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Liquefaction of soil during earthquakes: the potential of soils

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Abstract

During earthquakes, the ground Shaking may cause a loss of strength that results in the settlement of buildings, landslides, the failure of earth dams, and many other hazards. This process of Losing strength is called soil liquefaction. This phenomenon is associated primarily, with saturated cohesionless soils. In all Large Earthquakes, Soil Liquefaction is observed and, in some cases, it has caused much damage. The destructive effects of soil liquefaction were brought to the attention of engineers by the disastrous 1964 earthquake in Niigata, Japan. This earthquake caused more than $1 billion in damages, due mostly to widespread soil liquefaction. For critical structures, such as nuclear power plants and large earth dams, the possibility of liquefaction presents serious engineering problems. This study aims to present methods for understanding the liquefaction problem and providing a framework for evaluating the safety of sites and structures against liquefaction-related failures. The study discusses some liquefaction problems and makes references to existing literature. This study provides useful information to geographers.

Keywords*:* Earthquakes; liquefaction; soil; structure.

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1. Introduction

The word liquefaction includes all phenomena involving excessive deformations or movements because of the transient or repeated disturbance of saturated cohesionless soils [1-3]. Several similar findings helped us with this research directly or indirectly. Krim et al. [4] studied the influence of clay content and grading characteristics on the liquefaction resistance of sand–clay mixtures using triaxial tests performed on reformed sand–clay mixtures with varying clay content. The liquefaction resistance is found to be reduced with an increase in clay content [5-7].

Umar et al. [8] concluded that earthquake magnitude plays a very important role in the assessment of liquefaction, irrespective of soil type and water table of the site using a deterministic and probabilistic approach. In 2015, Konni conducted a project on an offshore artificial island located 84 km offshore [9]. The purpose of the project was to determine the level of compaction achieved for the artificial island and assess its potential for liquefaction using SPT, N, and CPT data. Based on the results of the tests, it was observed that CPT was a more suitable method for assessing liquefaction potential than SPT.

Dash & Sitharam [10] studied the effect of non-plastic fines on the behavior of silty sand subjected to cyclic loading. The results obtained from experimental investigation conclude that the nature of soil deposits plays an important role in defining the cyclic resistance ratio (CRR) and pore water pressure generation which occurs during earthquakes. Jaiswal [11] in his research cited that Biles and other researchers in 2010 conducted a study to determine the safety factor against liquefaction in alluvial soils in Tuzla. They used various methods to assess the soil's strength, including the Cone Penetration Test (CPT) [12], Standard Penetration Test (SPT) [13], and undrained shear strength (Su) [14-16].

Amini and Qi [17] conducted a study to investigate the behavior of silty sands under seismic liquefaction conditions when subjected to different levels of soil content and confining pressures that are typical of field conditions. The study aimed to understand how the behavior of these soils changes when they are separated or mixed.

In the context of this study, the word liquefaction is used to include all phenomena giving rise to a loss of shearing resistance or the development of excessive strains because of transient or repeated disturbance of saturated cohesionless soils. This use of the term liquefaction is general and covers a range of phenomena that are not necessarily of the same nature (e.g., problems of strength as well as problems of deformation). As will be noted, more restrictive definitions of liquefaction have also been proposed.

1.1. Purpose of study

The main objectives of the study were to find: To know about liquefaction, understand the phenomenon of liquefaction and its impact on structures; To Present methods for understanding the liquefaction problem and provide a framework for evaluating the safety of sites and structures against liquefaction-related failures; Summarize different approaches that have been used to analyze and evaluate the risk of liquefaction-related failures, ranging from empirical to theoretical methods.

This report focuses on important aspects of the liquefaction of soils during earthquakes, places different viewpoints into perspective, and identifies areas of agreement and disagreement. No attempt is made at a thorough, detailed presentation of the many and varied results found in the extensive literature. This report should instead be viewed as a guide to that literature. Its primary emphasis is on earthquake engineering problems, but its conclusions and recommendations have a broader applicability.

2. Materials and method

2.1. Liquification Phenomenon

The liquefaction phenomenon is described as the lowering of shear strength because of the pore pressure that builds up in the soil skeleton. The shear strength of cohesionless soil, τ, depends on the angle of internal friction and the effective stress acting on the soil skeleton and can be expressed as

$$\tau = \sigma' \tan \phi \qquad \text{Eq. (1)}$$

$$\sigma' = \sigma - u \qquad \text{Eq. (2)}$$

where τ = shear strength

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σ' = effective normal stress

σ = total normal stress

u = pore pressure

ϕ = angle of internal friction

When the loose saturated sands are acted upon by earthquake loading, primarily induced by upward propagation of shear waves from the bedrock, they happen to settle and densify. However, the time of the cyclic stress application is so short compared to the time required for the water to drain, that the soil volume contraction cannot occur immediately, and excess pore pressure will progressively build up.

2.2. Location of Site

The inspection site has been identified and its location has been marked on a satellite view of the area (figure 1). The latitude of the inspection site is 27 degrees, 13 minutes, and 51.67 seconds North, while its longitude is 78 degrees, 0 minutes, and 51.51 seconds East. These coordinates specify the precise geographic location of the inspection site on the Earth's surface and can be used to locate it using GPS or other mapping tools.

Fig 1. Map view of Inspection Site

The reason for selecting this site is its proximity to the Yamuna River and the type of soil found in the area, which is sandy soil. These factors suggest that the site has the potential for liquefaction to occur. In other words, during an earthquake or other vibration, the soil in this area could lose its strength and stiffness and behave like a liquid, which could lead to significant damage to buildings and other structures. Therefore, it is important to consider the risk of liquefaction when planning and constructing any buildings or infrastructure in this area. As per IS 1893:2002 (Part 1), India has been divided into 4 seismic zones, the selected area lies in zone III which is moderately affected by earthquake forces.

Poiya ghat is just near to the Yamuna River, which is in the vicinity of the Dayalbagh area, because the area is near a river, the soil present there is in loose condition even in its natural state. The selected site lies within the 2 km radius of the Yamuna River, a Google Earth satellite view of the same is attached for reference (figure 2).

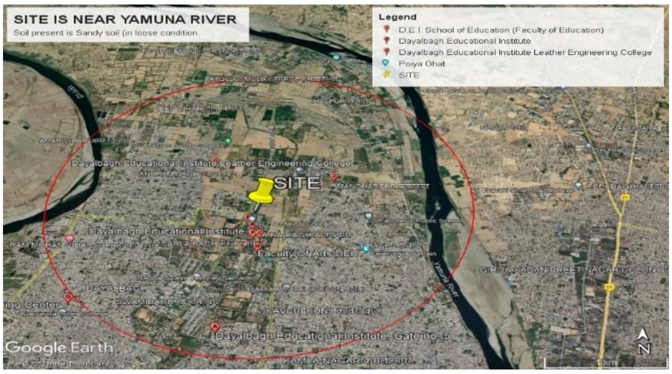

Fig 2. Distance between the site and Yamuna River (= 2 Km)

2.3. Method

For the study of Liquification of soil, we study two Methods for deep soil testing:

1. Cone Penetration Test

2. Standard Penetration Test

2.4. Compliance with Ethical Standards

This article does not contain any studies with human participants or animals performed by any of the authors.

3. Results

3.1. Cone Penetration Test

Design methods for shallow and deep foundations have been proposed based on cone resistance. A few laboratory studies have appropriate overburden pressure levels [18]. In either case, it is necessary first to develop scaling relations for extrapolating the model test results to the full-scale cone. Secondly, it would be necessary to account for the effects of the self-weight body force gradient present in field applications, which could not be simulated in the calibration chambers. To ensure that the gravity stress gradient present in field applications is properly represented in laboratory testing, a centrifuge can be employed. If the soil models are carefully prepared so that the properties are controlled and known, then models of the cone penetrometer tested in the increased gravity environment should produce penetration resistance profiles that can be related to fundamental soil properties.

From the CPT testing, unique plots of tip resistance versus vertical effective stress for each relative density model were determined. From these data, it is possible to determine a unique value that describes each. The relative density model developed by Olsen [19] provides a relationship between the corrected tip resistance qc1 and the relative density of soil. The model was later tested using a laminar box and earthquake actuator on a centrifuge to study liquefaction effects. The results from these tests were used to create prediction charts that relate field-measurable parameters such as qc1 with earthquake damage, including the thickness of the liquefied layer, lateral displacement, and settlement for a given soil deposit. Combining the results from both the relative density model and the liquefaction tests allows for the elimination of the relative density parameter and the creation of a direct correlation between qc1 and lateral displacement. This prediction chart can be used to estimate the potential damage from earthquakes based on qc1 measurements in the field.

3.2. Standard Penetration Test

Geotechnical engineers use different techniques to determine the liquefaction potential of soils [20]. The two most commonly used techniques are the Standard Penetration Test (SPT) and Cone Penetration Test (CPT). However, it is essential to use different site characterization tools together as they play complementary roles. The SPT was developed in 1927 and is one of the most widely used soil tests worldwide. The test involves dropping a hammer weighing 63.5 kg onto drill rods from a height of 0.76 m. The number of blows required to achieve a penetration just under the seating drive of 0.15 m in a standard sample tube is used to determine the soil's strength and endurance. However, due to the SPT's dynamic nature, there are significant concerns regarding its reliability and repeatability [21,22].

The CPT is gaining popularity as a reliable method of assessing liquefaction potential since it offers consistent and reliable data. The CPT involves pushing a cone-shaped probe into the soil and measuring the resistance to penetration. The measurement is taken at regular intervals, typically every 1.5 m. This provides a more detailed and accurate picture of the soil's characteristics than the SPT.

Overall, using multiple site characterization tools is important to get a comprehensive understanding of the soil and its liquefaction potential. While the SPT and CPT are the most used techniques, other methods such as seismic tests and shear wave velocity measurements can also be used to complement and verify the results.

4. Conclusion

This paper discussed some of the recently developed liquefaction mitigation techniques and soil liquefaction. Among the various seismic risks, liquefaction is regarded as a major critical hazard. The most common application of soil improvement techniques is to mitigate or decrease the liquefaction impacts. A large percentage of these methods. usually through trial and error. While traditional mitigation methods are widely used, they have drawbacks such as environmental influence, disruption to established buildings when applied to deformations and vibrations, and the area size to be mitigated.

A brief discussion of the liquefaction danger related to loosening sand sediments, as well as its assessment is monitored through an outline of field engineering functions, along with a concentration on soil improvement mitigation techniques. As liquefaction hazard mitigation, vibroflotation compacts, dynamic compaction, deep mixing soil, passive site stabilization, and piles compaction are used.

5. Recommendation

There have been conflicting findings in the literature regarding the impact of sample preparation and frequency of excitation/loading on the dynamic properties of soil. To fully understand the subject, more research is needed to determine how different factors influence soil's dynamic properties. This will enable us to use this knowledge more effectively for further research and practical applications.

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