due to the following healing process, there is no long-term loss of strength. Similar construction techniques are utilized in cement stabilization and lime stabilization. Nevertheless, it is essential to remember the following considerations:

1. There is almost no max time restriction between adding lime to the soil and the end of compaction since the response in the case of lime is modest. Nevertheless, care must be taken to prevent the process of carbonating lime.
2. Instead of dry powder, lime might have been added as a slurry.
3. Before applying lime or combining lime with soil, there should typically be one to four days rest.
4. The requisite max dry density of the soil lime is achieved.

Following compaction, the surface was damp for seven days before being coated with an appropriate coat. Occasionally, the wearing coat is used immediately after the compaction to keep the moisture in place [34].

4. Chemical stabilization

4.1. Stabilization with fly ash

Class C fly ash is an industrial by-product produced by coal-fired power plants comprising minerals, alumina, and silica with a calcium ion. These calcium compounds hydrate when exposed to water, creating cementitious materials that resemble those created throughout the Portland cement hydration process. Consequently, mixing and compacting fly ash as soon as is practicable is preferred [35].

The kind of ash collection system, the coal supplier, and the boiler design all affect the hydration characteristic. The coal's source determines the quantity and kind of organic materials in coal. A minor quantity of calcium is present in eastern coal sources. This fly ash is classified as class F and cannot self-cement. Western coal is categorized as class-C fly ash with a higher calcium content (20–35 percent on average) [36].

Fly ash impacts plasticity less than lime since it contains less calcium oxide than lime and is often coupled with silicate and aluminates. The rate of hydration affects the design and operation of boilers. Inorganic matter is fused during combustion, which causes the fused particles to cool quickly. Therefore, the fly ash particles lack crystal structure.

Compression must be done after blending to produce the most strength and density. Destroying these aggregations is necessary to densify the material because delayed hydration products start to bind with loose particles during compaction. As a result, maximum densities are decreased, and some compaction energy is used to overcome cementation [37].

The significant ignition loss in fly ash is caused by unburned carbon. Silica, alumina, and iron oxide make up 84.6 percent of the material, indicating its applicability as a pozzolanic material. Naturally, fly ash is non-plastic. The moisture level has little to no influence on the dry density. The fly ash has a high internal friction angle.

Fly ash is a substance with a fine grain size distribution, and 86 percent of the specimen passed thru a sieve with a 75-micron opening, showing that it is primarily a silt size material [38].

4.2. Stabilization with lime

Lime is added to the soil to stabilize it. Subgrade soil may be stabilized by doing this. Once lime interacts with soil, cations in the water layer that has been absorbed are exchanged, and the soil's plasticity is reduced. The end product is more friable and more suited for subgrade than the original natural soil. Limestone is converted to lime by burning it in a kiln. The parent material and the manufacturing method affect the quality of the lime. There are five varieties of limes [33]:

1. Calcium-rich, fast lime (CaO).
2. High calcium-hydrated lime [$Ca(OH)_2$].
3. CaO and MgO dolomitic lime.
4. Regular Dolomitic lime [$Ca(OH)_2$+MgO].
5. Dolomitic lime under pressure [$Ca(OH)_2$+MgO_2].

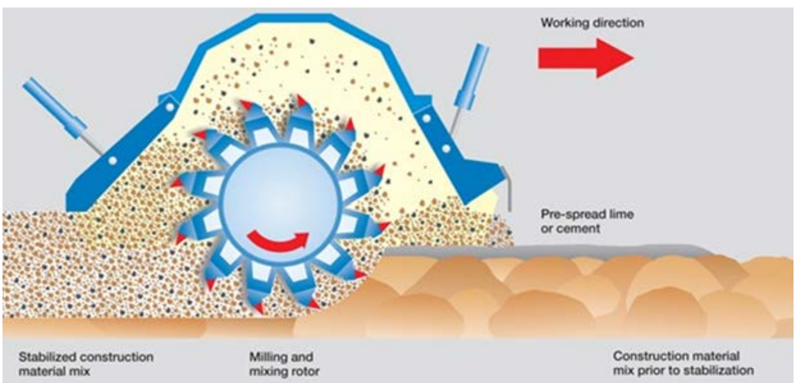

Fig. 3. Soil Stabilization Mechanism [39]

The two main forms of lime used in buildings nowadays are hydrated lime (calcium hydroxide) and quick lime (calcium oxide). When limestone is heated to high temperatures, quick lime is produced, and hydrated lime is created when water is added.

Formula illustrates the relationship between the production of quick lime and carbon dioxide as a by-product of heating limestone.

$$CaCO_3 + \text{heat} = CaO + CO_2$$

Hydrated lime and heating are produced when water is added to quick lime:

$$\text{Heat} + CaO + H_2O = Ca(OH)_2$$

The soil and mineralogical characteristics significantly influence the long-term strength increase for stabilization with lime.

5. Geosynthetic stabilization

A geosynthetic is described as "a planar manufactured product from polymer materials utilized with earth, rock, or, soil, other geotechnical engineering relevant items as an integral part of a man-made project structure or system" by the "American Society for Testing and Materials (ASTM) committee D35 on Geosynthetics" [40]. It describes all manufactured synthetic (often polymer) materials utilized for various geotechnical purposes, including light fill, erosion control, reinforcement, and drainage [40].

Road portions have been strengthened using geogrids. The roadway performance is altered by incorporating geogrids in sub-grades [41]. The main reinforcing processes included strain decrease, construction homogeneity, separation, lateral spreading reduction, confinement, and tensile reinforcement [42]. Over the last forty years, geosynthetics have been increasingly utilized in environmental and geotechnical engineering.

Traditional building materials will be constrained or much more costly in several technical challenges that these items have assisted builders and designers over the years [40]. The following are the primary geosynthetic categories: Geotextiles, Geogrids, Geonets, Geomembranes, Geocomposites, Geosynthetic clay liners, number six (GCLs), Geopiping, Geocells, and Geofoams.

After four years of operation, the fabric was discovered to be in sound condition, which is rather hopeful considering the experimental track's performance. It is regrettable and depressing that engineers, designers, builders, and contractors in a nation like Iraq only utilize this fantastic, developing land exclusively for drain infrastructure. Even though the world's most developed nations have tried and discovered that geotextiles are highly beneficial, long-lasting, desired, and economical, it is still a secondary option. Geotextiles were applied to pavements in various established and emerging areas across the whole pavement or only at the cracks in the concrete slab and minor potholes to save expenses. If the state of the pavement, and weather conditions, including soil and rainfall conditions, call for the first process, which is expensive.

Fig. 4. Geosynthetic Stabilization [43]

5.1. Geotextile functions

5.1.1. Separation

Geotextiles have often been utilized to divide two soil layers with varying particle sizes and preserve the integrity and functionality of each. The geotextile will stop the soils from combining when water enters the soil layer. AOS, tear, tensile strength, permeability, and permittivity are key performance characteristics for geotextile separating (apparent opening size) [44].

5.1.2. Filtration

As water is permitted to percolate through the soil, geotextiles serve as a filter by holding onto soil particles. The permittivity, permeability, and AOS are the three most crucial performance factors for geotextile filtration. In addition, the geotextile fabric has to prevent clogging and allow for proper flow and soil retention [45].

5.1.3. Drainage

Geotextiles may also serve as a drain, collecting and releasing any gases or liquids the structure does not need to operate. Geotextile drainage's three most crucial performance requirements are permeability, transmissivity, and mass [46].

5.1.4. Reinforcement

Geotextiles are a structurally stronger component of the soil matrix by acting as a reinforcing element. The soil that a geotextile is strengthening must be able to absorb the strength of the geotextile. For best efficiency, it must keep up that strength, allowing water to flow through smoothly while removing small particles that would erode the soil. Due to this, mass, tearing, elongation, and grab strength are the most crucial performance parameters for geotextile reinforcement [47].

5.1.5. Protection

Synthetic membranes are protected against puncture, abrasion, and perforation by geotextiles. The three most crucial factors for geotextile protection are puncture resistance, mass, and bursting strength [48].

5.2. Woven vs. nonwoven geotextiles

Polypropylene or polyester fibers are woven together to create woven geotextiles. These geotextile soil stabilization fabric kinds are primarily used to separate and reinforce [49]. Tensile strength, or resistance to breaking under strain, is used to classify woven geotextiles. Woven geotextiles have a plastic-like feel and are impermeable. Therefore, they provide little drainage. Due to their high load capability, woven geotextiles are typically utilized for roadways and parking lots. Woven geotextiles come in a variety of varieties. While monofilaments contain round fibers to provide more consistent opening widths for drainage purposes, silt-film wovens have flat strands for strength. To attain the appropriate performance qualities, high-strength and high-performance wovens may also be knitted or woven [50].

Nonwoven geotextiles, manufactured from polyester or polypropylene fibers, have a more felt-like texture. Two pieces of material are needle-punched and heated instead of woven together. Nonwoven geotextiles have been classified by weight rather than tensile strength and come in heavy-weight (10–16 oz.), medium-weight (6–8 oz.), light-weight (–5 oz.), and ultra-heavy-weight varieties (100 oz.). They are typically utilized for drainage and filtration since they are porous [51].

5.3. Common applications for geotextile soil stabilization fabrics

5.3.1. Embankments

Embankments may be built on soft soil foundations with a geogrid and a high-strength geotextile. At the base, geogrid or geotextile reduces differential settlement while providing stability. Because of this, it is possible to create side slopes that are steeper and taller than embankments [52].

5.3.2. Steepened slopes

Together, geotextiles and geogrids help strengthen slopes that are too steep. To offer tensile resistance and improved stability for the steepened slope, they have been laid out in layers throughout construction. The slope's face may be coated with geotextile and planted to improve aesthetics [53].

5.3.3. Retaining walls

It may also build a retaining or reinforced soil wall using geotextiles and geogrids. Contractors may employ on-site fill and a range of face alternatives, including segmented concrete blocks, treated wood, natural stone, or vegetation facings with geotextile-supported soil retaining walls.

5.4. Improving bridge backfill materials

The interaction between backfill reinforcing and material components significantly influences the performance of MSE walls. The backfill typically complies with appropriate gradation criteria and is free of organic or other harmful elements. To lower the total cost of construction, employing local materials where appropriate to a design may be recommended.

The soil characteristics must be improved when using fine-grained soils for backfill or clay with moderate to high plasticity. This procedure will improve the structure's stability by reducing settling and raising bearing resistance. Depending on structural performance standards, the kind of soil improvement (stabilization) is divided into three categories:

– Unbound materials – no discernible tensile strength was demonstrated, and resistance is mostly given by friction and cohesion between the particles. Shear, densification, and particle disintegration cause deformation.
– Modified materials – an unbound material's strength is increased, its sensitivity to moisture or frost is decreased, and the stiffness is not increased by adding a small quantity of a stabilizing chemical.
– Bound materials – a stabilizing substance is applied to improve the structural performance of unbound material. Consequently, the material has much higher tensile strength, considerable chemical bonding and cohesion, and newly created shear strength. Cracking brought on by shrinkage, fatigue, and excessive stress causes deformations.

The grade, plasticity index, climate, cost, accessibility of the material, the accessibility of construction equipment, the location workforce experience, etc., might influence the stabilizer choice. Atterberg limits and particle size distribution are often considered when determining the appropriate stabilization. Before beginning any fieldwork, all materials must be accurately inspected and extensively examined in a licensed laboratory to determine their consistency and quality.

5.5. Lime-stabilized backfill

Lime treatment may chemically convert unstable soils into usable materials, increasing strength and workability. The dirt may be dried and modified in small quantities to build temporary roadways and work platforms. Larger levels may cause soil to stabilize their structural integrity permanently. In the condition of lime slurry, hydrated lime (calcium hydroxide, $Ca[OH]_2$), or quicklime (calcium oxide, CaO), lime may stabilize the soil. Calcium carbonate (limestone, $CaCO_3$) is chemically converted into calcium oxide to produce quicklime. Quicklime has been chemically reacted with water to create hydrated lime. These chemical reactions take place nearly instantly once lime and water are combined with clay soil:

Drying of the soil: Quicklime begins chemically reacting with water and releasing heat immediately. The soil's water reacts, and the heat produced causes further moisture to escape, causing the soil to dry up. The resulting clay particles in the hydrated lime will then react, decreasing the soil's ability to retain water (additional drying). When the soil dries fast – in just a few hours – the contractor can compress the dirt more quickly than if they had to wait for the soil to dry naturally via evaporation. Only dry as a result of clay reaction occurs when using hydrated lime or slurry.

After the first phase, the clay particles undergo modification as calcium ions (Ca^{++}) from hydrated lime migrate onto them, dislodging water and other ions. In a few hours, a process known as "agglomeration and flocculation" results in the soil's PI drastically decreasing and its propensity to shrink and swell. It becomes simpler to deal with and compress the dirt.

Stabilization: Long-term reinforcement results from pozzolanic reactions that take place in an environment that is highly alkaline (pH >12 for a short period), which causes the clay particles to break down and allows the creation of calcium silicates and aluminates that form the matrix and increase the strength of lime-stabilized soil layers that changes the soil's composition and alters the clay's surface mineralogy, creating a hard, relatively impermeable layer and high load-bearing capacity. Even though the procedure is gradual and may take years, it starts within hours. Warm weather is often necessary for the procedure; the air temperature must rise by around 5 degrees centigrade during the reaction. When lime is used to dry moist soil, colder weather might result. A precise process should be followed while treating or avoiding frozen soil conditions.

Fine-grained clay soils are generally considered acceptable for lime stabilization if at least a 25 percent of them pass through the #200 sieve and have a plasticity index of at least 10. Because the lime stabilization procedure needs soil that includes natural pozzolan, clay components in the soil are necessary for it to react with the lime.

6. Comparision between chemical and mechanical methods

The current study will discuss the chemical and mechanical mechanisms by using cement and waste materials [54, 55] and geo-grid and fly ash [56].

Al-Khafaji et al., [54] assessed the soft soil qualities of several binary combinations made from ordinary Portland cement (OPC) and fluid catalytic cracking catalyst residue (FC3R), a by-product of the petroleum industry. These mixtures were cured with 9 percent binders. The ideal binary combination was investigated using geotechnical tests such as scan electron microscopy (SEM), unconfined compressive strength (UCS), and compaction. The utilization of FC3R as a cement substitute enhanced the soft soil strength after 28 days, according to the results, compared to utilizing OPC alone for soil stabilization. SEM showed the existence of OPC hydration products at various curing ages. Figure 5 shows that applying OPC and FC3R improves soil strength with untreated soil. As well as the SEM image shows the appearance of cement gel (CH and C–S–H) and Ettringite.

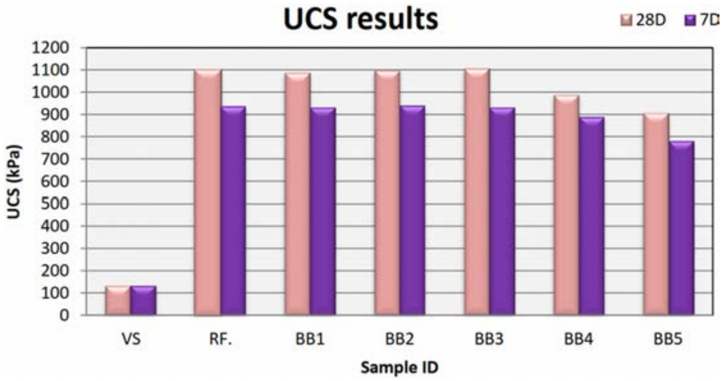

Fig. 5. Un-confined compressive strength test finding for both treated and untreated soft soil

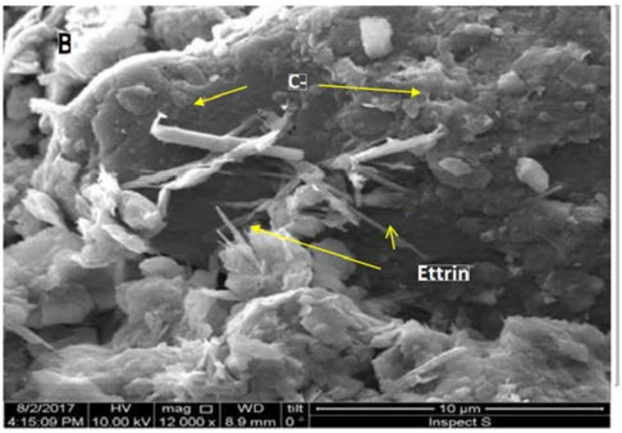

Fig. 6. SEM images for treated soil

A study by Karim et al. [56] looked at the effects of utilizing fly ash, Geo-grid, and fly ash + Geo-grid on the behavior of soft clayey soil when exposed to cyclic stress. Twenty-four models were tested, covering various boundary conditions, including untreated, Geo-grid reinforced, fly ash treated, and fly ash incorporated with Geo-grid models. The tests were conducted by adjusting parameters like footing altitudes, test velocity, and the number of geogrid layers. The investigation shows that modified models with fly ash and two Geogrid layers perform better than other enhancing methods regarding the settlement behavior of footings sitting on them. An increase in settling was also seen, which is consistent with the test velocity's jump from 6 to 9 mm/sec. Additionally, research shows that soil settling diminishes as footing depth increases. Generally, once depth is raised, the soil's bearing capacity rises, all things being equal.

The usual link between settlements and time for soil bed development with geogrid and fly ash layer is shown in Figures 7 to 10. The data show that fly ash in geogrid lowers settlement compared to models without treatment. Even if geogrid or fly ash was used in the models, this is consistent with Tejaswini et al. [57] investigation on the effectiveness of circular footings sitting in reinforced fly ash beds when subjected to repeated loads. The circular footing resting on reinforced fly ash beds performs better than its counterpart lying on unreinforced fly ash beds, according to the findings of studies. Furthermore, it is clear from these data that the total settling of a footing increases during the load and achieves

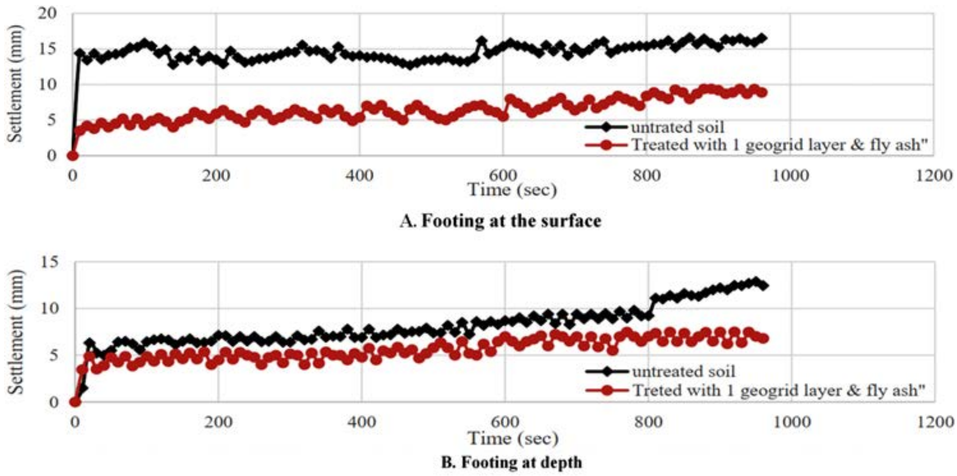

Fig. 7. Settlement against time for treated and untreated with fly ash one and geogrid layer models with velocity

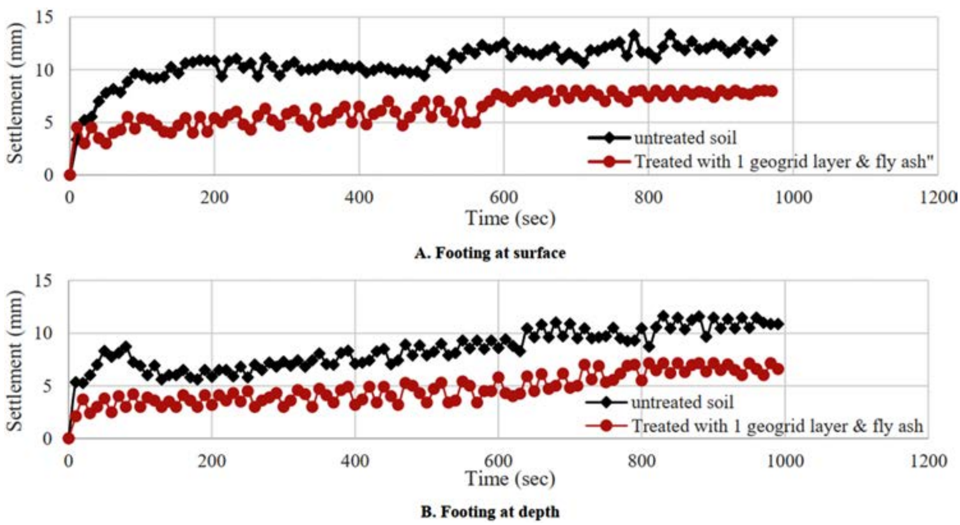

Fig. 8. Settlement against time for treated and untreated with fly ash and one geogrid layer models with velocity = 6 mm/sec and various depth

a maximum value in most figures after the test. The settlement measured after the test improved by more than 40% for models treated with one geogrid layer and fly ash, with footings placed at the surface (Df = 0) and at the depth Df = 100 mm with test velocity = 9 mm/sec.

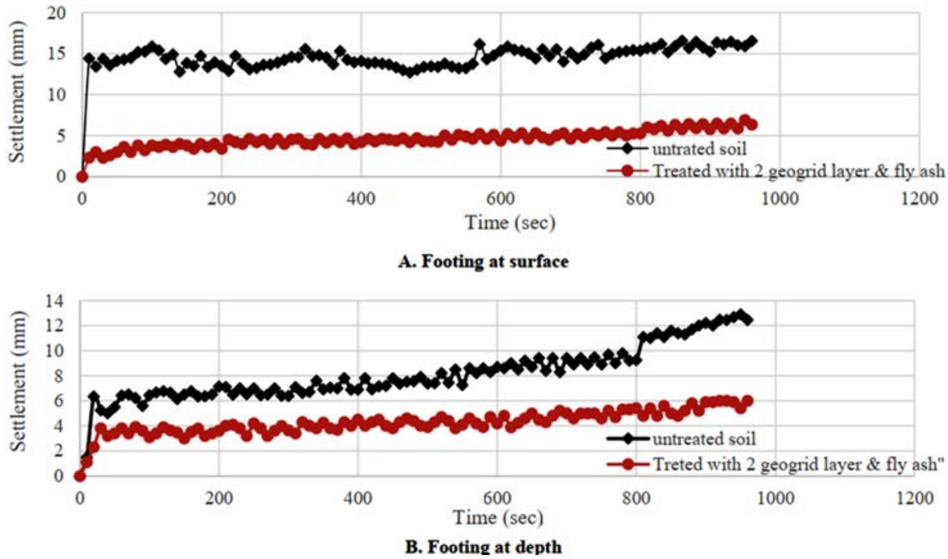

Fig. 9. Settlement against time for treated and untreated with fly ash and two geogrid layers models with velocity = 9 mm/sec and various depth

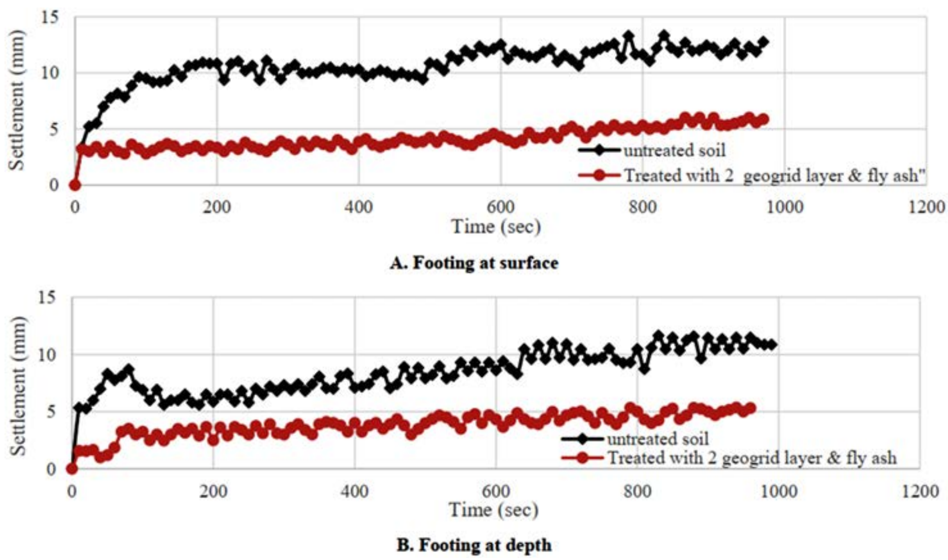

Fig. 10. Settlement against time for treated and untreated with fly ash and two geogrid layers models with velocity = 6 mm/sec and various depth

Additionally, compared to untreated models, models treated with two geogrid layers and fly ash showed a statistically significant decrease in settlement value after the test. That is equivalent to 6.89 mm and 5.87 mm for footing at Df = 0 with a 9 and 6 mm/sec velocity. With the addition of geogrid reinforcement, performance improves, consistent with the findings of [58, 59].

7. Conclusions

The current review paper aim to present an overview about bridge failures due to soft soil, and the using of two ways of stabilizing soil by chemical and mechanical methods, the following finding has been obtained based on the selected article of comparison:

- The unconfined compressive strength of soil is increased by adding FC3R; after 28 days of curing, UCS findings showed a considerable increase in soil strength from 134.2 kPa for the untreated specimen to 1107 kPa for the specimen treated with (70% OPC + 30% FC3R).
- According to UCS findings, soil specimens treated with 9% binder had compressive strengths more incredible than those of the control samples.
- The same cementitious products detected in the specimen containing OPC alone as a binder were also present, including 30% FC3R of the total binder, according to SEM pictures.
- Based on Karim et al. [56] adding fly ash is reduced settling by around 40 to 50 percent for footing at the surface and at different depths.
- The settlement is marginally reduced when clay is reinforced with a single layer of geogrid. While the settlement is significantly reduced with two geogrid layers, whether the footing is placed at depth or at the surface.
- Compared to models treated with either geogrid alone or fly ash only, the inclusion of fly ash with geogrid (1 or 2 layers) decreases the settlement to roughly 50% for both velocities.

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