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(Research Article)

The silent influence: Plastic and non-plastic fines alter sand liquefaction resistance

Anjali Saji *

Department of Civil Engineering, Vidya Academy of Science and Technology, Technical Kampus.

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Abstract

This study investigates the effect of plastic and non-plastic fines on the liquefaction potential of sand. Laboratory triaxial tests were conducted to understand how varying fines content influences the mechanical response, pore pressure generation, and overall stability under undrained conditions. The results indicate that the presence of fines significantly alters the soil's dilatancy behaviour, pore pressure development, and post-liquefaction characteristics.

Keywords: Liquefaction potential; Mechanical Response; Undrained; Dilatancy

1. Introduction

In developing countries like India, the land is utilized for various engineering structures such as roadways, highways, airways, sky scrapers etc. In contrast with the past, the primary issue in constructing a structure is the availability of adequate soil conditions. Liquefaction phenomenon is the one of the most complex topic in geotechnical engineering. Many modern man-made structures collapsed during the earthquake without any damage to the structure. The matter was highlighted the importance of focusing on the problem of liquefaction and influencing parameters more than ever. During liquefaction, the soil mass are subjected to high pressures due to dynamic loading and acts as a fluid subjected to major deformations. Soil failure is caused by a sudden increase in pore water pressure. Saturated loose sands, which is subjected earthquake shaking, creates additional pore water pressure due to its limited density and dissipation restraint from the surrounding soils which gradually reduces its confining pressure. Eventually the confining pressure reaches zero and the loose soil the strength, liquefy and expand. The soils will later regain its strength as the excess pore water pressure decreases and stabilize. However, during the transition, the top soil and Superstructure formed in the soil will be affected great distress or failures. For the past 50 years, there has been a great deal of research attention and excellence on liquefaction issues, so several attempts were made to understand the phenomena of liquefaction. However, because of the liquefaction's complexity and spread issues, soil liquefaction remains a hot research topic in the geotechnical engineering profession. Particularly fine content effect soil liquefaction resistance, reliable and accurate predictive methods have to be developed.

* Corresponding author: Anjali Saji

This chapter gives a description about the materials used for the study, their collection and various test done on the soil.

2. Materials used

2.1. Soil

Soil sample used for this study is locally available sand which is collected from the quarry near Malayalapuzha, Pathanamthitta (District), Kerala (India). Sand is a granular material composed of finely divided rocks and mineral particles. In order to prepare soil specimens, the soil is oven dried for 24 hrs. to remove moisture from the soil and the oven dried sand. The dried sample passing through 4.75 mm sieve was used for the study. Soil type used in this study is poorly graded sand (SP). The uniformity coefficient (Cu) of the soil is 3.71, and the coefficient of curvature (Cc) is 0.6173. The grain size distribution shows that D10 is 0.35 mm, D30 is 0.53 mm, and D60 is 1.3 mm. The specific gravity of the soil particles is 2.727. The maximum void ratio (emax) is 0.777, while the minimum void ratio (emin) is 0.466. The maximum dry density of the soil is 1.86 g/cc, and the optimum moisture content (OMC) is 8%. The coefficient of permeability (K) is measured to be 0.0756 cm/sec.

2.2. Non-plastic fines (Silt)

If a thread cannot be rolled out to a depth of 3.2 mm at any moisture possible is known as non-plastic fines. Silt was collected from the Pamba River bed near Aranmula, Pathanamthitta (District), Kerala (India).The collected silt which is sieved through 0.075mm sieve. It is brown in colour and fine texture in nature.

Plastic fines are generally meaning the soil is predominantly clay. Plasticity is the ability of a material to undergo permanent deformation under stress without cracking. Clay was collected from Aranmula, Pathanamthitta (District), Kerala (India). In order to prepare specimens, the clay is oven dried for 24 hrs. to remove moisture from the soil and the oven dried clay.

The soil used in this study is classified as clay. The specific gravity of the soil particles is 2.185. The liquid limit (LL) is determined to be 62.5%, and the plastic limit (PL) is 36.36%, resulting in a plasticity index (PI) of 18.18. The soil exhibits an optimum moisture content (OMC) of 24%, and the maximum dry density is measured as 1.378g/cc.

2.3. Particle Interaction and Liquefaction Resistance

The introduction of fine particles among coarse sand grains reduces inter-particle contact points, resulting in fewer particle interactions. Consequently, the barrier to liquefaction is greatly diminished.

2.3.1. Triaxial Test Observations

Table 1 Summary of Triaxial Test Parameters and Results

Fine Type Fine Content (%)	Deviatoric Stress (kPa)	Pore Pressure Ratio Behavior Type
Non-Plastic	0	120
Non-Plastic	10	95
Plastic	10	90
Plastic	20	80

Results from consolidated undrained triaxial tests demonstrate that for both plastic and non-plastic fines, an increase in fines content leads to a more contractive response. This is accompanied by a lower mobilized deviatoric stress.

2.3.2. Liquefaction Potential (Lp) Analysis

The Lp value representing the liquefaction potential decreases with an increase in both plastic and non-plastic fines. The evolution of the minor principal stress (σ_3') during undrained shearing governs the soil response. As large pore water pressure develops, σ_3' reduces rapidly, leading to a higher Lp value—indicating higher susceptibility to static liquefaction.

2.3.3. Comparative Behavior of Cohesive and Non-Cohesive Soils

In general, cohesive soils show greater resistance to liquefaction than fine sands when density conditions are similar. Strength degradation in cohesive soils depends on total accumulated displacement, which increases over time. However, the residual strength mobilized under large deformations can be lower than that of sandy soils at comparable densities.

2.3.4. Post-Liquefaction Behavior

The post-liquefaction behavior of sand containing fines is primarily influenced by its dilatancy characteristics and the nature of loading. Soils with higher dilatancy exhibit quicker recovery of shear strength after liquefaction.

2.4. Future Scope

Although several investigations have been performed on liquefied sand using different laboratory techniques, research on improving the shear strength and liquefaction resistance of fine-containing sands remains ongoing. The present study can be extended in the following directions:

2.4.1. Cyclic Triaxial Testing:

Conduct cyclic triaxial tests to determine the liquefaction potential under repeated cyclic loading, simulating earthquake conditions.

2.4.2. Field-Based Studies:

Since field conditions involve non-uniform and multidirectional loading, further research should incorporate real-time field problems.

2.4.3. In-situ Testing:

Utilize Standard Penetration Test (SPT) and Cone Penetration Test (CPT) data to establish empirical correlations for liquefiability evaluation.

2.4.4. Numerical Modelling:

Develop numerical simulations using finite element or discrete element models to validate laboratory findings.

Table 2 Recommended Future Research Directions

Research Focus	Method Suggested	Purpose
Cyclic Liquefaction	Cyclic Triaxial Test	Assess soil resistance to earthquake loading
Field Correlation	SPT/CPT Tests	Establish empirical liquefiability charts
Modeling	FEM/DEM	Simulate stress-strain-pore pressure response
Material Improvement	Stabilization using additives	Enhance shear strength and reduce pore pressure buildup

2.5. Research Focus Method Suggested Purpose

- Cyclic Liquefaction Cyclic Triaxial Test Assess soil resistance to earthquake loading
- Field Correlation SPT/CPT Tests Establish empirical liquefiability charts
- Modeling FEM/DEM Simulate stress-strain-pore pressure response

- Material Improvement Stabilization using additives Enhance shear strength and reduce pore pressure buildup

3. Conclusion

The study confirms that both plastic and non-plastic fines significantly influence the liquefaction behavior of sand. Increasing fines content generally promotes contractive response, reduces deviatoric stress, and lowers Lp values. While cohesive soils resist liquefaction better than non-cohesive sands, their residual strength may still degrade under prolonged deformation. Further cyclic and in-situ investigations are recommended for a comprehensive understanding.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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