Investigation of Liquefaction of Silty Sandy Soils Using Cyclic Triaxial Stress Test

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The history of previous earthquakes demonstrates that the liquefaction phenomenon significantly impacted damage. The impact of factors like cyclic stress ratio and percentage of non-paste fine grain in constant all-round pressure on the liquefaction potential of silty sand was investigated in the current study using a periodic triaxial test. The sand and silt near the Euphrates River in Al-Ammari village have been used in this regard. Four types of soil were studied, each with a different amount of sand and silt, including pure sand without silt, 75% sand and 25% silt, 50% sand and 50% silt, and pure silt without sand. In the following this samples were consolidated according to the 100 kPa all-round pressure, and the triaxial periodic consolidated undrained (CU) test was performed. The intermittent tension control loading operates in three different CSR modes, including 0.1, 0.15, and 0.2. The results show that the soils containing 25% and 50% silt have a higher and lower liquefaction potential than the other investigated samples. Also, results show that when CSR=0.2, liquefaction occurs faster and with fewer cycles, whereas CSR=0.1 liquefaction occurs later and requires more cycles. The soil sample containing 50% silt reached liquefaction sooner than the other soils at CSR=0.1 but later at CSR=0.2. The soil containing 25% silt liquefied faster than the rest at CSR=0.2. Finally, it can be concluded that soil behavior characteristics such as liquefaction are heavily influenced by the composition of different soil types, applied pressure, the presence of cyclic load, and so on; therefore, investigation of various situations is critical.

Keywords: Liquefaction, earthquake, silt, triaxial stress test.

1. Introduction

Liquefaction is a phenomenon that happens when saturated soil fails its strength and hardness as a result of intense stress and begins to behave like a fluid [1]. The mentioned stress can be caused by earthquake tremors or sudden changes in soil stress conditions [2]. According to research, the pasty characteristics of the soil, in addition to granulation, influence the liquefaction ability of fine-grained soils [3]. Because the paste range of most sandy soils in sedimentary piles and construction embankments is less than 15, the effect of the fine-grained paste state in them is small. Most studies on sands with refined grains conducted for this purpose are related to sands with non-paste refined grains [4]. Coarse-grained layers that are not sticky or pasty are prone to liquefaction. According to the cases mentioned, liquefaction can occur in many soils. However, the amount of compaction and the percentage of non-paste and pasty refined grains can significantly impact the liquefaction tendency [5, 6].

Terzaghi coined the term "liquefaction" in 1925 to describe the collapse of saturated soils, but liquefaction caused by seismic loading was not considered a vital engineering issue until 1953 [7]. Following the earthquakes in Tokyo (1948) and Morgan and Kobe (1953), researchers proposed for the first time that soil liquefaction could occur due to seismic loading. Liquefaction caused the foundations of buildings to break, bridges to collapse, buried structures to float, and many pieces of built equipment to float during the Niigata earthquake (1964) [8].

The liquefaction phenomenon focused researchers' attention on the undrained behavior of saturated sands in the seismic load conditions [9]. As a result, one of the significant factors in the design of structures built on loose and saturated sandy soils was the appearance of liquefaction [10]. One of the important risks in many parts of the world is the liquefaction of granular, saturated, and loose soils during an earthquake. Liquefaction causes significant damage to engineering structures during an earthquake. These damages are caused by ground deformation, sand boiling, and subsidence [11].

When soil deposits are sheared quickly and bidirectionally due to seismic movements, the water pressure inside the soil pores rises [12]. The pore water pressure rapidly increases in loosely saturated, non-cohesive soils. This value may reach such a level that the particles are suspended separately from each other, and the strength and hardness of the soil are completely lost for a brief moment [13]. Soil liquefaction during an earthquake reduces soil strength. This action could cause structure settlement, landslides, the acceleration of earthen dam ruptures, and other hazards [14]. Liquefaction is typically associated with increased pore water pressure, sand boiling, and deformation modes. Engineers only notice these deformations when they are large and cause structural damage. Liquefaction-prone soils are generally defined as saturated deposits or deposits capable of being saturated with groundwater [15].

Because of the widespread damage caused by the liquefaction phenomenon in recent decades, several efforts have been made to examine and analyze the liquefaction potential [16]. Many variables in soil properties (such as compaction, all-around stress, particle size, and fine grain amount) and determining their effect during liquefaction have resulted in empirical liquefaction potential assessment methods [17]. In this regard, these primary methods of estimating liquefaction potential have been continuously updated as actual data from new events has increased [18].

Usually, the most effective method for dealing with liquefaction and preventing its destructive effects is to identify and provide a map of liquefaction-prone areas, which allows for the prediction and implementation of necessary structural stability measures prior to the implementation of construction plans [19]. Today, there are numerous methods for improving soils with liquefaction potential, including removing or replacing undesirable soil, compacting the soil in place, and improving the soil in the area through injection, chemical stabilization, and installing drainage columns, among others [20].

Previously, studies in liquefaction were frequently focused on clean sands, as it was assumed that liquefaction only occurs in clean sands and that sands mixed with fine or coarse grains have little liquefaction potential [21]. However, because liquefaction in sandy soils mixed with other types of soils was observed in several previous earthquakes, studies on saturated mixed soils and evaluating their behavior and level of resistance against liquefaction were also considered [22].

According to the findings of mixed soil research, the complexity of liquefaction behavior in sandy soils mixed with silt or sand is much higher than in clean sandy soils [23]. Furthermore, while there is complete agreement among researchers regarding the behavior and factors affecting the liquefaction of clean sands, there are yet contradictions about the liquefaction behavior of mixed soils, which requires additional research and studies [24, 25]. On the other hand, Sandy soils are rarely found in their pure form in nature and are usually mixed.

The reasons mentioned above highlight the need for additional research on the liquefaction of mixed soils; thus, this study investigated the liquefaction resistance of sand mixed with varying percentages of silt utilizing periodic triaxial tests. The impact of increasing silt percentage and different amounts of CSR on the liquefaction resistance of sand and silt has been studied. The present study's innovation is to conduct the desired experiments on the soil adjacent to the Euphrates River.

2. Materials and Methods

Liquefaction occurs when soil resistance is drastically reduced or even lost in a short period. Liquefaction is more common in saturated loose soils and sediments subjected to dynamic loads [26]. Many researchers have introduced various methods to estimate the liquefaction potential in recent years. All common methods for examining liquefaction potential in the laboratory and on-site are broadly classified into two categories: a) liquefaction potential estimation based on cyclic stress and b) liquefaction potential estimation based on cyclic strain [27]. In the current study, the cyclic stress method is used. Using the relationships and diagrams provided by various researchers, it is possible to evaluate the cyclic stress ratio (CSR) created in the soil by an earthquake. Another critical parameter is r_u, equal to pore water pressure changes divided by effective vertical stress. When the value of r_u equals one, liquefaction occurs.

2.1. Test specifications

In the current research, the sand and silt near the Euphrates River in the area of Al-Ammari village have been used, whose characteristics are presented in Table 1. A three-axis periodic machine was used to conduct the necessary investigations. This test was based on ASTM D5311, and the samples were made by the wet compression method. There were four types of soil studied, each with a different amount of sand and silt: a) pure sand (0), b) 75% sand and 25% silt (25%), c) 50% sand and 50% silt (50%), and d) pure silt without sand (100%).

Table 1. Characteristics of the studied soils

Soil type	Density (g/cm^3)	Maximum dry unit weight (kN/m^3)	Minimum dry unit weight (kN/m^3)
Sand	2.68	16.71	13.82
Silt	2.17	14.64	11.43

Wet compression with 30% density was used to prepare samples with dimensions of 5 cm in diameter and 10 cm in height. At this point, an all-around pressure of 10 kPa was used to the sample after the cell was closed, preparing it and filling it with water around it. Furthermore, to liquefy the sample and thoroughly saturate it with a saturation percentage greater than 95, the all-around pressure and pressure inside the sample have been increased. This procedure is repeated in stages until the sample has a saturation ratio of 95%.

The sample is then consolidated according to the desired all-round pressure (100 kPa), and isotropic consolidation is performed to ensure the consolidation pressure is uniform throughout the sample. The loading stage follows, and to perform the triaxial periodic consolidated undrained (CU) test and liquefy the sample, the drain valve of the sample is closed so that water does not leave the sample and the pore water pressure does not deplete during loading. It should be noted that the loading is a tension control type, intermittent, and operates in three different CSR modes, including 0.1, 0.15, and 0.2.

2.2. Mechanism of soil behavior

When a granular soil sample is loaded, the forces applied to it are supported by a group of different-sized particles. As a result, the active contacts at the boundaries of these particles that bear vertical and shear forces form a chain of internal forces [28]. The chain of internal forces and their active contacts change direction when the soil's external load changes. As the external load increases, the subassemblies in the soil and their contact reach a point where the overall soil assembly undergoes large and unlimited deformations [29].

Under the assumption that soil grains are spherical, all grains contribute to transmitting applied forces to the soil. Contrary to the assumption, mixed soils comprise particles of various shapes and sizes. Some smaller grains are placed in the space between the larger particles and do not make significant contact with the grains around them, so they do not play a significant role in force transfer and shear force bearing. As a result, only a portion of the seeds are responsible for bearing and transmitting forces. In general, the tolerance of small particles and the transmission of forces depend on their size and quantity in the mixed soil; the larger the particles or the greater the proportion of these particles, the more effective their function will be [30].

3. Results and Discussion

The findings of the tests performed on the samples are presented in this section. Figure 1 depicts the CSR changes chart in terms of liquefaction initiation cycles.

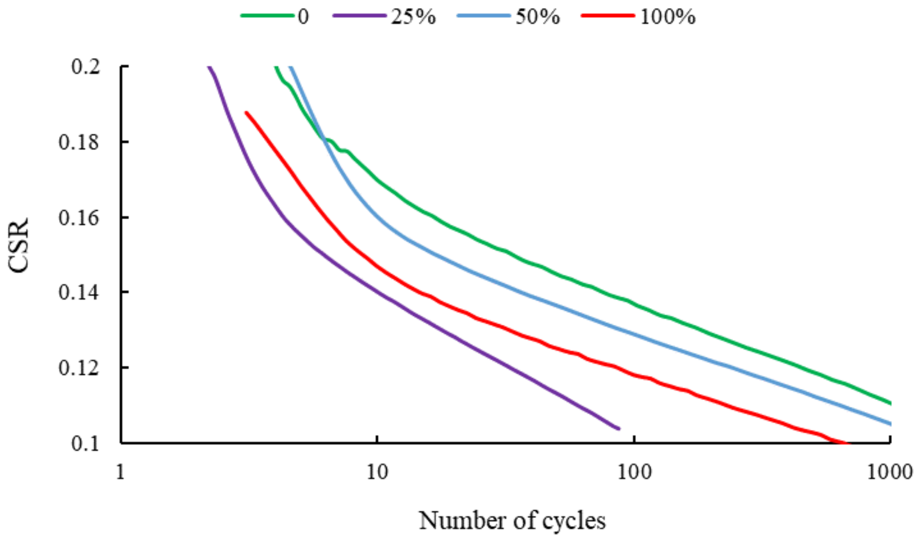

Figure 1. The CSR changes chart in terms of liquefaction initiation cycles

Figure 1 depicts the CSR chart regarding the liquefaction cycles required for a complete range of soils. In CSR=0.2, pure sand after 4 cycles, soil containing 25% silt after 2 cycles, soil containing 50% silt after 4 cycles, and pure silt after 3 cycles have all liquefied. At CSR=0.15, pure sand liquefied after 32 cycles, soil containing 25% silt after 6 cycles, soil containing 50% silt after 17 cycles, and pure silt after 9 cycles. As a result, as the proportion of silt to pure sand increases up to 25%, the liquefaction potential increases and then decreases.

By comparing the different graphs in Figure 1, it is possible to conclude that the soil containing 25% silt has a higher liquefaction potential than the other investigated samples. Pure sand is also less prone to liquefaction. As a result, for the range of CSRs investigated in the current research, a suitable estimate of the cycles needed for liquefaction can be considered based on the liquefaction curves of each of the mentioned soils. Furthermore, the results revealed that the increasing trend of the axial strain is similar to the diagrams shown in Figure 1.

Figures 2 and 3 depict the impact of CSR on r_u. Graphs relating to soil samples containing 25% and 50% silt under different CSRs have been presented for this purpose. Figures 2 and 3 show the results up to a maximum of 20 cycles.

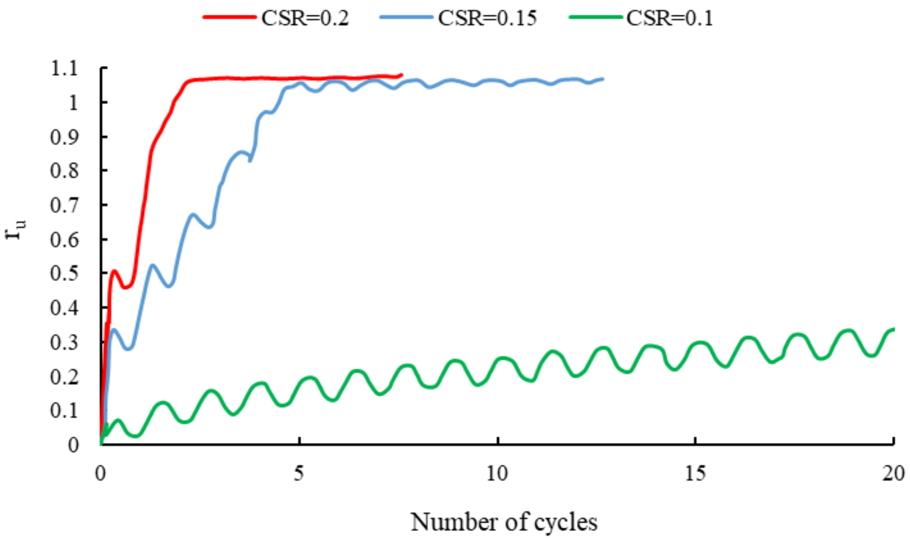

Figure 2. Effect of CSR on r_u for soil samples containing 25% silt

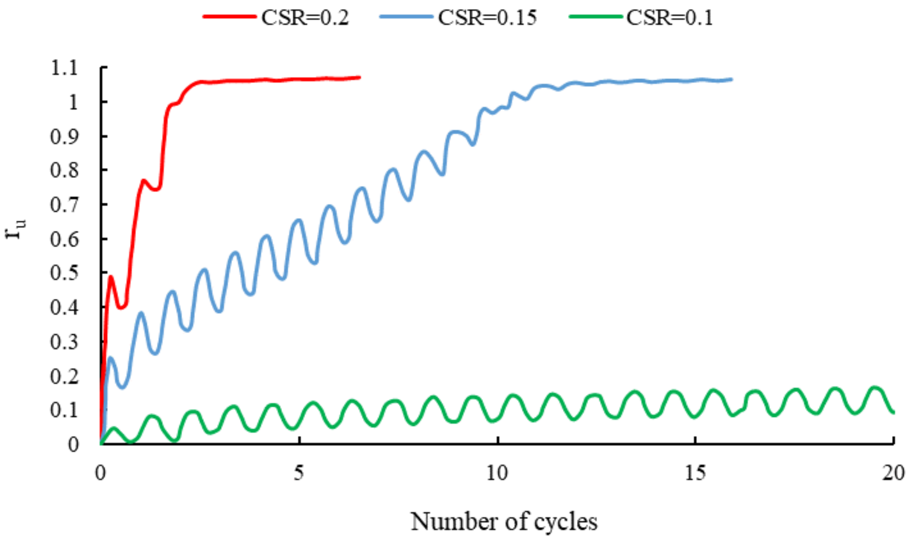

Figure 3. Effect of CSR on r_u for soil samples containing 50% silt

Figures 2 and 3 show that at CSR=0.2, liquefaction occurred in cycle 2. At CSR=0.15, cycle numbers 6 and 11 occurred for soil samples containing 25% and 50% silt, respectively. For CSR=0.1, liquefaction did not occur until the cycle number 20. As a result, it is concluded that when CSR=0.2, liquefaction occurs faster and with fewer cycles, whereas when CSR=0.1, liquefaction occurs later and requires more cycles.

Figures 4 and 5 show the impact of different amounts of silt on r_u for various CSIs. Previous research has shown that the amount of critical silt required to produce the maximum pore water pressure and cause liquefaction varies by the value of CSR [31-33].

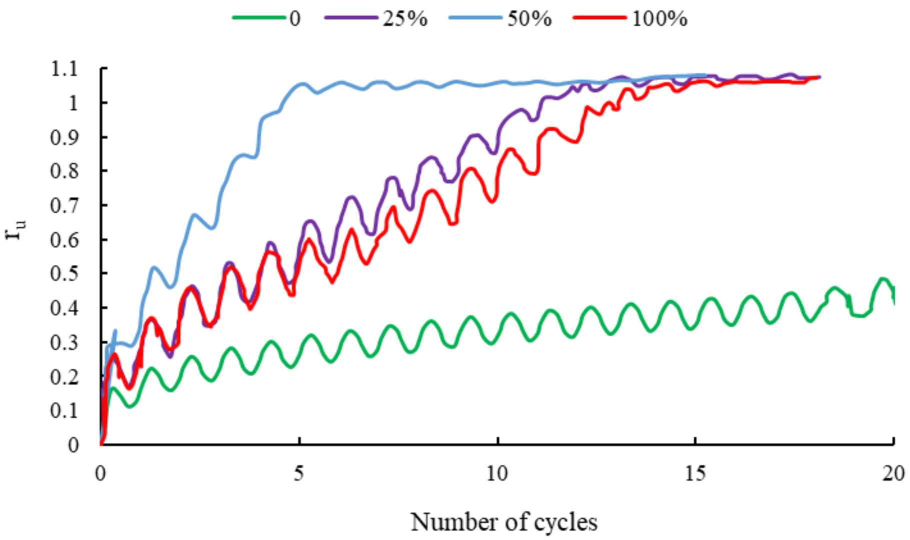

Figure 4. Impact of silt content on r_u in CSR=0.1

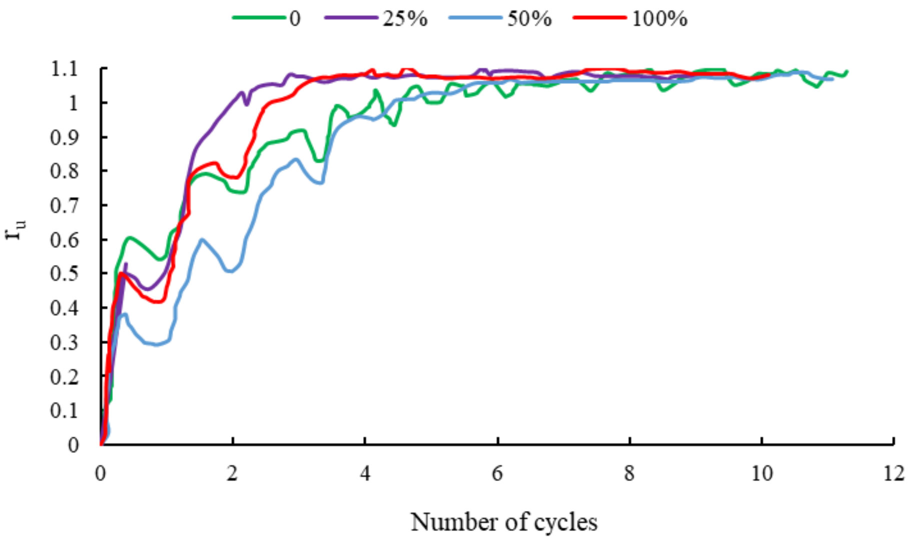

Figure 5. Impact of silt content on r_u in CSR=0.2

According to Figure 4, at CSR=0.1, liquefaction occurred in cycles 11, 5, and 13 for soil samples containing 25%, 50%, and 100% silt, respectively. At CSR=0.1, liquefaction did not occur for pure sand (soil without silt) until the 20th cycle. According to Figure 5, at CSR=0.2, liquefaction occurred in cycles 4, 2, 5, and 3 for soil samples containing 0, 25%, 50%, and 100% silt, respectively.

Figures 4 and 5 compare the impact of CSR on soil liquefaction behavior. As a result, it is clear that at CSR=0.2, the r_u diagrams for the four types of soil are closer together, whereas, at CSR=0.1, the deodars are further apart. The soil sample containing 50% silt reached liquefaction sooner than the other soils at CSR=0.1 but later at CSR=0.2. The soil containing 25% silt liquefied faster than the rest at CSR=0.2. Also, it was concluded that until reaching the liquefaction stage, samples at CSR=0.2 experience more axial strain than samples at CSR=0.1.

Some studies have found that the amount of silt does not affect the liquefaction potential [11, 24], while others have found that the amount of silt increases the liquefaction potential [7, 34]. Furthermore, most studies in this field have shown that increasing the amount of silt up to a certain amount increases the liquefaction potential and then decreases the liquefaction potential [35-37], consistent with the current study's findings.

According to the current study, the limit of behavior change is 25% of silt. Because the placement of fine silt particles among the coarser sand particles fills the space between the sands as you move from pure sand to sand with 25% silt. This causes the soil's drainage capacity to decrease during earthquakes or periodic loading vibrations, and as a result, the liquefaction resistance decreases in these situations. Then, an increase in silt above 25% changes the behavior of the soil, causing the soil to become fine-grained and the liquefaction resistance to increase. It should be noted that the condition between 25% and 50% silt is not considered in the current study's set of experiments.

4. Conclusion

In the current study, a three-axis periodic test was conducted on four distinct soil types containing varying amounts of sand and silt to investigate the liquefaction potential. By analyzing various types of soil, it was discovered that increasing silt by 25% decreased liquefaction resistance, whereas increasing silt by 50% increased liquefaction resistance. Also, the impact of CSR on the liquefaction examined in the current research is evident; consequently, the proportion of refined grains that generate the highest pore water pressure has changed with the periodic stress ratio. For future research, other soil compositions should be investigated and compared to the findings of the current study.

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