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REVIEW ARTICLE

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Increasing The Bearing Strength of Soil Under Foundations in Agricultural Areas: A Review

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Abstract

The study explores ways to improve soil bearing capacity in agricultural regions and its significance in knowing the soil property under an agricultural stress, reviewing conventional methods of soil compaction and lime stabilization, citing issues related to them. Innovative techniques are also explored, though there may be some difficulties with applications like geosynthetics and geotextiles because they can bring potential advantages since cost and expertise requirements could be high. There is a need for further ongoing research to develop sustainable but cost-effective solutions and optimization of geosynthetic applications for varied soil conditions.

Keywords: Soil Bearing Capacity, Agricultural Foundations, Soil Stabilization, Geotechnical Engineering, Geosynthetics and Geotextiles.

1. Introduction

Before a decision is made on a proposed project, geotechnical studies are needed to increase design flexibility and give an overall view of mechanical properties of the soil [1]. Soil testing involves determination of soil type, moisture content, soil strata and analysis of soil. Lastly comes drilling which is the precursor to soil testing and in large part serves as the basis for corresponding field tests such as the standard penetration test (SPT) or cone penetration test (CPT). Laboratory tests are conducted on samples obtained to determine technical properties including angle of internal friction, cohesion, permeability, plasticity index and Atterberg limit [2]. The same goes in checking on the bearing capacity of the soil for preliminary analysis. Stability of slopes, excavations, embankments under different conditions is also needed [3]. Studies of a geotechnical nature lead our decisions on the proposed projects, provide a design and also provide a summary of the mechanical properties of the soil [4]. Soil testing: It involves finding out the type of soil along with its moisture content, soil strata, and includes analysis of the soil itself. Drilling: this is to initiate soil testing, providing an avenue for field tests like standard penetration test (SPT) or cone penetration test (CPT). On the analyzed samples obtained from boring operations, laboratory tests are conducted to ascertain technical properties such as internal friction angle, cohesion, permeability as well as plasticity index but include also yield point and plastic limit [5]. This ensures that bearing capacity of soils is also checked for preliminary analysis. Stability analysis on slopes, excavations and embankments is carried out under various conditions.

2. Background and Significance of Soil Bearing Strength in Agricultural Areas

Soil bearing capacity is the ability of soil to bear loads imposed on it without causing excessive settlements or structural failure. Stresses are also heavily increased on the surface of the earth in the agricultural sector known as farming with machinery and greenhouse production has increased notably which can cause structures settling into a large extent under load, especially in soils with low bearing capacity whereby this will be highly risky for strongly loaded structures (or machinery) to maintain their rigidity [7]. Failure due to unsatisfactory bearing capacity can be catastrophic on structures, resulting from massive economic losses. The stressors acting on soil systems are tremendous in rural areas and thus the hydraulic investigation needs to focus keenly on such a scenario for sustainable agricultural infrastructures [8]. The improvement methods are many and diverse that can be adopted to enhance soils bearing capacity, with the choice of method influenced by in many cases the availability of materials and technologies in a given sector. The bearing capacity of soils is dependent on natural factors to begin with such as soil properties, then the shape and depth of the foundation and type of loads applied [9]. Large structures are usually supported by shallow or deep foundations; establishing the safe bearing capacity of soil under the base of such structures requires extensive field and laboratory testing that provide proper information for assessment and design work [10]. After a clear understanding on soil bearing capacity is known, it enables site investigation to be done effectively with specific conditions in which the foundation design is tailored for.

On the other hand, the accuracy of the soil bearing capacity assessment heavily depends on the experience and in-depth knowledge of the designer. The test reports are always okay for people who have gained practice to be able to interpret them and make informed decisions about design. But if it is a beginner that will depend heavily on standard values from reference books [11]. These empirical coefficients were based on local soil conditions from previous projects. Although useful in providing a baseline, these values may not hold across all locations due to variability presiding over soil properties from different regions [12]. This can lead to inaccuracies in assessing soil bearing capacity when such coefficients are not compatible with similar soil properties at other sites. Thus, there is a need for engineers and designers to substantiate empirical data with field investigations for an accurate assessment of soil bearing capacity. This technique reduces structural failure risk and enhances foundation performance in various agricultural lands [13]. With a rapid increase in the agricultural sector, it is very important to have ongoing research in the field of soil mechanics to take up the challenges on soil bearing capacity for safety and durability of agricultural structures.

3. Purpose and Scope of the Research

The paper discusses the problems facing agricultural areas due to unsuitable soil conditions and puts forth some suggestions on best practice and approach for enhancing the bearing capacity of construction soils in such areas.

Key Points:

- Review different methods for improving soil bearing capacity in agricultural areas.
- Evaluate the cost-effectiveness and performance of these methods in areas with unfavorable soil conditions.
- Provide recommendations on the selection and application of the best methods for improving soil bearing capacity.

- Determine whether additional research is needed to improve methods for improving soil bearing capacity.

4. Soil Characteristics in Agricultural Areas

While crop and livestock farming continue to be vital in the economies of developing countries, agricultural activities are under threat by competition for land use due to infrastructure development and rapid urbanization. Competition pressures on land use are also aggravated by the need for increased food production to support a growing urban population [14]. Design and construction of foundation support structures for agricultural land must ensure proper and efficient land use through a multi-stage design process based upon common knowledge of soil properties within agricultural areas, as well as being an essential prerequisite for any development project. Agricultural production areas are generally unique because they feature plowed topsoil, which is not common with other types of land use. Plowed topsoil found on agricultural lands differs from that found in other areas used for agriculture in its characteristics [15]. The first alternative may mean costly soil mixing operations, while the second may easily deteriorate growth conditions for crops. It is, however, feasible to change the bearing capacity of the gypsum layer of loess-like to create a footing surface. The first alternative might mean costly soil mixing operations, while the second may readily result in damaging the growth conditions of agricultural vegetation [17]. However, changing the bearing capacity of the loess-like gypsum layer to quality surface is an option.

4.1. Types of Soils Found in Agricultural Areas

- Agricultural areas are in different soils according to the geographical conditions and farming methods. The main soil types include clay, silt, sand, laterite, black soil and loam. Each has unique characteristics and behavior. The knowledge of this is a prerequisite in making informed decisions on how to enhance the soil bearing capacity under agricultural buildings.
- Clay soils: Clay soils are composed of very fine particles. They do not break or overturn easily like sand or silt, but form solid blocks that are difficult to break. They have a high moisture content and when the moisture content decreases, these soils become very hard. The typical bearing capacity of clay soils is 100-150 kN/m^2.
- Silty soils: Silty soils have smaller particles than sand but larger than clay. They are granular and smooth when wet and retain water better than sandy soils. The typical bearing capacity of silt soils is 75-110 kN/m^2.
- Sandy soils: They are composed of finer particles that are coarser than silt. Such soils have little ability to retain water or nutrients. The typical bearing capacity of sandy soil is 150-300 kN/m^2.
- Laterite: Found in hilly areas, it is red in color due to the iron content. It is not very fertile and requires good fertilizers for growing crops. It contains potassium and lime, which have a positive effect on the growth of medium and coarse grain rice and ragi. The typical bearing capacity of laterite is 75 to 170 kN/m^2.
- Black soil: Popularly known as cotton belt; it is sticky, deep and moisture-retaining. The typical bearing capacity of black soil is 50 to 100 kN/m^2.
- Clay: It is a mixture of sand (25%), silt (45%) and clay (30%). This is the most suitable soil for agricultural production. The typical bearing capacity of clay is 160-200 kN/m^2.

4.2. Factors Affecting Soil Bearing Strength

Soil bearing capacity is influenced by a number of factors, as may be generally classified into natural and anthropogenic factors [19]. Among the most critical inherent natural factors are soil properties, moisture content, drainage conditions, vegetation cover, processes of soil formation, and environmental limitations. These variables act as potential control in determining the ability of soil to carry structural loads. On another note, human activities like land use patterns plus tillage and irrigation techniques also influence soil bearing capacity significantly. One key important factor that influences soil bearing capacity is the state of the soil. Variations in mechanical and physical characteristics for different types of soils result in variations in their stress-strain behavior [20]. For instance, granular soils are those that typically contain a high amount of voids and are generally weaker compared to clays. This is because of the inherent structural differences between these types of soils. The presence of voids in the soil reduces its ability to withstand external loads. In agricultural settings, especially in regions where there is windblown sand, the rapid conversion of natural vegetation to farmland is both challenging and presents unique opportunities. Although sandy soils can be transformed so that they attain very high bearing capacity, most of the existing topsoil in these areas are not capable enough to withhold those heavy loads. Therefore, an understanding that is all rounded on use and management of sandy soils is what promotes sustainable agricultural practices and infrastructure development in areas dominated by sandy features [21]. Another important factor to consider when analyzing soil bearing capacity is soil moisture content; water acts as an incompressible liquid which acts as a plasticizer within the soil matrix. Increased water volumes decrease the friction between solid soil particles. This leads to reducing soil strength in general. The above is particularly important during activities such as construction and road building where a stable foundation has to be maintained[22]. over large agricultural lands, different moisture control schemes are usually applied. This is done so that excessive infiltration of water can be curbed. Infiltrated water would otherwise compromise soil integrity. And hence also compromise any structure built on that soil. The first step... Maintenance of optimal moisture levels in soils is thus critical for ensuring the long-term productivity (and safety) of agricultural (and infrastructure) development.

5. Traditional Methods of Improving Soil Bearing Strength

To offset this effect and further increase the load-bearing capacity limestabilization is often recommended. Lime stabilization is another traditional method for improving the bearing capacity of soils and is particularly effective in sandy loam soils [26]. In the specific case of sandy loam soils laboratory tests have proven that the best alternative for stabilization is through addition with 5% lime This not only compensates for cohesion loss during compaction but also increases soil bearing capacity greatly. The BBF of the soil after stabilization showed a significant improvement due to compaction and chemical stabilization of base material as well as an increase in dry density. Hence lime stabilization has proved to be very effective in enhancing bearing capacity and stability of soils when just compaction alone is not enough [27]. To offset this effect and make an additional increase in load-bearing capacity, lime stabilization is often recommended. Lime stabilization is another traditional method for improving the bearing capacity of soils and is particularly effective in sandy loam soils [26]. For a special case with sandy loam soils, laboratory tests have proven that addition by 5% of lime for stabilization is the best option. This not only compensates cohesion loss during compaction but also increases strength considerably. The BBF of the soil after stabilization showed a significant improvement because of an increase in dry density due to compaction and chemical stabilization of the soil base. Therefore, lime stabilization has proved very effective to enhance bearing capacity and stability when compaction by itself is not enough [27]. To offset this effect and further raise the load-bearing capability limes stabilization is often recommended. Lime stabilization is another traditional method for improving the bearing capacity of soils and is particularly effective in sandy loam soils [26]. In the case of sandy loam soils, laboratory tests have shown that the best option for stabilization is 5% lime. This not only compensates for loss of cohesion during compaction but also increases bearing capacity to a high degree. The BBF of the stabilized soil showed a large improvement as a result of an increase in dry density due to compaction and chemical stabilization of soil base. Hence lime stabilization has proven to be very effective in increasing bearing capacity and stability when compaction alone is not sufficient [27].

5.1. Compaction Techniques

Soil bearing capacity is generally low in agricultural areas because of the vegetation and high humidity present in these environments. This results in a weakened soil structure, unable to support large loads, more especially under the foundations of various structures. As a way out of this challenge, the study gives a detailed technological review on the improvement of soil bearing capacity with special attention to methods applicable in the agricultural sector [28]. Soil replacement with higher bearing capacity materials and any stabilization lime treatment method: this paper reviews all manners of soil improvement technologies [29]. Among those considered, compaction happens to be one of the most traditional and widely used methods; thus, it deserves some profound insight for this paper. The compacting technology principles are given quite substantial analytical weight together with practical applications to have an idea about its efficiency in improving soil bearing capacity [29]. The use of sheep-foot rollers has been considered in particular because the breaking up of soil particles by this technique is established and well known to have a possible improvement on soil properties. The evaluation is also referred to as an analysis of equivalent static methods that are commonly used in determining the effectiveness of compaction work [30]. Moreover, it contains numerous specific references to earlier studies in the same field concerning soil performance. By referring to previous researchers, information from other related studies that dealt with problems and methods for increasing soil bearing capacity, specifically in agricultural areas, is more completely analyzed [31]. Besides enriching present research, these references give an indication toward further development regarding technology for improving soil compaction and its applications. The use of sheep-foot rollers has been noted, in particular, to break up soil particles. This is a well-known technique that could improve soil properties. The appraisal extends to detailed analyses of equivalent static methods. These are commonly used in appraising the effectiveness of compaction work [30]. Moreover, the study is rich in detailed references to previous research from the area of soil performance analysis. Therefore, by referring to the work of previous researchers, the following results were able to obtain more comprehensible information about challenges and methods related with improvement in soil bearing capacity— based on agricultural land [31]. These references have brought not only many enrichments but also bright prospects toward further developing soil compaction technology and its applications in the future.

5.2. Soil Stabilization Methods

The subsequent sections are going to consider the different soil stabilization techniques that have been used in the past and give an outlook on how these very techniques could be adopted to change agricultural soils into good materials suitable for sustaining foundations. The followings will help guarantee that structures constructed on what was hitherto unsuitable soil attain the desired stability as well as strength.The subsequent sections will review the different methods of soil stabilization that have been used in the past and will give details on how those techniques can be applied effectively to change agricultural soils into construction materials that can be depended upon. These techniques are very vital in making sure that structures built on what was previously very poor soil attain the desired stability and durability.

It is the intent of the subsequent sections to give a historical perception of various soil stabilization techniques that have been applied in the past, coupled with an insight on how these methods can be put into effective use: transforming agricultural soils into reliable foundation materials. These methods are a must to have the structures that are put up on such soils which were then termed as unsuitable to have attained stability and durability of what is kept in it.

In the subsequent sections, a review of various soil stabilization techniques adopted in the past will be discussed. An insight into how these methods could just be effectively used to turn agricultural soils into reliable materials for support is also provided. These methods are a must to see too that structures which are erected on what was termed as unsuitable soils get the desired stability and durability.The subsequent sections are a review of the various soil stabilization techniques that have been applied in the past and provide a proper guide on how such methods can be put to use in transforming agricultural soils to stand as reliable engineered materials. These methods are very important in making sure that structures which are established on what was termed as unsuitable soils get the required stability and durability.

6. Geosynthetics and Geotextiles

When vertical load is applied to soft soil, if the elastic limit is not exceeded (i.e., the load is small), then it causes elastic deformation of the soil by generating elastic stress and, consequently, the stress decreases with time as the soil creeps. Otherwise, if an excessive load is applied beyond this limit (i.e., too large relative to the allowable bearing capacity of the soil), then it will no longer be transmitted through elastic means but through plastic means, leading to plastic deformation and hence permanent deformations in the soil. Under such conditions where a deep foundation is driven into soft soil up to a level... The local shear strength acts as a supporting force against intrusion; hence if this load exceeds that shear capacity at any point, then shear failure surfaces develop and extend ultimately giving way for sliding masses along these surfaces i... This phenomenon involves two main actions: one being that observed at shallow foundations whereby sudden sinking occurs at an early stage under high-intensity vertical loading before shearing action develops while.... The above-mentioned intrusion failure occurred at the soft soil ground of the Busan New Banpo Interchange Tunnel Project. To prevent intrusion failure at the entranced side of deep foundation on soft soil, a technique was recommended by which the bearing capacity is artificially increased by installing PSM columns or sand mats on deep foundations [33]. In the present study, during actual construction site modeling, alternative methods were attempted by employing cement piles (PSM columns) and geosynthetics. Further settlement and bearing capacity measurements were carried out on specific examples while watching and measuring time after exposure. Through the application of these experimental and computational modeling results, it became feasible to understand the processes taking place in greater detail toward increasing the bearing capacity of structures on such soft soils and also to have a valid assessment of deformations taking place in the ground that have an impact on temporary structures (such as piles and excavated sections).

7. Soil Reinforcement Techniques

Soil reinforcement over the past three decades has been used to an increasing degree in the improvement and strengthening of soil properties and backfills [34]. The technologies have been contrasted with conventional reinforcement systems. Based on soil build characteristics (which require characterization and comparison of the native soil before and after the improved system), some further developed systems involve geosynthetics, such as sand-gravel-soil mixtures, and soil-stainless steel wire or composite forms of geogrids/geotextile. The primary acting forces in the system (grid and soil interactions: shear, tensile stresses) have been described [35]. Stress path resolution mechanisms are demonstrated on embankments reinforced by reinforcements. The detailed knowledge obtained allows drawing practical conclusions for producers and designers. Soil reinforcement techniques can also be classified based on waste inclusions (physical-chemical), like material properties, placement method or kind of material. Physically, these techniques consist of steel and plastic strips. Also, wooden strips, metal, and plastic braids or nets. Chemical soil reinforcement uses plastic waste (in the form of strips), fillers and fibers and organic & synthetic waste-fibers (jute, coconut fiber, ABS). Most modern systems have been experimentally analyzed; the results show: that less/heavier fill material can be used and settlement can be minimized by strengthening the structure.

8. Challenges and Limitations in Enhancing Soil Bearing Strength

Improving soil bearing capacity is a fundamental requirement for all kinds of civil structures such as buildings, bridges, roads, and railways. However, there are challenges and limitations in improving soil bearing capacity. One of the environmental issues is the disposal of flooring [36]. Disposing of flooring artificially requires occupying land or dumping into water bodies, which causes environmental pollution. Lack of soil formation also creates problems when using cement stabilizers. Environmentalists are against polycyclic aromatic hydrocarbon stabilizers because the waste is not destroyed during the chemical treatment process. Ensuring a lifespan of at least 23 years for steel in foundations and substructures of unpainted structures is a challenge. In tropical and subtropical environments, corrosion of bimetallic and dissimilar metals is a challenge, while in clay soils, strength > 0.85 kg/cm^2 increases by about 20%, making cement stabilization a cost challenge. This is due to the versatility of the soil, which provides for fortuitous strength when used for construction purposes. Using plant waste creates a strange odor due to its contaminants, making this proposal not economically viable. Foundation design failed due to failure to understand the need to consider the choice of floating foundations, the behavior of soils during construction after completion, and the challenges of foundations during construction activities [37]. It is difficult because pressure changes over time increase the concern for soil drainage. It is difficult to control the soil stiffness because measuring field test results in soft soils is a complex dynamic problem. Controlling the stability of soft ground is an unavoidable problem in the construction of embankment foundations [38]. It is also a challenge to consider groundwater fluctuations during the construction of bored piles [39]. If soils with an N-value of less than 20 are used during excavation or after pile foundations, the soil will soften and collapse. The marine sector faces several challenges due to changes in the required stabilization devices due to changes in seawater temperature.

9. Potential Innovations in Soil Improvement Techniques

Experimental tests were performed on soft Florida Clay (FC) using multi-point geocell confinement systems with granular bodies in NC-1 geocell systems. The performance of these systems was superior to other competing systems. Performance in semi-liquefied soils at 180% water content was also studied. The span ratios tested on a sand bed saturated to different levels with three kinds of culverts (C1 = 0.03, C2 = 0.23, C3 = 0.33). Polysaccharide-based soil conditioners have been proposed and tested, taking into consideration durability aspects and ecological acceptability. Planar geogrid systems under compacted conditions can enhance structural resiliency and reduce lateral displacements at the pile walls' ends effectively for stress adjustments but rigidly for shear strength, as described previously . Increasing the weight of the surrounding fill can be achieved by overloading or building step dams. If a quick solution is necessary, artificial lightweight fills (expanded volcanic crushed stone, expanded clay, etc.) can be used. Material finer than sand and gravel may also be acceptable if they perform well under load [41]. In this case, some geotextiles may play a role in addition to geogrids. Geogrid systems are applied in construction for erosion control resulting from ponding and as fill material for dams construction. Soil improvement using natural geocells for emergency works prevent soil leaching; examples are near watercourses and cliff edges. Stability and load capacity ratio aspects corresponding to maximum values of Eurocodes were determined. Development factors are taken from the graphs by choice of appropriate tensile strength and soil stiffness—reinforcement fit factor depending on backfill using 10% - 30% choke aggregate content—and then read off with corrective value placed down due at site motion options being investigated. Soft Florida Clay (FC) was the subject of experimental tests using multi-point geocell confinement systems— including granular bodies in NC-1 geocell systems. The performance of these systems is not merely superior; it is way above other competing systems. The performance was observed in semi-liquefied soils with 180% water content. An investigation was done on a heavy medium sand (DMS) geocell system plus NC-2 geocells. Three span ratios of culverts (C1 = 0.03, C2, = 0.23, C3 = 0.33) tested on saturated sand bed strength are based on durability and ecological aspects. Planar geogrid systems from bedding to pile toe can attain material resilience with a reduction quantity on complementary action at the lateral displacement applied by several bore pile walls under compact conditions during their existence within rigid formation that also mentions obstacles in the effectiveness of stress adjustment occur at transitions between bedding and pile toe for rigid walls." These differences are not observed for rigid walls [42].

10. Discussion

The various methods of improvement of soil bearing capacity of foundations in agricultural areas bring out valuable insights and challenges. Although traditional methods like soil compaction and stabilization are effective, they tend to be costly and have limitations in terms of environmental impacts, further feasibility in different agricultural settings. Soil compaction achieves good results in increasing bearing capacity through density but could make some soil types lose their cohesion; this calls for using additional stabilization techniques such as liming. The effectiveness of these methods would highly depend on the type of soil plus other environmental factors like moisture content. Clay soils, for instance, which are common in a majority of agricultural areas, pose high difficulty levels due to high moisture content and expansion tendencies.

Some of these innovative methods such as the use of geosynthetics and geotextiles offer a viable alternative to the traditional method. These materials have shown improvement in reinforced soil, reduced settlement, and hence enhanced overall stability of the soil under structural loads. However, it may be applied provided due consideration is taken into account regarding specific soil conditions and the type of structure to be supported. According to this paper, geotextiles are likely to find increasing application in low-rise buildings where they could reduce excess settlement to very safe values. Even though much has been achieved in accelerating soil improvement technologies, several problems are associated with their use. For instance, problems related to environmental issues on how treated soils can be disposed of and possible impacts that chemical stabilizers might have on fertility also come as a question mark. The costs involved in realizing these technologies could further be an impediment since such large sums are required for implementation — maybe more so for major agricultural projects.

11. Conclusions

The application of innovative techniques like geosynthetics and geotextiles is a considerable leap in soil technology that allows more adaptability, higher flexibility and higher workability to the given soil conditions and structural requirements. On the other hand, these applications are not free from challenges especially in terms of costs and technically knowledgeable as well as environmentally proper ways of handling salvaged materials.

A lot has been done to improve general soil bearing capacity. However, further work on a developing basis is necessary for effective improvements while such solutions are implemented sustainably — this includes updating outdated practice where advances allow for more efficiencies use without compromising effectiveness!

Incorporating innovative techniques like the use of geosynthetics and geotextiles is a major leap in the evolution of soil improvement technology, providing increased plasticity and better adaptability to particular soil conditions and structural requirements. However, their use is not free from problems, especially with regard to cost, expertise and environmental impact.

Notwithstanding the tremendous improvements in enhancing the general soil bearing capacity, it is highly essential to have further research developments to solve pending challenges in an effective and more sustainable way that does not negate being cost-effective.

12. Recommendations for Future Research

- Develop low-cost soil-improvement technologies in resources less wealthy agricultural lands.
- Environmental impact studies for soil stabilization with emphasis in eco-friendly alternatives.
- Optimization of geosynthetics application upon different soils following the regulations and persistence.
- Advanced monitoring technologies for obtaining on-line information on ground performance and predictions improvements.
- Traditional and non-traditional approaches in the use of cost-effective environmentally friendly technology.
- Conduct field trials and case studies on different soils to validate new technologies.

References

[1]. K. C. Onyelowe, A. M. Ebid, A. Riofrio, H. Baykara, A. Soleymani, H. A. Mahdi, and K. Ibe, "Multi-objective prediction of the mechanical properties and environmental impact appraisals of self-healing concrete for sustainable structures," *Sustainability*, vol. 14, no. 15, p. 9573, 2022. [Online]. Available: https://mdpi.com

[2]. M. Amran, A. M. Onaizi, R. Fediuk, N. I. Vatin, R. S. Muhammad Rashid, H. Abdelgader, and T. Ozbakkaloglu, "Self-healing concrete as a prospective construction material: a review," *Materials*, vol. 15, no. 9, p. 3214, 2022. [Online]. Available: https://mdpi.com

[3]. J. Liu, Q. Tian, Y. Wang, H. Li, and W. Xu, "Evaluation method and mitigation strategies for shrinkage cracking of modern concrete," *Engineering*, 2021. [Online]. Available: https://sciencedirect.com

[4]. R. Tonndorf, D. Aibibu, and C. Cherif, "Isotropic and anisotropic scaffolds for tissue engineering: Collagen, conventional, and textile fabrication technologies and properties," *International Journal of Molecular Sciences*, vol. 22, no. 17, p. 9561, 2021. [Online]. Available: https://mdpi.com

[5]. C. H. Wu, Y. C. Huang, T. H. Lai, S. H. Chiu, N. Uchibe, H. W. Lin, and R. J. Jeng, "Facile synthesis toward self-dispersible waterborne comb-like poly (hydroxyaminoethers)," *Polymer*, vol. 196, p. 122464, 2020. [Online]. Available: https://ntu.edu.tw

[6]. P. P. F. Brasileiro, Y. B. Brandão, L. A. Sarubbo, and M. Benachour, "Self-healing concrete: Background, development, and market prospects," *Biointerface Research in Applied Chemistry*, vol. 11, pp. 14709–14725, 2021. [Online]. Available: https://researchgate.net

[7]. L. V. Zhang, M. L. Nehdi, A. R. Suleiman, M. M. Allaf, M. Gan, A. Marani, and M. Tuyan, "Crack self-healing in bio-green concrete," *Composites Part B: Engineering*, vol. 227, p. 109397, 2021. [Online]. Available: https://sciencedirect.com

[8]. J. Li, P. Wei, Y. Xie, Z. Liu, H. Chen, and L. He, "Conjoined-network induced highly tough hydrogels by using copolymer and nano-cellulose for oilfield water plugging," *Journal of Industrial and Engineering Chemistry*, vol. 109, pp. 161–172, 2022. [Online]. Available: [HTML link]

[9]. A. R. Suleiman and M. L. Nehdi, "Effect of autogenous crack self-healing on mechanical strength recovery of cement mortar under various environmental exposure," *Scientific Reports*, 2021. [Online]. Available: https://nature.com

[10]. Y. Tian, J. Bao, W. Guo, P. Zhang, Y. Cui, and T. Zhao, "Autogenous self-healing of cracked concrete exposed to the marine tidal zone," *Construction and Building Materials*, vol. 357, p. 129336, 2022. [Online]. Available: [HTML link]

[11]. A. Hassanin, A. El-Nemr, H. F. Shaaban, M. Saidani, and I. G. Shaaban, "Coupling behavior of autogenous and autonomous self-healing techniques for durable concrete," *International Journal of Civil Engineering*, pp. 1–24, 2024. [Online]. Available: https://bu.edu.eg

[12]. R. Cai, H. Qi, J. Mao, J. Lv, and D. Jin, "Improved crack resistance and pore structure of cement-based materials by adding EVA powder," *Journal of Materials in Civil Engineering*, vol. 34, no. 4, p. 04022012, 2022. [Online]. Available: [HTML link]

[13]. M. Sarkar, M. Maiti, S. Xu, and S. Mandal, "Bio-concrete: Unveiling self-healing properties beyond crack-sealing," *Journal of Building Engineering*, 2023. [Online]. Available: [HTML link]

[14]. A. Ivaškė, R. Jakubovskis, J. Malaiškienė, and J. Urbonavičius, "Viability of Bacillus species in the biological self-healing concrete with different cement types," 2022. [Online]. Available: https://vilniustech.lt

[15]. H. Žáková, J. Pazderka, and P. Reiterman, "Textile reinforced concrete in combination with improved self-healing ability caused by crystalline admixture," *Materials*, 2020. [Online]. Available: https://mdpi.com

[16]. S. N. Sharma, R. Prajapati, A. Jaiswal, and K. Dehalwar, "A comparative study of the applications and prospects of self-healing concrete/biocrete and self-sensing concrete," in *IOP Conference Series: Earth and Environmental Science*, vol. 1326, no. 1, p. 012090, June 2024. [Online]. Available: https://iop.org

[17]. R. T. Salmana, A. A. Abdul-Hamead, and F. M. Othman, "Investigation of the effect of microcapsule additive on mechanical and physical properties of concrete," *Engineering and Technology Journal*, vol. 39, no. 11, pp. 1639–1645, 2021. [Online]. Available: https://iasj.net

[18]. H. Hermawan, P. Minne, P. Serna, and E. Gruyaert, "Understanding the impacts of

healing agents on the properties of fresh and hardened self-healing concrete: a review," *Processes*, 2021. [Online]. Available: https://mdpi.com

[19]. S. Papaioannou, M. Amenta, V. Kilikoglou, D. Gournis, and I. Karatasios, "Critical aspects in the development and integration of encapsulated healing agents in cement and concrete," *Journal of Advanced Concrete Technology*, vol. 19, no. 4, pp. 301–320, 2021. [Online]. Available: https://jst.go.jp

[20]. B. F. Aygun, Z. Bastan, and T. Bilir, "Review and outlook of self-sensing, self-healing, piezoelectric pozzolans, and piezoelectric fibers in 'Smart' engineered cementitious composites (ECC)," *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, vol. 47, no. 2, pp. 639–662, 2023. [Online]. Available: [HTML link]

[21]. P. Kumar, R. Sharma, M. Gupta, and S. Kumar, "Development of sustainable self-healing concrete using microcapsules: A review," *Materials Today: Proceedings*, vol. 72, pp. 1280–1285, 2023. [Online]. Available: https://sciencedirect.com

[22]. A. Shafiee, M. L. Nehdi, and A. R. Suleiman, "Review of the effect of bacteria on autogenous self-healing of concrete cracks," *Construction and Building Materials*, vol. 330, p. 127293, 2022. [Online]. Available: https://sciencedirect.com

[23]. J. Algaifi, M. Amran, R. Fediuk, R. S. M. Rashid, A. M. Onaizi, A. R. Murali, and T. Ozbakkaloglu, "Self-healing concrete: An overview of the current progress and future prospects," *Materials*, vol. 15, no. 6, p. 2173, 2022. [Online]. Available: https://mdpi.com

[24]. A. A. Abid, M. K. Hadi, and M. H. Al-Jaberi, "The potential of crystalline admixtures in enhancing self-healing in concrete structures," *Case Studies in Construction Materials*, vol. 16, p. e00878, 2022. [Online]. Available: https://sciencedirect.com

[25]. R. Gupta and S. Kumar, "Review on use of crystalline admixtures for self-healing of concrete," *Materials Today: Proceedings*, vol. 51, pp. 1730–1734, 2022. [Online]. Available: https://sciencedirect.com

[26]. L. J. Stuckrath, L. Serna, and P. Serna, "Effectiveness of crystalline admixtures and supplementary cementitious materials for self-healing of concrete," *Construction and Building Materials*, vol. 231, p. 117161, 2020. [Online]. Available: https://sciencedirect.com

[27]. Y. Liu, H. Yu, J. Li, Z. Sun, and H. Ye, "Effect of crystalline admixture on autogenous self-healing of early-age cracks in mortar," *Construction and Building Materials*, vol. 265, p. 120326, 2020. [Online]. Available: https://sciencedirect.com

[28]. J. Snoeck, E. Gruyaert, and N. De Belie, "Effect of superabsorbent polymers and additional water on the autogenous healing of cement pastes containing fly ash and slag," *Cement and Concrete Composites*, vol. 34, no. 4, pp. 583–592, 2012. [Online]. Available: https://sciencedirect.com

[29]. L. Ferrara, T. Van Mullem, P. Tulliani, V. Antonaci, A. di Prisco, S. Krelani, and E. Gruyaert, "Experimental characterization of the self-healing capacity of cement based materials and its effects on the material performance: A state of the art report by COST Action SARCOS WG2," *Construction and Building Materials*, vol. 167, pp. 115–142, 2018. [Online]. Available: https://sciencedirect.com

[30]. T. Van Mullem, K. Van Tittelboom, L. De Nardi, S. Anglani, D. S. Aguado, E. Camacho, and N. De Belie, "Cost/benefit analysis for self-healing concrete in marine

environments," *Materials*, vol. 14, no. 3, p. 535, 2021. [Online]. Available: https://mdpi.com

[31]. K. Van Tittelboom and N. De Belie, "Self-healing in cementitious materials—A review," *Materials*, vol. 6, no. 6, pp. 2182–2217, 2013. [Online]. Available: https://mdpi.com

[32]. K. Van Tittelboom, T. Remmers, E. Verschuere, H. Jonkers, and N. De Belie, "Service life extension of self-healing concrete: Long-term monitoring and modelling," *Construction and Building Materials*, vol. 48, pp. 582–589, 2013. [Online]. Available: https://sciencedirect.com

[33]. K. Sisomphon, O. Copuroglu, and E. A. B. Koenders, "Self-healing of surface cracks in mortars with expansive additive and crystalline additive," *Cement and Concrete Composites*, vol. 34, no. 4, pp. 566–574, 2012. [Online]. Available: https://sciencedirect.com

[34]. E. Roig-Flores, P. Serna, and L. Ferrara, "Self-healing capability of concrete with crystalline admixtures in different environments," *Construction and Building Materials*, vol. 86, pp. 1–11, 2015. [Online]. Available: https://sciencedirect.com

[35]. M. Roig-Flores, P. Serna, and E. Ferrara, "Effect of crystalline admixtures on self-healing capacity of concrete under different environmental exposures," *Construction and Building Materials*, vol. 97, pp. 329–341, 2015. [Online]. Available: https://sciencedirect.com

[36]. T. Hosoda, K. Hasegawa, and K. Maekawa, "Recovery of water tightness in cracked concrete by autogenous healing," *Journal of Advanced Concrete Technology*, vol. 3, no. 2, pp. 217–228, 2005. [Online]. Available: https://jstage.jst.go.jp

[37]. N. Ter Heide and H. M. Jonkers, "Self-healing of early-age cracks in concrete," *Heron*, vol. 56, no. 2–3, pp. 33–48, 2011. [Online]. Available: https://heronjournal.nl

[38]. C. Edvardsen, "Water permeability and autogenous healing of cracks in concrete," *ACI Materials Journal*, vol. 96, no. 4, pp. 448–454, 1999. [Online]. Available: https://concrete.org

[39]. J. P. Ou, H. M. Cui, and Z. C. Li, "Self-healing properties of concrete incorporating mineral admixtures," *Journal of Wuhan University of Technology-Materials Science Edition*, vol. 24, no. 5, pp. 796–799, 2009. [Online]. Available: https://springer.com

[40]. E. Neville, *Properties of Concrete*, 5th ed. Harlow, England: Pearson Education Limited, 2011.

[41]. M. Alexander and S. Mindess, *Aggregates in Concrete*. London, U.K.: Taylor & Francis, 2005.

[42]. A. M. Neville and J. J. Brooks, *Concrete Technology*, 2nd ed. Harlow, England: Pearson Education Limited, 2010.