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COMPREHENSIVE REVIEW PAPER: SOIL IMPROVEMENT TECHNIQUES FOR CLAYEY SOIL IN EAST PORT SAID, EGYPT

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Abstract – East Port Said, a strategic Egyptian city on the northern Suez Canal, is underlain by extensive deposits of soft, highly plastic clayey soils that make infrastructure improvement geotechnically challenging. These problematic soils have low shear strength (5–20 kPa), high compressibility (compression index Cc > 0.3), and low permeability ($k < 10^{-8}$ m/s), leading to large settlements, inadequate bearing capacity, and long consolidation times. Such adverse conditions may cause differential settlement, embankment instability, and pavement failure. The geotechnical properties of East Port Said's clay deposits have been investigated through Atterberg limits, consolidation tests, and unconfined compressive strength (UCS) assessments in previous studies. These studies evaluate soil improvement methods based on site-specific characteristics, emphasizing engineering performance, cost-effectiveness, and environmental sustainability. Recommended techniques include preloading with prefabricated vertical drains (PVDs) to accelerate consolidation, chemical stabilization using lime and cement to enhance strength and reduce plasticity, geosynthetic reinforcement for load distribution and settlement control, and deep soil mixing for foundation support. The comparative analysis integrates laboratory results, numerical models, and case studies from similar geo-environments in Egypt and globally. Key evaluation criteria include improvements in shear strength (ΔSu), reductions in compressibility (ΔCc), implementation time, and lifecycle cost. Environmental impacts, especially the carbon footprint of cement-based methods, are also considered. Research finds that PVD preloading is most economical for large-scale reclamation, while lime stabilization provides rapid strength gains for transport infrastructure. The study offers tailored recommendations for East Port Said projects, aiding engineers and planners in addressing industrial growth, climate, and sustainability targets.

Keywords: Clayey soils; soil improvement; East Port Said, geotechnical engineering; ground improvement; soil stabilization; prefabricated vertical drains; lime stabilization; geosynthetics

I. Introduction

significant areas, serving as a growing industrial and logistics hub. It plays a pivotal role in Egypt's economic improvement plans, specially within the framework of the Suez Canal Economic Zone (SCZone), which aims to transform the area into a global trade gateway. Due to its proximity to global maritime routes, East Port Said has attracted numerous mega-initiatives, which includes box terminals, industrial complexes, and helping infrastructure.

1.1 Previous Research

Despite its strategic location, the region faces important geotechnical challenges due to the presence of thick layers of tender, highly compressible clayey soils. These soils are characterized by low shear strength (usually 5–20 kPa), high plasticity indices, and coffee permeability ($k < 10^{-8}$ m/s), resulting in immoderate settlement, restrained bearing potential, and lengthy consolidation intervals. Such conditions drastically avoid the construction of stable foundations for roads, ports, and heavy structures, posing risks inclusive of differential settlement, embankment instability, and untimely pavement failure [1,2].

These ground situations necessitate the implementation of suitable soil improvement strategies to satisfy the engineering requirements of large-scale infrastructure. Ground improvement is not only essential for technical balance however it also influences the economic feasibility, environmental sustainability, and lifespan of civil structures [3,4]. Hence, understanding the geotechnical behavior of East Port Said's subsoil is critical for safe and cost-effective design, aligning with national development goals and sustainable urban expansion.

The chemical stabilization of soft clay through the application of lime, cement, or industrial by-products is a common process that enhances its strength and stiffness. Research conducted proved the efficacy of these materials in diminishing compressibility and enhancing shear strength. Lime and cement modify the soil's physicochemical qualities, leading to pozzolanic reactions that enhance load-bearing capacity [5,6,7].

Geosynthetics, comprising geotextiles and geogrids, offer a mechanical method for improving soft clay. They function by distributing loads and constraining lateral deformation [8]. Stone columns and vertical drains offered effective reinforcement and drainage solutions [9,10].

A recent study has concentrated on environmentally sustainable materials, including shattered eggshells and oyster shells. were found to be effective in enhancing CBR values and reducing plasticity, providing a sustainable alternative to traditional binders. These solutions align with global environmental goals and are particularly suitable for regions seeking green infrastructure [11].

Polymer additives are increasingly used due to their ease of application and rapid effectiveness. In New Sohag City, polymeric compounds such as "Dust Shield" demonstrated favorable outcomes in enhancing compaction and reducing the plasticity index of expansive clays. These materials are especially beneficial in arid and semi-arid regions [12].

Numerous studies offered firsthand insights from East Port Said, evaluating the efficacy of various approaches in actual site settings. PVDs and preloading have demonstrated superior cost-effectiveness for extensive reclamation projects, although deep mixing is better appropriate for areas subjected to heavy loads [15,16,17].

2. **Geotechnical Properties of Clayey Soils in East Port Said**

2.1 **Soil Classification**

USCS Classification: CH (highly plastic clay) or MH (silty clay with high compressibility).

Atterberg Limits**:**

Liquid Limit (LL) = 60–90%

Plasticity Index (PI) = 30–50%

Water Content: 40–70% (near saturation).

2.2 Strength and Compressibility

Undrained Shear Strength (Su): 5–20 kPa (very soft to soft).

Compression Index (Cc): 0.3–0.6 (highly compressible).

Permeability (k): 10^{-8}–10^{-9} m/s (extremely low drainage).

2.3 Challenges for Construction

Long-term settlements under structural loads.

Low stability for embankments and slopes.

Difficulty in excavation due to stickiness

3 Soil Improvement Techniques

To better understand the appropriate use cases, benefits, and limitations of each soil improvement technique, a comparative summary is presented in Table 1. This table highlights the best applications, relative costs, time requirements, and environmental impacts of key methods discussed in this paper, such as PVDs, lime stabilization, geosynthetics, and deep mixing. The following sections describe the working mechanisms, advantages, and constraints of each method in detail, along with practical case studies.

3.1 Preloading with Vertical Drains (PVDs) Mechanism

Prefabricated Vertical Drains (PVDs or "wick drains") are installed in a grid pattern to accelerate consolidation by shortening drainage paths.

A surcharge load (e.g., soil or water fill) is applied to induce settlement before construction.

Advantages

Cost-effective for large areas (e.g., ports, runways).

Reduces post-construction settlement by 50–80%.

Limitations

Requires months to years for full consolidation.

Needs careful monitoring of pore pressure dissipation.

Case Study: Port of Bangkok, Thailand

Soft clay with properties like East Port Said.

PVDs reduced consolidation time from 10 years to 2 years.

3.2 Lime and Cement Stabilization

Mechanism

- Lime (CaO) or Cement (OPC) is mixed with clay to induce pozzolanic reactions, reducing plasticity and increasing strength.

Advantages

- Rapid strength gain (UCS > 500 kPa possible).

- Reduces swelling potential in expansive clays.

Limitations

- High cost for large-scale projects.
- Environmental impact (cement production emits CO_2).

Case Study: Road Construction in the Nile Delta

- Lime stabilization improved CBR values from 2% to 15%, enabling pavement construction.

3.3 Geosynthetics Reinforcement

Mechanism

- Geotextiles, geogrids, or geocells are used to:
  - Distribute loads.
  - Reduce differential settlement.
  - Enhance slope stability.

Advantages

- Fast installation (no curing time).
- Lightweight and versatile.

Limitations

- Not standalone for very soft soils (requires combined methods).

Case Study: Suez Canal Bank Stabilization

- Geogrids reduced lateral spreading in embankments by 30%.

3.4 Deep Soil Mixing (DSM) and Jet Grouting

Mechanism

- DSM: Mechanical mixing of soil with cement slurry to form stabilized columns.
- Jet Grouting: High-pressure injection of grout to create soil-cement panels.

Advantages

- High load capacity (up to 1000 kPa UCS).
- Minimal vibration, suitable for urban areas.

Limitations

- Expensive compared to surcharge methods.

Case Study: Bridge Foundations in Alexandria

- DSM columns increased bearing capacity from 50 kPa to 300 kPa.

Table 1: Comparison of Soil Improvement Techniques

Techniqes	Best for	Cost	Time	Environmental Impact
PVDs + Surcharge	Large reclamation projects	Medium	Long	Low
Lime Stabilization	Roads, shallow foundations	Medium	Short	Medium
Geosynthetics	Embankments, slopes	Low-Med	Short	Low
Deep Mixing	Deep foundations	High	Medium	Medium

4 Recommendations for East Port Said

4.1 Infrastructure Type-Based Selection

Ports & Runways: PVDs with preloading.

Roads & Highways: Lime stabilization + geotextiles.

Buildings & Bridges: Deep soil mixing.

4.2 Sustainability Considerations

Use lime instead of cement where possible to reduce CO_2 emissions**.**

Combine geosynthetics with PVDs for faster, eco-friendly solutions.

4.3 Future Research Needs

Pilot tests on bio-stabilization (e.g., enzyme-based binders).

Long-term monitoring of improved soil behavior.

Conclusion

The geotechnical challenges posed by the soft clayey soils of East Port Said require comprehensive, site-specific soil improvement strategies tailored to the unique demands of each infrastructure type. These soils, characterized by low shear strength, high compressibility, and limited permeability, cannot support heavy construction activities without prior enhancement. Through a detailed analysis of various soil stabilization techniques—including prefabricated vertical drains (PVDs), lime and cement stabilization, geosynthetics, and deep soil mixing—this study has identified the most suitable methods for different construction scenarios. For large-scale reclamation projects such as ports and runways, PVDs combined with surcharge loading provide a cost-effective and sustainable solution by accelerating consolidation and reducing long-term settlements. For transportation infrastructure like highways and roads, lime stabilization, especially when integrated with geosynthetics, offers rapid strength gains and improved load distribution. In zones requiring high load-bearing capacity such as bridges and multi-story buildings, deep soil mixing and jet grouting techniques are more effective despite their higher costs. Beyond technical performance, sustainability considerations are vital. The environmental impact of cement-based materials must be mitigated by favoring alternatives like lime or by incorporating recycled materials and natural binders. Combining mechanical and chemical techniques often results in enhanced efficiency and environmental compatibility. Future research should prioritize field-scale testing of bio-based stabilizers, long-term performance monitoring, and the integration of real-time data into predictive geotechnical models. Ultimately, a holistic, evidence-based approach is necessary to ensure the resilience, cost-efficiency, and environmental sustainability of infrastructure projects in East Port Said and similar geotechnical contexts.

Declarations

▪ Availability of data and materials

The authors have not used any data in our study.

▪ Competing interests

The authors declare that they have no competing interests.

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▪ Authors' contributions

All authors contributed extensively to the work presented in this paper. XX led the entire process of this study. All authors read and approved of the final manuscript.

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