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Research on liquefaction resistance of fine sand distributing in Hanoi by density

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Abstract

The paper introduces the experimental results of potential liquefaction for fine sand in Hanoi area by using cyclic triaxial test. The results showed that it was possible to built up the liquefaction boundary and equation with empirical coefficients corresponding to the density was presented. In addition, sand liquefaction corresponding to the density was determined by Standard Penetration Test and empirical coefficients was also introduced. Through these results, the assessment of the sand liquefaction potential in practice would be done easily and smoothly.

Keyword: sand liquefaction; liquefaction boundary; cyclic triaxial; earthquakes in Hanoi

1. Introduction

Hanoi is located in the strong earthquake zone. In which, the fine sand distributed widely with the shallow depth and high thickness, particularly in the south and southwest of the city and along the Red River dike. These are also areas where the distribution depth of Holocene aquifer is only a few meters. Therefore, the risk of sand liquefaction is high during earthquakes. Currently, the study of this fine sand liquefaction is still limited, some experiments were conducted on recompacted specimens with a certain density but has not yet determined the effect of relative density (D_r) to the sand liquefaction potential. In fact, some authors also mentioned the application of how to assess the potential of sand liquefaction by the results of Standard Penetration Test (SPT). However, these applications also have not been fully evaluated yet for a particular area. The study of this fine sand liquefaction boundary and the relation between these results and actual density of the sand determined by SPT will be useful in the assessment of liquefaction conveniently and accordingly with the particular geological conditions.

2. The research results on the sand liquefaction potential by cyclic triaxial test

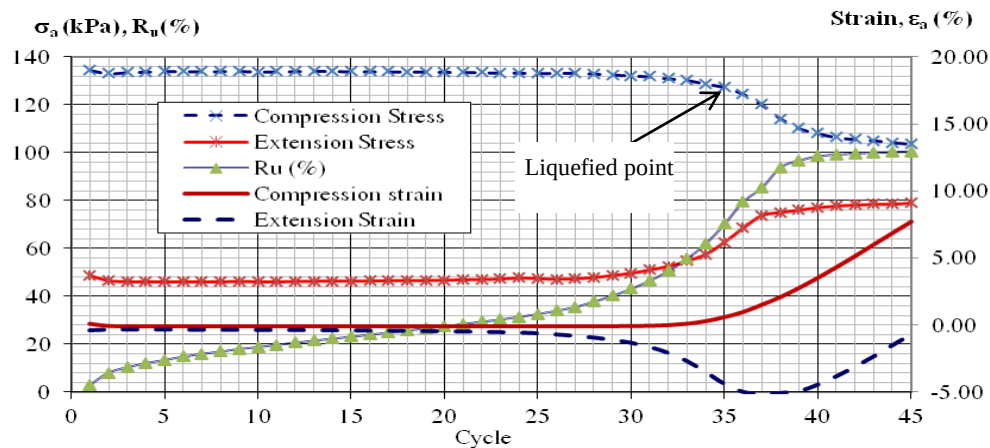
In the area of the south and southwest of Hanoi, the fine sand layer distributed popularly at the depth of 5m to 30m [1]. In order to study liquefaction potential of this sand, the samples were taken from an average depth of about 10 to 17m in the most popular distribution area, which is Lien Ninh commune, Thanh Tri district (sample C_1) and in the Southwest urban - Nam Tu Liem district (sample C_2). The grain composition and properties of this sand are shown in Table 1.

Testing equipment is Tritex 100 made by Controls - Group (Italy). The experimental procedure for determination of sand liquefaction was done in accordance with ASTM - D5311. Accordingly, the specimens were prepared by pouring and tamping method (according to the required density) in a mold (70x140mm), saturated by backpressure (σ_b) and consolidated with the cell pressure (σ_3).

Table 1. Experimental results of grain composition and physical indicators of the studied samples

Soil type		The content of the particle size (mm)					Specific weight γ_s (g/cm ³)	Pore ratio	
		2-1	1-0,5	0,5-0,25	0,25-0,1	<0,1		e_{min}	e_{max}
C1	Fine sand	0,1	0,2	11,1	75,2	13,5	2,66	0,605	0,992
C2	Fine sand	-	2,0	7,0	83,0	8,0	2,66	0,652	1,008

The specimens were tested with different amplitude of cyclic loads (method A) and experimental frequency is 2Hz. Based on experimental results, we could build the graphs of stress, strain and the pore pressure ratio versus cycles (figure 1). The liquefied point is determined based on the analysis of these graphs, the point where pore water pressure ratio $R_u = 100\%$ and dramatically change appearance of stress and strain (stress drops suddenly, strain increase dramatically).

Fig.1. The variation of the stress, strain and R_u in the sand liquefaction (C₂-2)

Parameters and test results are shown in Table 2 [3], in which there are seven tests (C₁) tested in relative density $D_r = 0.53 \pm 0.02$; two tests (C₂-2 and C₂-4) in the density of 0.35 and three tests (C₂-1, C₂-3, C₂-5) with $D_r = 0.26 \pm 0.01$. The liquefied boundaries were built on chart of CSR - t_d (CSR is the cyclic stress ratio, t_d is the time of liquefaction) based on the experimental points corresponding to each relative density D_r and showed on Figure 2 and Figure 3 (dashed line).

Table 2. Summary of liquefaction experiments

Test No.	Wet density γ (g/cm ³)	Relative density D_r	Cell pressure σ_3 (kPa)	Amplitude of stress σ_a (kPa)	CSR	Liquefied Cyclics	Liquefied Time (s)
C ₁ -8	1,84	0,53±0,02	100	21	0,32	389	194,5
C ₁ -7	1,84		100	22	0,33	350	175,0
C ₁ -6	1,81		100	20	0,35	150	75,0
C ₁ -1	1,85		100	28,5	0,43	35	17,5
C ₁ -5	1,86		100	30	0,53	21	10,5
C ₁ -3	1,81		100	30	0,65	16	8,0
C ₁ -2	1,82	0,35	100	35	0,63	15	7,5
C ₂ -2	1,81		180	44	0,25	35	17,5
C ₂ -4	1,82	0,26 ± 0,01	180	50	0,28	23	11,5
C ₂ -1	1,78		180	49	0,28	8	4
C ₂ -3	1,78		180	40	0,22	26	13
C ₂ -5	1,78		180	35	0,19	96	48

The result of the built-up experimental liquefaction boundary is useful for the assessment of the sand liquefaction with the density corresponding to experimental density. However, the sand density changes in reality and has been evaluated by SPT, so the application of this results has certain limitations.

3. The expression of liquefaction boundary and the change rules of empirical coefficients

For the convenience of applying research results in practice, the liquefaction boundary should be represented by the mathematical expression [2] as:

$$t_d = b \cdot \frac{\arccot \sqrt{\frac{CSR_{gh}}{a} - 1}}{\sqrt{\frac{CSR_{gh}}{a} - 1}} \quad (1)$$

In which, t_d is the time to reach liquefied state; CSR_{gh} is cyclic stress ratio caused liquefaction; a is the coefficient of shear angle; b is the coefficient of cyclic collapse time. The coefficients a and b are determined based on the experimental points on the $CSR - t_d$ graph (figure 2 and 3). Theoretically, a and b can be determined based entirely on empirical 2 points.

Equation (1) describes the liquefaction boundary and is completely determined if the coefficients a and b are known.

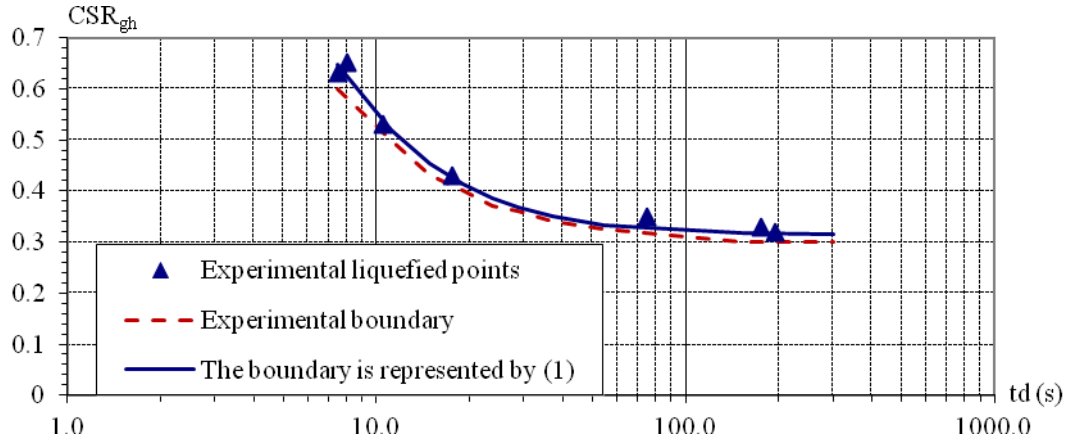


Fig.2. Liquefaction boundaries of fine sand at $D_r = 0,53 \pm 0,02$ (C_1)

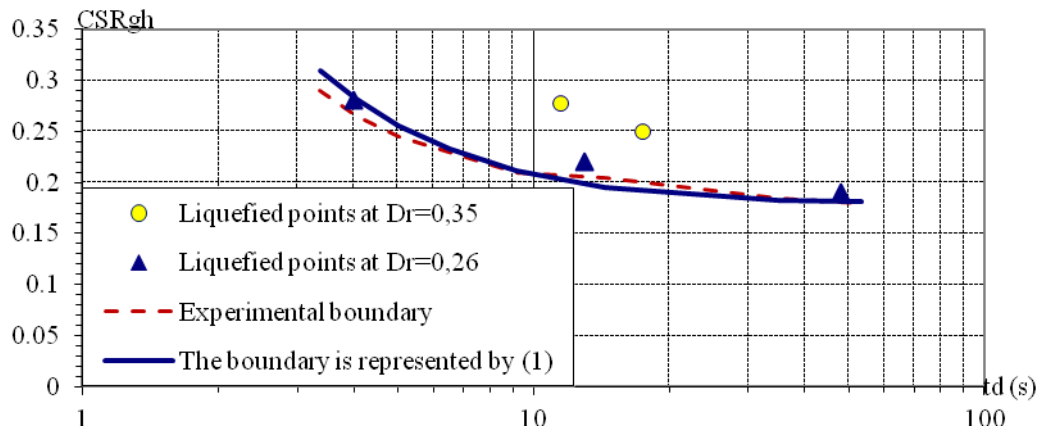


Fig.3. Liquefaction boundaries of fine sand at $D_r = 0,35$ and $0,26 \pm 0,01$

The coefficients a and b for three liquefaction boundaries corresponds to three D_r were identified based on the experimental points in Figure 2 and 3. The results are summarized in Table 3.

In order to enhance the efficiency of research results, assuming two sand samples (C_1 , C_2) have the same grain composition (fine sand) and ignoring the influence of the cell pressure, thereby determining the change rules of the coefficient (a , b) with D_r and shown in Figure 4. Using this chart, it is easy to determine the coefficients a and b with any density in the range of $0,26 \leq D_r \leq 0,53$. That means it is able to identify

liquefaction boundary or expression (1) if known D_r .

Table 3. Summary of identifying empirical coefficients

Soil type		Cell pressure (kPa)	Density D_r	Empirical coefficients	
				b (s)	a
C ₁	Fine sand	100	$0,53 \pm 0,02$	10	0,315
C ₂	Fine sand	180	0,35	5	0,221
			$0,26 \pm 0,01$	3,5	0,185

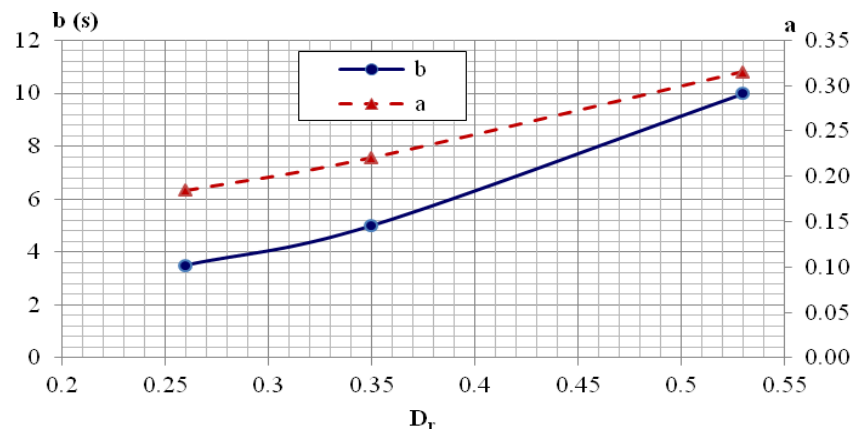


Fig.4. The variation of the coefficients a, b with D_r

In fact, the density of sand is usually determined based on the results of SPT. Therefore, the coefficients a and b as well as the sand liquefaction boundary can be identified based on D_r received from SPT. The results are summarized in Table 4 and Figure 5 are useful information for the assessment of sand liquefaction.

Table 4. The coefficients a and b determined by SPT values

SPT	Relative density D_r	a	b (s)
6	0,26	0,18	2,82
8	0,30	0,19	3,71
10	0,33	0,21	4,59
12	0,36	0,23	5,48
14	0,40	0,25	6,36
16	0,43	0,26	7,25
18	0,46	0,28	8,13
20	0,50	0,30	9,02
22	0,53	0,31	9,90

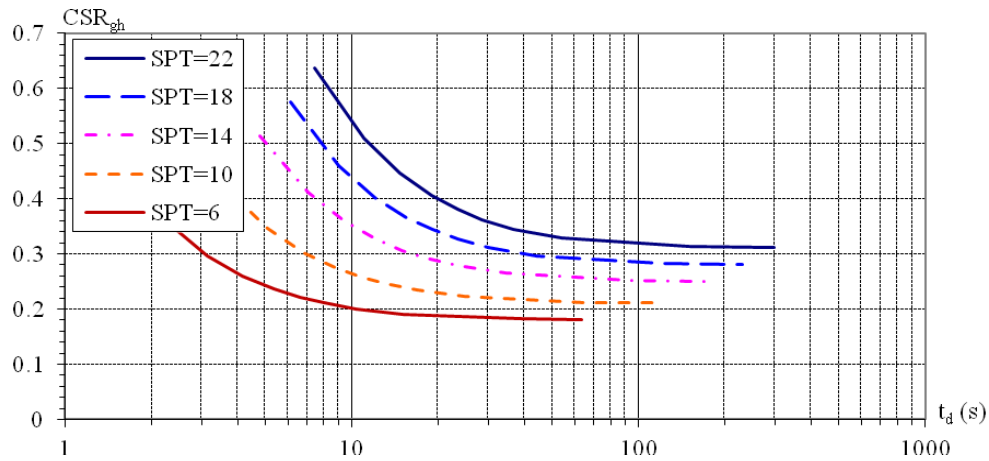


Fig.5. The boundaries of fine sand liquefaction corresponding SPT values

4. Conclusions and Recommendations

The minimum of cyclic stress ratio could cause sand to liquefy is: $CSR = 0.185$ with $D_r = 0.26$ and $CSR = 0.315$ with $D_r = 0.53$; and these values are respectively $CSR = 0.205$ and $CSR = 0.53$ if the earthquake lasts for 10 seconds.

The rule of sand liquefaction under dynamic load is represented by the liquefaction boundary and can be described by equation (1) with the empirical coefficients a and b . These coefficients are determined based on the experimental liquefaction point.

The coefficients a and b of the studied sand change proportionally to the density D_r (see Fig. 4). The analysis of this relationship helps identifying the sand liquefaction boundaries corresponding to each D_r value.

The research results are applied in practice by using SPT values and the data in Table 4 and Figure 5 to evaluate the possibility of the sand liquefaction in specific conditions.

It is necessary to have further research to determine the effect of particle size and the cell pressure to the sand liquefaction with a sufficiently large number of samples to enhance the reliability of research results.

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