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Soil Liquefaction Screening and Evaluation a Review

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Abstract - **Soil resistivity plays a critical role in structural and material science in various situations. However, there are specific concerns regarding soil resistance when subjected to dynamic or cyclic loads. The process of 'Soil Liquefaction' is a significant cause of soil loosening, leading to a loss of strength and potential destruction of structures. It is crucial to screen and analyze areas susceptible to liquefaction to prevent substantial property damage and loss of life. This study addresses this issue by identifying regions prone to liquefaction, enabling the avoidance of constructing residential and commercial buildings in such areas. In case construction is necessary, several measures must be taken to mitigate risks before building.**

Keywords —Liquefaction Susceptibility, shear strength, earthquake, dynamic loading, Standard Penetration Test (SPT).

I. Introduction

Soil liquefaction is typically associated with significant earthquakes and relative ground failures. The technical definition of liquefaction refers to the reduction of strength and stiffness in loose, saturated, and cohesionless soil resulting from earthquake shaking or other rapid loading. This loss of strength primarily occurs due to the buildup of pore water pressure, resulting in the effective stress being equal to zero and the soil mass flowing like a liquid. Monotonic, cyclic, or shock loading can cause this liquid-like flow due to the loss of shear resistance in the soil mass. While earthquakes are often the trigger for liquefaction, other activities like blasting can also lead to increased pore water pressure. Soil strength decreases due to liquefaction, and the construction supporting capacity of the soil reduces, leading to structural failure. The phenomenon also exerts high pressure on retaining walls, causing them to slide or tilt, resulting in extensive damage. It is essential to assess the possibility of liquefaction or the liquefaction potential of soil or the existing conditions in a soil deposit to avoid significant property damage and loss of life from this destructive phenomenon before any seismic or similar loading occurs.

1.1 How liquefaction occurs

When a dynamic load is applied, rapid shearing occurs, leading to an undrained shearing condition. This condition causes an increase in pore pressure, resulting in a decrease in effective stress, while total stress remains constant. According to Terzaghi, since shear strength is only a function of effective stress, the shear strength decreases. When the pore pressure increases significantly, the effective stress becomes zero, indicating that the soil skeleton cannot bear any load, and the entire load is governed by water, which cannot take any shear load. The soil behaves more like a viscous fluid, causing heavy structures to sink and light structures to float. The strength of cohesionless soil is a function of overburden pressure and the angle of friction, i.e., S = σ' tan. When the excess pore water pressure ratio (ru) reaches 1, it is defined as "full liquefaction," and S = 0. During liquefaction, even if σ' becomes zero, the soil shows some shear strength due to cohesion. However, due to the generated pore pressure, water will dominate, and since it cannot take any shear load, the entire clay material will be pumped out, referred to as clay pumping or mud pumping. For dry soil, shear fluidization occurs when a dry soil sample is placed on a table and heaved up to a certain height depending on its angle of repose. If the table is

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shaken vigorously, the soil flows on the entire table, which is similar to liquefaction.

1.2 Susceptibility of soils to liquefaction

The phenomenon of liquefaction is often associated with loose cohesionless soil subjected to rapid dynamic loading such as high-intensity and high-duration earthquakes. The occurrence of liquefaction is less likely if the soil has some degree of cohesion, which provides it with some strength. The relative density of soil and particle gradation are also important factors to consider. Loose soils and uniformly or poorly graded soils are more vulnerable to liquefaction, while dense and well-graded soils are less susceptible. Adequate soil compaction can also reduce the potential for liquefaction. The presence of plastic fines in the soil can also reduce its liquefaction potential. The location of the groundwater table is another important factor; saturated soils are more prone to liquefaction. However, loose soils with high permeability, such as gravel, allow for easy dissipation of pore water pressure and are thus less likely to liquefy.

1.3 Preliminary screening for liquefaction

Liquefaction assessment involves two primary stages: Screening investigation and Quantitative evaluation. During screening, the area to be investigated is reviewed for relevant information, including geology, topography, soil conditions, and maps of the ground contour. Other critical data sources, such as the presence and location of the water table, water well logs, and agricultural soil survey maps, are also examined. Screening is designed to determine if further investigation for liquefaction is required, and it involves the following steps:

- Check if the soil is saturated: If the highest level of groundwater is more than 50 feet below the existing ground surface or the proposed finished grade, soil is considered safe against liquefaction, and no further assessment is required. The water table's current, past, and future maximum level is also checked.
- Check if the site is underlain by bedrock: If the site is underlain by bedrock or similar lithified formational material, there is no need for liquefaction assessment because rocky material is not prone to liquefaction.
- Check the corrected SPT N60 value: If the corrected SPT N60 value for a sufficient number of tests is greater than 30 blows per foot, then the tests for liquefaction are not required.
- Check if the site is underlain by clayey material: If the soil classifies as clay throughout the site, further quantitative liquefaction assessment is not required because clayey soil is not prone to liquefaction due to its cohesion.

If the preliminary investigation indicates a potential for liquefaction, a quantitative evaluation of the site is necessary before any new construction work is carried out.

1.4 Simplified procedure for liquefaction

The simplest and most widely used method for evaluating liquefaction potential is the "Simplified Procedure," which was first introduced by Seed and Idriss (1971) and then improved by Youd and Idriss (1997), Youd et al. (2001), and Seed et al. (2003). This procedure determines a factor of safety against liquefaction for a soil layer at a given depth.

FS1 = CRR7.5CSR

FS1 is the factor of safety, which compares the cyclic resistance ratio (CRR) with the cyclic stress ratio (CSR) induced by an earthquake at a specified design earthquake. CRR is the cyclic stress required to cause liquefaction for a soil layer with specific properties at a given depth, or the soil's resistance to liquefaction. CSR is the seismic demand on a soil layer, based on peak ground surface acceleration and an associated moment magnitude, or the actual cyclic stress developed due to a particular earthquake or dynamic loading. However, the CRR value for soil is calculated for an earthquake with a moment magnitude of 7.5, as the resistance to different earthquake magnitudes varies.

If the value of CSR exceeds the resistance power of soil (CRR), the soil will liquefy. For FS1 $<$ 1, liquefaction has occurred, while for FS1 $>$ 1, the soil is safe from liquefaction. A factor of safety of 1.3 is recommended, but this value also depends on hazard severity, importance and vulnerability of structure, tolerable settlements or level of risk acceptable to owner or regulating body, confidence and certainty in underlying data and assumptions. A lower factor of safety of 1.1 may be acceptable for single-family dwellings where potential for lateral spreading is low, and differential settlement is the main hazard.

II. LITERATURE REVIEW

2.1 Guangyin Du et al (2019): The Su-xin highway project utilized the resonant compaction method, which involves assessing the liquefaction potential of soil using the piezocone penetration test (CPTU) and the standard penetration test (SPT). The CPTUs provide an index for the soil's behaviour, known as the Soil Behaviour Type Index (IC), while the SPTs provide the Standard Penetration Test Index (N63.5). The IC and N63.5 values are then analysed for standard silty sand and silt. A linear relationship between IC and N63.5 is established, which is given by the equation N63.5 = -18.8IC + 52.0. Larger values of IC indicate greater soil viscosity, which results in smaller values of N63.5. The calculated value of N63.5 is compared to the critical value of the standard penetration test value NCR. If N63.5 is greater than NCR, then liquefaction does not occur. Otherwise, the soil is considered to be liquefied.

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2.2 Dr. R. P. Rethaliya and Kanan Thakkar (2015): According to a research conducted by Dr. R. P. Rethaliya and Kanan Thakkar in 2015, liquefaction requires the soil to be cohesionless, loose, saturated and subjected to a dynamic force such as an earthquake. Additionally, the depth of soil should not exceed 12m for liquefaction to develop. Liquefaction is expected to occur when the average shear stress (τavg) is greater than the cyclic resistance ratio (τn). When the SPT (standard penetration test) value is below 10, the likelihood of liquefaction is high, while it is unlikely to occur when the SPT value is above 40.

2.3 Rashmi Rawal et al (2015): In their study, Rashmi Rawal and colleagues (2015) explained that soil liquefaction is a phenomenon in which soil loses its strength due to ground shaking during an earthquake. However, not all soils are prone to liquefaction. Soils that are most susceptible to liquefaction have the following characteristics:

- They are composed of sands and silts that are loosely packed without any cohesion.
- They are located below the water table, where the spaces between the grains are filled with water. Dry soils located above the water table are not prone to liquefaction.
- During an earthquake, the rapid and violent shaking causes the grains of sand and silt to compress the water-filled spaces. However, the water in the pores pushes back and builds up pressure until the grains float in the water. Once that happens, the soil loses its strength and behaves like a fluid. This liquefied soil cannot support the weight of structures above it, causing it to flow out onto the surface as boils, sand volcanoes, and rivers of silt. In some cases, the flowing soil can erode and widen cracks in the ground, creating hazards for infrastructure and buildings.

2.4 Seed et al (2003): Seed et al (2003) investigated the liquefaction assessment of soil by utilizing the Modified Chinese Criteria, taking into account the percentage of fines. The research shows that soils containing non-plastic or low plastic fines (PI<=12%, and LL<=37%) and high water content relative to their liquid limit (w>0.85 LL) are highly susceptible to liquefaction. These soils pose a greater risk of liquefaction as they have low permeability and retain water well, which results in slow dissipation of excess pore pressure. The study divided soils into three zones: Zone A is likely to be susceptible to liquefaction, soils in Zone B are in the transition range, while soils in Zone C are not generally prone to liquefaction, but may still be sensitive and vulnerable.

Fig.02: Assessment of Liquefiable Soil Types (Seed et al., 2003)

2.5 Andrews and Martin (2000): Andrews and Martin (2000) proposed modifications to the Chinese criteria established by Seed and Idriss, adapting it to the US standard. They produced a new evaluation index by refining the empirical data, with a limit of 0.0002 mm being used to distinguish between clay and silt particles, and the liquid limit being determined using the casagrande apparatus.

Table 01: liquefaction susceptibility of silty and calyey sands (after Andrews and Martin, 2000)

Clay content	**Liquid limit < 32%**	**Liquid limit >=32%**
<10%	Susceptible	Further studies required (considering plastic non-clay sized grain-mica)
>10%	Further studies required (considering non-plastic clay sized grain-mine and quarry tailings)	Not Susceptible

2.6 Seed and Idriss (1971): Seed and Idriss (1971) established the well-known Chinese criteria for recognizing the susceptibility of soil to liquefaction, which consists of three basic criteria. First, the soil should have a percentage of fines (clay fraction < 0.005mm) of less than 15%. Second, the liquid limit of the soil should be less than 35%. Lastly, the soil must contain moisture content that is 90% higher than the liquid limit of the soil. They proposed semi-empirical procedures to assess the potential for liquefaction in saturated cohesionless soils during earthquakes, and discussed several factors such as the stress reduction factor (rd), the earthquake magnitude scaling factor for cyclic stress ratios (MSF), the overburden correction factor for cyclic stress ratios (kσ), and the overburden normalization factor for penetration resistances (CN). Seed and Idriss presented recently modified relationships, which were used to re-evaluate the case history databases of Standard Penetration Test (SPT) and Cone Penetration Test (CPT). Based on these findings, revised SPT- and CPT-based liquefaction correlations were suggested for use in practice.

III. CONCLUSION

Soil liquefaction screening and evaluation are crucial for assessing the potential for liquefaction in soil during earthquakes. The process involves evaluating various characteristics of the soil, such as the soil type, water content, groundwater table depth, and seismic activity in the area.

- Different methods, including the Standard Penetration Test (SPT), the Cone Penetration Test (CPT), and Shear Wave Velocity (SWV) measurements, can be used to assess the soil's liquefaction potential.
- These screening and evaluation results are vital in designing safe and reliable structures in

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earthquake-prone regions. By identifying the potential for soil liquefaction, engineers can design foundations and structures that can withstand seismic activity and prevent damage or collapse.

- Furthermore, soil liquefaction screening and evaluation can help identify the need for ground improvement techniques to stabilize the soil and increase its resistance to liquefaction. Overall, soil liquefaction screening and evaluation are crucial in ensuring the safety and reliability of structures built in earthquake-prone regions.
- By using the appropriate methods and techniques, engineers can accurately evaluate the potential for soil liquefaction and design structures that can withstand seismic activity, guaranteeing the safety of people and property in these areas.

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