

Study on Geosynthetic *Encased* Stone Column

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Abstract--In India, 60 -70 % of soil falls under the soft soil category. Due to characteristic of soft soil, it becomes risky to construct foundation in it as a result construction in soft soil is avoided. However these characteristics of soil can be improved using effective ground improvement techniques. This research investigates solutions to challenges posed by soft soil conditions in construction projects. It examines the limitations of conventional ground improvement methods and introduces stone columns as a promising solution. It evaluates the effectiveness of geosynthetic encased stone columns in addressing the issues. subsequently, it explores the advantages of geosynthetic encasement in stone columns, highlighting its ability to mitigate deformation patterns and enhance soil stability. Case studies are analyzed to demonstrate the superior performance of geosynthetic encased stone column over conventional techniques. The findings emphasize the potential of Geosynthetic stone column to significantly improve construction outcomes in soft soil regions.

Keywords-- Stone Columns, Ground Improvement, Geosynthetic Encasement

I. INTRODUCTION

In civil engineering, a strong foundation is essential for the safety and stability of any structure, but constructing on natural soft soil is highly risky due to its low bearing capacity, high compressibility, and poor shear strength. Such soils, which cover nearly 65-70% of India's land, are prone to excessive settlement and uneven subsidence that can lead to structural failure, loss of life, and economic damage. Although pile foundations provide a reliable solution, their high cost makes them unsuitable for low-rise buildings and small infrastructure projects where some settlement is acceptable. This creates a strong need for cost-effective ground improvement techniques that can make soft soil suitable for construction. Methods like surcharge loading, prefabricated vertical drains, dynamic compaction, chemical stabilization, and stone columns are commonly adopted to improve soil strength, reduce settlement, and accelerate consolidation. Among these, stone columns have become popular because they are economical, easy to install, and effective in reinforcing soft ground by replacing weak soil with compacted stone, thereby increasing load capacity and improving drainage.

The present study is important to utilize India's large areas of soft soil for urban development, to develop sustainable and low-cost techniques, to minimize risks to life and property, and to reduce environmental impact by reusing waste materials like demolished concrete and tyres. The main objectives are to identify problems in conventional stone column methods, study the effect of vertical and horizontal encasement, and compare the performance of geosynthetic encased stone columns in improving soft soil behavior for safer construction. Stone columns, recognized for their effectiveness in mitigating settlement and enhancing soil stability on soft ground, are not immune to challenges and limitations. Despite their widespread application as a ground improvement technique, practitioners encounter various issues that can impact the design, installation, and performance of stone columns in geotechnical projects. A stone column is similar to a pile, but with some other features, i.e., it would bulge if the lateral confinement from the surrounding soil is not enough. Many of these types of deformation above may happen at the same site or even for the same column, but the predominant deformation is always bulging (Kelly, 2014). The geometry of stone columns such as length, diameter, spacing, and footing size may have some influence on their deformation (McKelvey et al., 2004). A common classification of stone column is based on their length, so if a stone column reaches the bearing stratum, it can be classified as "end bearing" or "fully penetrated"; otherwise it would be referred to as "floating" or "partially penetrated".

II. LITERATURE SURVEY

2.1 Stone Column

Adalier & Elgamal (2004): Adalier and Elgamal conducted a detailed study on the mitigation of liquefaction and ground deformation using stone columns. Their research focused on evaluating how stone columns improve the stiffness and drainage of liquefiable soils under earthquake loading. Through field case histories and numerical modeling, they demonstrated that stone columns effectively reduce excess pore pressure buildup and lateral spreading during seismic events, making them a reliable ground improvement technique for earthquake-prone areas.

Azhani Zukri & Ramli Nazir (2018): Azhani Zukri and Ramli Nazir (2018) analyzed the performance of stone columns reinforced with geosynthetic encasement. Their study, presented in an IOP Conference paper, involved laboratory-scale models to evaluate the load-bearing behavior of soft soils improved using encased stone columns. The results indicated a significant enhancement in vertical load capacity and reduced lateral bulging, confirming that geosynthetic encasement improves column confinement and settlement control.

Murugesan & Rajagopal (2007): Murugesan and Rajagopal conducted experimental model tests on geosynthetic-encased stone columns installed in soft clay. Their findings revealed that the use of geosynthetic encasement notably improved the load-carrying capacity and reduced bulging deformation of columns compared to conventional unreinforced ones. This pioneering study laid the foundation for later research on the use of encasement materials in stone column applications for soft ground improvement.

Shahu, Madhav & Hayashi (2000): This research focused on the numerical analysis of soft ground reinforced with stone columns and a granular pile–granular mat system. Using computational models, they examined stress distribution, settlement, and load transfer behavior. Their study showed that stone columns, when combined with a proper granular mat, effectively reduce differential settlement and enhance the bearing performance of weak subsoil layers, offering practical insights for foundation design.

K. Ali, J.T. Shahu & K.G. Sharma (2010): Ali, Shahu, and Sharma investigated the behavior of reinforced stone columns in soft soils through field and numerical studies. Their analysis emphasized the influence of encasement stiffness and column spacing on load-settlement performance. The study concluded that geosynthetic reinforcement substantially increases the lateral confinement of columns, reduces bulging, and improves the overall stability of embankments constructed over weak ground.

2.2 Research Gap

- Prior to this study, limited research existed on the dynamic behavior of stone column–improved ground during earthquakes, especially in terms of excess pore pressure reduction and lateral spreading control under real seismic loading.
- Previous works had not experimentally validated how different encasement materials and configurations affect the performance of stone columns in soft soils. This study addressed that lack of laboratory-based performance data.

- Before this study, there was little experimental evidence quantifying the improvement in load capacity and reduction in bulging achieved through geosynthetic encasement. Their work established a foundational understanding for future research.

2.3 Problem Statement:

- Liquefaction and ground deformation during earthquakes pose serious risks to structures built on loose, saturated soils. There is a need to investigate how stone columns can mitigate these effects by improving soil stiffness and drainage properties under seismic loading conditions.
- Conventional stone columns in soft soils often experience excessive lateral bulging and limited load-bearing capacity. The study aimed to determine whether geosynthetic encasement could enhance the performance of stone columns by improving confinement and reducing settlement.
- Soft clay foundations present challenges for conventional stone columns due to inadequate lateral confinement. This study sought to experimentally evaluate whether geosynthetic encasement could increase the load-carrying capacity and minimize deformation in such conditions.

2.4 Objectives

- To investigate the effectiveness of stone columns in reducing liquefaction potential and ground deformation in loose, saturated soils under earthquake loading conditions, with particular emphasis on improving soil stiffness and drainage characteristics.
- The study further aims to examine the limitations of conventional stone columns, especially their susceptibility to lateral bulging and reduced load-bearing capacity in soft clay foundations due to inadequate confinement.
- Additionally, the objective is to experimentally evaluate the performance of geosynthetic-encased stone columns in overcoming these limitations by providing enhanced lateral confinement, increasing load-carrying capacity, and minimizing settlement and deformation.
- The study also seeks to compare the behavior of conventional and encased stone columns to determine the extent of improvement achieved through geosynthetic encasement under static and seismic conditions.

III. MATERIALS AND METHODOLOGY

3.1 Materials

Types of geosynthetics

- Geotextile
- Geonets
- Geomembrane

- Geocells
- Geogrids

3.1.1 Geotextile: A geotextile is defined as any permeable textile material that is used with foundation, soil, rock, earth, etc. to increase stability and decrease wind and water erosion. A geotextile may be made of synthetic or natural fibres. In contrast, a geo-membrane is a continuous membrane-type liner or barrier.



Fig. No.3.1 Geotextile

3.1.2 Geonets: Geonets are 3D geosynthetic materials made from extruded, high-density polyethylene (HDPE) or polypropylene (PP) ribs, forming a diamond-shaped, honeycombed, or parallel structure for high-flow drainage,

filtration, and soil stabilization. They are flexible, lightweight, and often paired with geotextiles (geocomposites) to prevent clogging in landfill, road, and environmental projects.

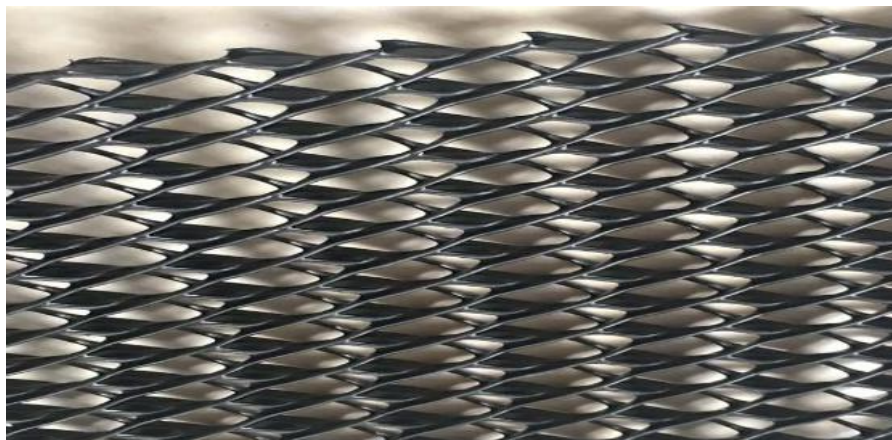


Fig. No. 3.2 Geonets

3.1.3 Geomembrane: A geomembrane is a very low-permeability synthetic membrane liner used in geotechnical engineering to control fluid and gas migration in human-made projects.

Primarily made from polymers like HDPE, PVC, and EPDM, these durable, flexible sheets prevent leakage in landfills, mining, agriculture, and water containment. They are crucial for environmental protection, offering UV resistance and long-term durability.



Fig No. 3.3 Geomembrane

3.1.4 Geocells: Geocells are three-dimensional, honeycomb-like cellular confinement systems made from high-density polyethylene (HDPE) strips, designed to enhance soil stability and load-bearing capacity.

When filled with gravel, soil, or aggregate, they create a stiff mattress that prevents lateral movement and erosion, making them ideal for slope protection, road base reinforcement, and retaining walls.



Fig. No. 3.4 Geocell

3.1.5 Geogrids: Geogrids are geosynthetic materials, typically made from high-strength polymers like high-density polyethylene (HDPE), polypropylene (PP), or polyester (PET), used to reinforce soil and aggregate in construction.

They are designed with open mesh structures (apertures) that lock with soil to improve stability, distribute loads, and increase soil strength in retaining walls, pavements, and slope applications.



Fig. No. 3.5 Geogrid

3.2 Methodology

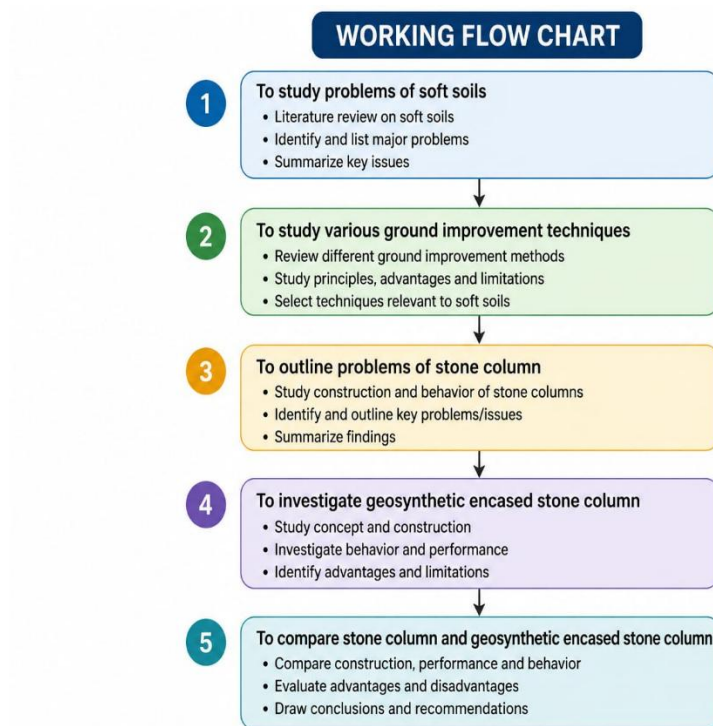


Fig. No. 3.6 Working Flow Chart

3.2.1 Soil Properties:

The properties of the surrounding soil, such as its stiffness, compressibility, play a significant role in determining the deformation pattern of stone columns. Soft or highly compressible soils may undergo significant settlement and lateral

3.2.2 Column Spacing and Layout:

The spacing between adjacent stone columns and their arrangement within the soil mass can influence the deformation pattern. Closer column spacing and uniform distribution of columns may lead to more uniform settle behavior compared to wider spacing or irregular layouts.

3.2.3 Column Diameter and Length:

The diameter and length of the stone columns load-bearing capacity and interaction with the surrounding soil. Larger diameter columns and longer columns typically provide greater reinforcement and resistance to deformation, resulting in a different deformation pattern compared to smaller or shorter columns.

3.2.4 Column Material and Strength:

The type and strength of the material used in the construction of stone columns, such as crushed stone or aggregate, can impact their resist deformation. Higher strength materials may exhibit less deformation under applied loads, leading to a different deformation pattern compared to lower strength materials.

3.2.5 Bulging Deformation

Bulging is the most common and dominant mode of deformation in stone columns installed in soft cohesive soils. It generally occurs in the upper one-third of the column, where the lateral confinement provided by the surrounding soil is insufficient to resist outward expansion of the column material.

3.2.6 Shear Failure (Diagonal or Progressive Shear)

Shear failure occurs when the shear strength of the surrounding soil or the composite ground system is exceeded by the applied load. This type of failure is characterized by the formation of an inclined shear plane extending from the edge of the loaded area down through the column and surrounding soil.

3.2.7 Column Shortening (Compression or Settlement Deformation)

Column shortening refers to the vertical compression of the stone column due to the weight of the overlying structure or embankment.

It occurs when the stone particles rearrange and densify under load, leading to vertical settlement of the column and surrounding soil.

3.2.8 Punching Failure

Punching failure occurs when a rigid footing or embankment load pushes the stone column downward into a very soft underlying stratum. This deformation is common when the column is not properly seated on a firm bearing layer or when the base soil is extremely weak.

IV. DISCUSSIONS BASED ON LITERATURE SURVEY

4.1 Problem with Ordinary Stone Columns

- Cost-effective and simple but fail due to bulging and punching in very soft clay.
- Lack of lateral confinement from weak surrounding soil limits load capacity.

4.2 Role of Geosynthetic Encasement

- Acts as a confining membrane around the stone column.
- Prevents outward displacement of aggregates and restricts bulging.
- Improves load transfer from soil to column and increases stress concentration ratio.

4.3 Performance Improvements

- Higher vertical and lateral load capacity than conventional stone columns.
- Increased stiffness and shear strength of the composite soil-column system.
- Reduced total and differential settlement.
- Better performance under both static and dynamic loads.

4.4 Materials and Durability

- Geosynthetics like geotextiles/geogrids made of polyester or polypropylene.
- High resistance to chemical, biological, and environmental degradation → long-term stability.
- Allows use of recycled materials like waste concrete and tyre chips, making it sustainable.

4.5 Design Considerations

- Full-length vertical encasement gives maximum improvement.
- Partial/horizontal wrapping is useful when cost or depth is a constraint.
- Performance depends on geosynthetic type and tensile strength.
- FEM and DEM tools help optimize spacing, diameter, depth, and encasement stiffness.

4.6 Advantages over Traditional Methods

- More economical and faster than deep foundations, chemical stabilization, or preloading.
- Overcomes bulging, punching, shearing, and bending failures of ordinary stone columns.
- Environmentally sustainable due to waste reuse and lower resource use.

4.7 Applications

- Suitable for embankments, roadways, railways, and foundations.
- Especially valuable in coastal, reclaimed, and soft soil areas common in India.

4.8 Overall Outcome

- GESCs provide safer, more reliable, cost-effective, and sustainable ground improvement.
- Enhances safety, serviceability, and durability of structures on weak soils.
- Supports sustainable and resilient civil engineering development.

V. CONCLUSIONS BASED ON LITRATURE SURVEY

Soft soils pose major challenges in construction due to their low bearing capacity, high compressibility, and poor shear strength, leading to excessive settlement and instability. Considering that a large portion of land in India consists of soft soil, the need for effective and economical ground improvement techniques is essential for safe infrastructure development.

This study shows that while conventional methods like stone columns are cost-effective and widely used, they suffer from limitations such as lateral bulging and reduced performance in very soft soils due to insufficient confinement. The introduction of geosynthetic encasement significantly enhances the performance of stone columns by providing additional lateral support, thereby increasing load-carrying capacity and reducing deformation.

The findings highlight that geosynthetic-encased stone columns offer improved strength, stiffness, and settlement control compared to ordinary stone columns. Vertical encasement provides maximum confinement, while horizontal encasement aids in better stress distribution. The combined use of both can further optimize performance depending on site conditions.

Additionally, the use of geosynthetics along with recycled materials contributes to sustainable construction practices by reducing environmental impact and promoting resource efficiency.

Overall, geosynthetic-encased stone columns prove to be a reliable, economical, and sustainable solution for ground improvement in soft soils. Proper design and selection of materials are crucial to achieve optimal performance, ensuring safety, durability, and long-term stability of structures.

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