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The effect of frequency and effective consolidation stress on liquefaction potential of alluvial sand of Thai Binh Formation ($aQ_{2\text{-}3}{}^{tb}{}_{1}$) in cyclic triaxial experiment

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ABSTRACT

This paper presents the results about the effect of frequency and effective consolidation stress on potential liquefaction of alluvial sand, within the lower part of Thai Binh Formation (aQ_2^3tb1) in the Hanoi area by using cyclic triaxial experiment, which is an effective method to study the potential of liquefaction. The results indicated great influence of frequency and effective consolidation stress on the liquefaction potential. The higher the frequency is the greater the liquefaction becomes. On the contrary, the liquefaction potential decreases when the effective consolidation stress increases. When the effective consolidation stress is higher than 140kPa, frequency is 2Hz, the magnitude of shear stress is 50kPa, and the sample is practically non-liquefiable.

1. Introduction

Loose saturated materials, when affected by increase of the dynamic stress, especially during an earthquake, might decline effective stress as the sequence of the abrupt increase in pore water pressure. Consequently, soil would be lost its shear strength, and behave similarly to a fluid. This phenomenon is called liquefaction, which results in a large deformation, slope instability, and infrastructure damage. Many research on the earthquake-induced liquefaction was presently carried out. Many methods are used to study liquefaction as in-situ and laboratory tests. However, laboratory tests are preferentially used to clarify and get an insight into the influences of frequency, effective consolidation stress, and magnitude. In this study, the samples of alluvial sand in Thai Binh Formation ($aQ_3^2tb_1$) in the area of Hanoi were used for experimental studies, which were performed by the cyclic triaxial experiments under

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undrained and controlled pressure conditions. The data of experimental results play an important role for applications in design and construction.

2. Distribution and physical properties of alluvial sand of Thai Binh Formation aQ^3_2tb1

The alluvial sand of Thai Binh Formation is widely distributed in the area of Hanoi under the layer of brownish and yellowish brown silty clay. It could be observed in the area of the West Lake, along the bank of the Red River from Tay Ho, Long Bien district to Thanh Tri district. It could also be observed at the areas of Sword lake, Bach Khoa, Chua Boc, Nga Tu So, Cau Giay. The thickness of the layer ranges from 0.6m to 32.5m and the average thickness of layer is 14.2m. The average depth is from few meters to 16.5m and the maximum value of depth is 34m in Dong Da area.

The layer is mainly composed of fine sand, mixed with greyish brown, black silt. According to the results from 685 constructions in the areas, the layer is available and physic-mechanical properties of the material, shown in the Table 1, are highly homogeneous. The particle size distribution varies slightly for locations and depths of the layers (Nguyen, 2004).

3. Cyclic triaxial experiment

3.1. Experiment equipments

Experiment equipment in Figure 3, provided by Wykeham Farrance-Controls, are used in this research is the cyclic triaxial experiments. The equipment is automatically controlled. This is one of the most advanced appliances, which can be used to evaluate the following properties: liquefaction potential, reduction of shear strength under the influence of cyclic load, identification of shear modulus and damping ratio, elastic modulus, the influence of sea wave to costal lines, and the influence of blasting in mining engineering.

3.2. Sample preparation

To assess liquefaction potential of sandy soil by laboratory experiments, the sample preparation schedule is principal. Recently, three methods are used to prepare sandy samples for triaxial test: dried pouring, wetting tamping, and sediment in water methods (Ishihara, 1996).

Table 1. Particle size distribution and physical properties

Order	Parameter	Sign	Unit	Value	
1	Particle size distribution	P	%	1 mm	0
				0,5 mm	0,1
				0,25 mm	13,24
				0,1 mm	75,86
				0,05mm	6,8
				<0,05mm	4,0
2	Specific gravity	g_s	kN/m³	26,6	
3	Grain size	D_{10}	mm	0,105	
		D_{30}	mm	0,12	
		D_{60}	mm	0,19	
4	Uniformity coefficient	C_u		1,81	
5	Coefficient of curvature	C_c		0,72	
6	Maximum void ratio	e_{max}		1,014	
7	Minimum void ratio	e_{min}		0,632	
8	Average SPT	N	Blow	13	

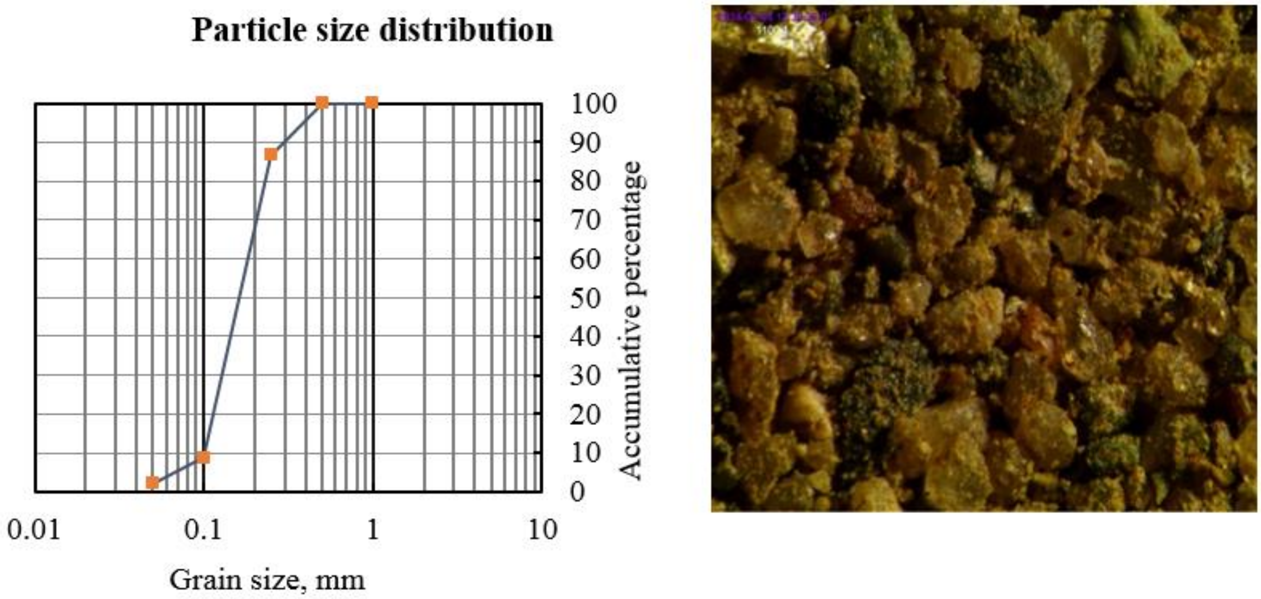

Figure 1. Graph of particle size distribution and the image of sample under microscope.

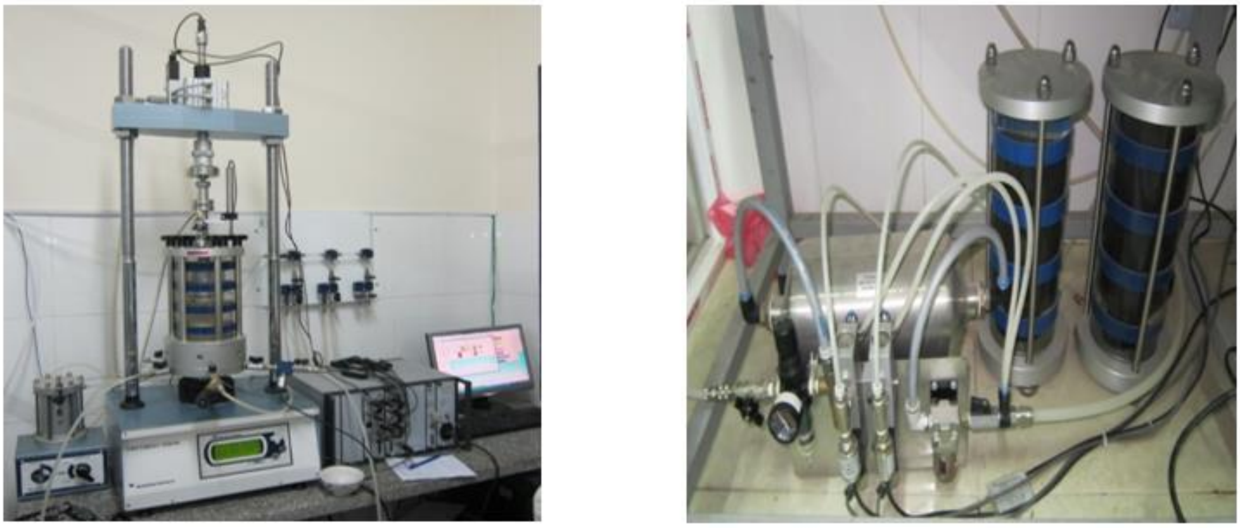

Figure 2. Equipment for cyclic triaxial experiments

Figure 3. Dried pouring equipment and the sandy sample

In this study, samples were prepared by dried pouring process, as shown in Figure 3, in which the samples of dried sand are filled in a cone shaped slender funnel with a nozzle about 12mm in diameter. The sand is spread in the forming mould with zero height and a fall at a constant speed until the mould becomes filled with the dry sand. Tapping energy is applied by hitting the side of the mould to obtain a desired density. Then, the sample is encased in the membrane. The samples have a diameter of 70mm and height of 140mm. The density of the samples was based on the density of sand in reality, which ranges from 50% to 60%.

3.3. Parameter selection and experiment progress

Typical parameters including: amplitude of cyclic vertical load, frequency, and effective consolidation stress. These parameters were chosen based on characteristics of cyclic loads, as well as natural pressure state applying on samples. In this study, pressure due to earthquake in the city of Hanoi was simulated corresponding with SIN shape harmonic loading. According to the research on earthquake in Vietnam, the area of Hanoi is located in the region where the amplitude of earthquake could reach 8 grade, equivalent to 5.1 to 7.2 Richter, with the maximum ground acceleration being of 0.4g, and frequency ranging from 1Hz to 5Hz. The experiments were conducted with the frequency of 1 Hz, 1.5 Hz, 2 Hz, 3,5Hz, shear stress amplitude (σ_a) of 30kPa, 35kPa, 40kPa, 45kPa, and effective consolidation stress of 50kPa, 80kPa, 100kPa, 12kPa, 130kPa, 140kPa, 150kPa, 200kPa.

Such experiments conform to ASTM D3999 standard integrated in the control program of the apparatus. They were conducted under the Stress-controlled and undrained conditions. During the process, vertical deformation, cell pressure, back pressure, harmonic loading, volumetric deformation, and pore water pressure were recorded by highly sensitive sensors.

4. Result and discussion

Results of 15 samples have exhibited the relation between liquefaction potential of soil and effective consolidation stress, frequency, and amplitude of cyclic stresses, as well as the relation between the alteration of shear stress, shear deformation, and pore water pressure under the effect of cyclic stress. From the results, for non-liquefied samples, shear stresses were almost constant under cyclic stresses, while the shear deformation were minor, being of 0.1-0.4%, and the relation between deviatoric stress ($q=\sigma_1-\sigma_2$) and the mean stress ($p'=(\sigma_1+2\sigma_2)/3$) is essentially linear. Especially, the ratio of pore water pressure ($r_u=\Delta u/\sigma'_c$) did not exceed 0.4 (Figure 4).

Table 2. Sample in the Cyclic triaxial Test with the alteration of frequency

No.	Sample No.	Dried unit weight γ_w kN/m^3	Amplitude of shear stress σ_d kPa	Frequency f Hz	Confining stress σ_c kPa	Number of cycles N	Pore water pressure ratio, r_u
1	TB18	16.4	50	1	100	15	1
2	TB23	16.5	50	1.5	100	6	1
3	TB19	16.4	50	2	100	4	1
4	TB21	16.5	50	3	100	3	1
5	TB20	16.4	50	5	100	2	1

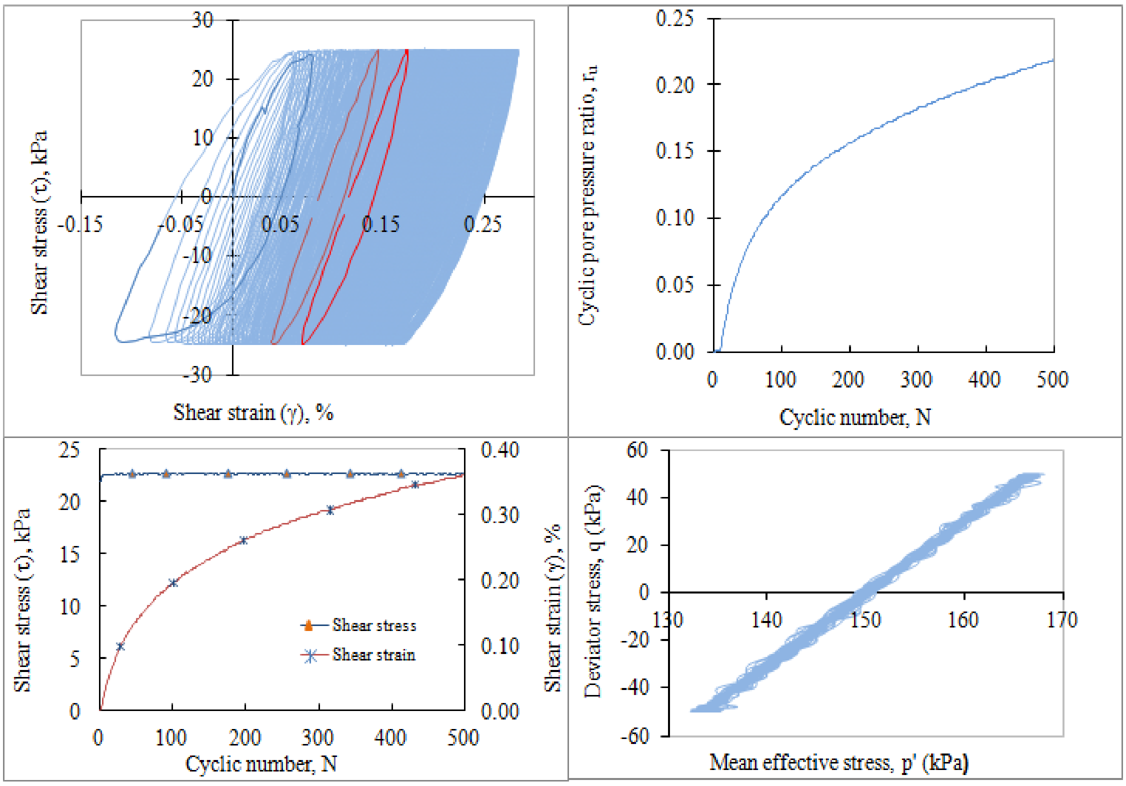

Figure 4. Sand sample TB15 Dr = 53.8%, σ_d = 50 kPa, f = 2Hz, σ'_c = 150 kPa

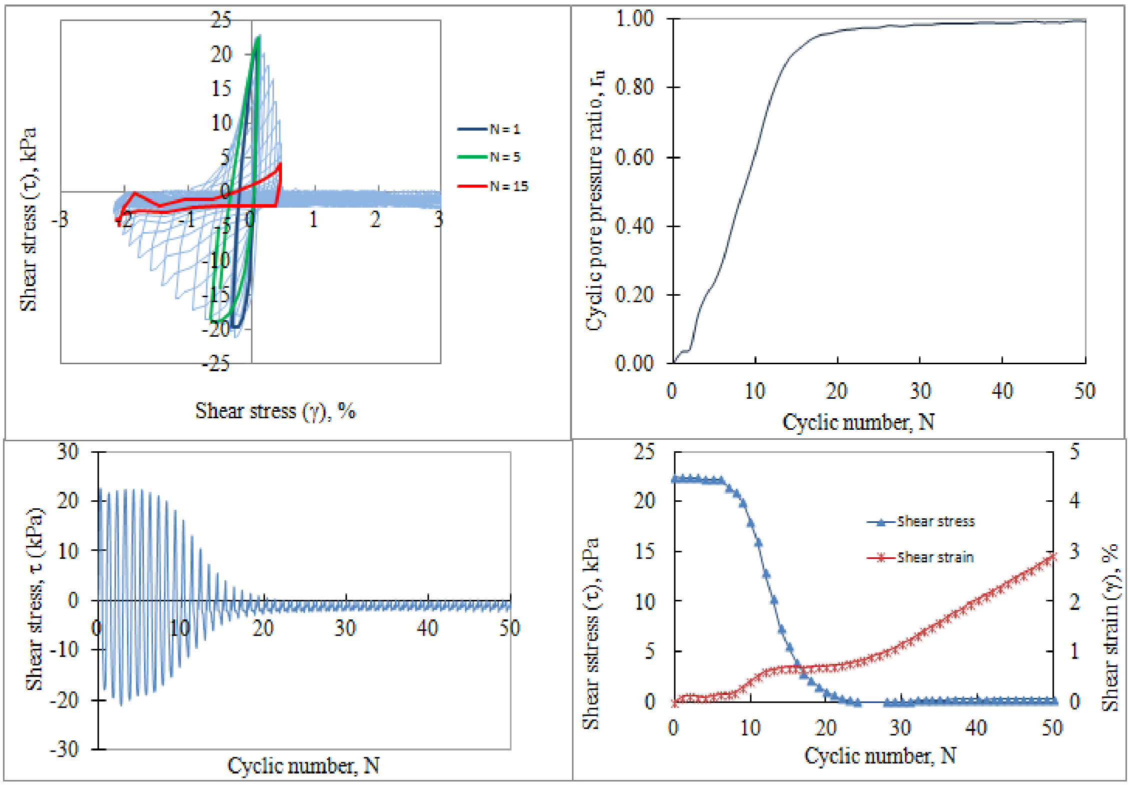

Figure 5. Sand sample TB18: Dr = 50.2%, σ_d = 50 kPa, f = 1Hz, σ'_c = 100 kPa

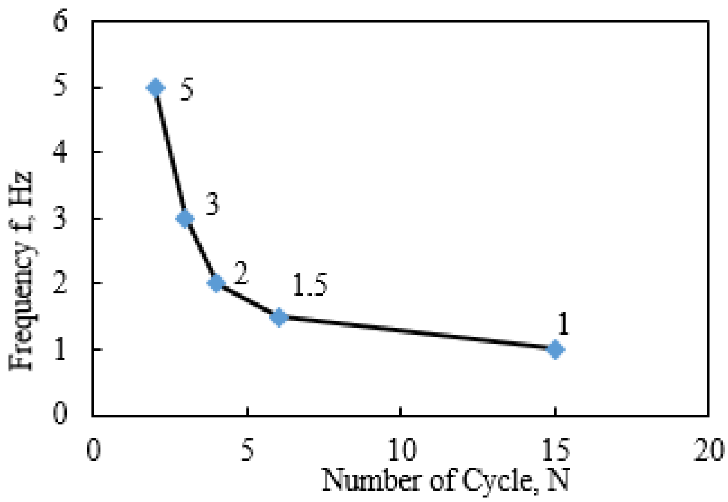

Figure 6. Relation between frequency and number of cycle

Table 3. Result with various confining values

Order	Sign Sample	Dried unit weight γ_w kN/m^3	Shear stress amplitude σ_d kPa	Frequency f Hz	Effective consolidation stress σ_C kPa	Liquefaction Cycle N	Pore water pressure r_u	Liquefiable
1	TB14	16.5	50	2	50	3	1	Yes
2	TB13	16.5	50	2	80	3	1	Yes
3	TB19	16.4	50	2	100	4	1	Yes
4	TB4	16.6	50	2	100	7	1	Yes
5	TB16	16.6	50	2	130	73	1	Yes
6	TB10	16.7	50	2	140	250	0.15	No
7	TB11	16.8	50	2	140	500	0.276	No
8	TB15	16.5	50	2	150	500	0.218	No
9	TB9	16.8	50	2	200	500	0.121	No
10	TB22	16.6	50	2	200	500	0.129	No
Yes is the same as Liquefaction				No is the same as Non - Liquefaction				

Oppositely, samples that were liquefied have exhibited abrupt decrease in shear stress, as well as cyclic resistance ratio (CRR). Shear deformation dramatically increased, which could reach 7-10%. The relation between deviatoric stress and the mean stress were non-linear. Also, the significant rise in pore water pressure were also observed, being of 1. At that time, sample started to entirely liquefy, as shown in Figure 5.

4.1. Influence of frequency

Experiments were conducted with frequency of 1Hz, 1.5Hz, 2Hz, 3Hz, and 5Hz respectively. Other parameters such as density, pressure amplitude, and confining stress remained constant as shown in Figure 2. Experiment results have showed that frequency has notably impact on the liquefaction possibility. The higher the frequency is, the less the cycle that is needed for liquefaction. Subsequently, liquefaction possibility of soil became higher in Figure 6.

Increment in frequency means the number of cycle in a time period also rises, which in turn causes pore water pressure to increase remarkably to a higher liquefaction potential.

4.2. Effect of effective consolidation stress

Seed and Lee (1966) indicated that the liquefaction resistance of saturated sand substantially depends upon the natural pressure state. In the cyclic triaxial apparatus, the primary pressure state was simulated by confining stress, which is the effectively consolidated pressure during the experiment process. Based on the results from 10 samples with various confining stress values, it could be seen that when confining stresses were higher, the liquefaction potential was lesser. It could be explained by the fact that when the effective consolidation stress is high, the density of soil is also greater, resulting in the increase in the liquefaction resistance of soil. Table 3 shows that, when the effective consolidation stress increases, the number of cycle needed to induce liquefaction also shoot up. With the effective consolidation stress value, higher than 140kPa, frequency of 2Hz, shear stress amplitude of 50kPa, the samples were non-liquefied, and deformation of samples were 0.1-0.4%, pore water pressure ratio ranged from 0.15-0.3.

5. Conclusion

Frequency, amplitude of cyclic stress, and effective consolidation stress are the primary parameters that markedly affect to the liquefaction potential of soil. Soils are easily liquefied under the high frequency condition.

For $aQ_2^3tb_1$ sand, when effective consolidation stress increases, the liquefaction resistance of soil could be improved. Under this condition, pore water pressure gradually increase which make it difficult to induce liquefaction. When effective consolidation stress is higher than 140kPa, soil is non-liquefiable. Natural stress condition greatly influence to liquefaction resistance of soil.

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