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Effect of Compaction on Liquefaction of River and Sea Sand in Hai Phong City, Vietnam

C.L. Nguyen [1], Q.P. Nguyen[2], H.H. Nguyen[3] and D.M Nguyen[4]

[1]*Geotechnical Engineering, University of Transport and Communications, Hanoi, Vietnam*

[2]*Civil Engineering Faculty University of Transport and Communications, Hanoi, Vietnam*

E-mail: nguyenchaulan@utc.edu.vn, nguyenquangphuc@utc.edu.vn, haihaqd@ utc.edu.vn , ndmanh@utc.edu.vn @utc.edu.vn

ABSTRACT: Haiphong city is situated on the north-eastern coast of Vietnam. This city has a large coastal and sea area, which is advantage for marine economic development. However, in order to reclamation the coastal area, river sand material is much demand which lead to face some environmental problems due to exploitation of river sand. Thus, the intensive laboratory experiments were conducted including physical, chemical and mechanical tests of river sand and sea sand to evaluate the potential use of sea sand in road embankment in Haiphong city. The samples were prepared by compacting to value of 90% and 95% of maximum density defined by the Standard Proctor test. Consolidated undrained cyclic triaxial tests were conducted for sea sand samples and river sand samples. The cyclic triaxial test results showed that all samples are not liquefied under normal vehicle conditions which corresponding to cyclic deviator stress about of 8 kPa and frequency of 1Hz. In addition, sea sand samples were not liquefied when increasing the compaction effort to 95% of maximum density. Therefore, it is possible to use sea sand instead of river sand in some cases for reclamation land in Haiphong area.

Keywords: dynamic properties, road embankment, CU triaxial test, liquefaction

1. INTRODUCTION

Earth quakes and traffic loading are the most sources of cyclic loading which may trigger the liquefaction of granular material. Liquefaction characteristic of granular soil was studied carefully under the earthquake load condition. There are several methods to determine the liquefaction which including laboratory testing or based on the simple data from the field such as Standard Penetration Test (N1 or (N1)60) , Cone Penetration Test (CPT), and relied on experience from the earthquake occurred during the past (Ishihara, 1977; Bolton, M. and Ignacio, 1983; P. and J., 1995; Jakka, Datta and Ramana, 2010; Y. and J., 2014).

The primary aim of this study is to determine the liquefaction capacity of the sea sand and river sand samples at density corresponding to 90% and 95 % of maximum dry density.

A series of undrained cyclic triaxial tests were conducted for sea sand and river sand samples which were taken in Hai Phong city area. These tests were considered the effect of compaction, frequency, amplitude and stress ratio to study the dynamic characteristic of sand fill in loading condition due to vehicle loading.

2. MATERIALS AND METHODS

2.1 Material

The sea sand and river sand material are taken from Hai Phong city. The characteristic of materials is shown in Table 1. The sea sand and river sand samples are prepared by compacting to reach the compaction density of 90% and 95% of maximum dry density. Compaction ratio is defined of ratio between dry density for prepared sample and maximum dry density which were conducted by Standard Proctor test. The maximum dry density was from 1.584 to 1.644 g/cm^3 and from 1.651 to 1.713 g/cm^3 for sea sand and river sand, respectively.

Table 1 Initial characteristic of sand sample

No.	Group of Sample	Sample	Compaction Ratio (R)	$\gamma_{d\,max}$ g/cm^3	γ_s g/cm^3	Note
1	S04	B01	0.95	1.644	2.58	Sea sand
2		B02	0.90	1.644	2.58	
3		B03	0.95	1.644	2.58	
4	S01	B04	0.90	1.631	2.58	
5		B05	0.90	1.631	2.58	
6		B06	0.90	1.631	2.58	
7	S02	B07	0.90	1.584	2.57	
8		B08	0.90	1.584	2.57	
9		B09	0.90	1.584	2.57	
10	S06	B10	0.95	1.584	2.57	Sea sand
11		B11	0.95	1.584	2.57	
12		B12	0.95	1.584	2.57	
13	S03	B13	0.95	1.655	2.675	
14	S05	B14	0.90	1.597	2.675	
15	S01	B15	0.95	1.682	2.675	
16	S03	B16	0.95	1.635	2.670	
17	S04	B17	0.95	1.676	2.674	
18	S05	B18	0.95	1.676	2.658	
19	S06	B19	0.95	1.645	2.669	
20	S07	B20	0.95	1.649	2.670	
21	RS-S01		0.95	1.651	2.590	River sand
22	RS-S02		0.90	1.713	2.570	
23	RS-S03		0.90	1.681	2.590	

2.2 Method of undrained cyclic triaxial test

2.2.1. Cyclic Triaxial equipment

The cyclic Triaxial test was conducted at Laboratory of Geotechnical Engineering Department, Hanoi University of Mining and Geology. The name of equipment for cyclic triaxial test is Tritech 100 from Controls – Group Italia. The advanced of the machine is following:

- ✓ This equipment can determine in both the static condition (effective stress and stress line) and cyclic condition.
- ✓ It remedies automatically the back pressure/ cell pressure during cyclic triaxial test
- ✓ Maximum control frequency is 10 Hz (based on test condition)
- ✓ Two load option/ dynamic deformation
  - Maximum is ±25 mm with ±5 kN double-effect actuator
  - Maximum is ±15 mm with ±14 kN double-effect actuator

2.3.1. Testing preparation.

Samples with 70 mm in diameter and 140 mm in height, were compacted with optimal moisture content to ensure that the sample were reached the density ratio corresponding with 90% and 95% of maximum dry density. All samples were conducted in undrained condition accordance to ASTM D 5311-92-1996.

2.3.2. Testing procedure.

The samples were tested by the cyclic triaxial test and listed in Table 2. The sample goes through into 3 steps: saturation process, consolidation process and after finish consolidation steps, the vale is closed to ensure that no water dissipated during the loading process. In the final step, the sample was subjected dynamic loading by acting the cyclic load with different amplitude of shear strain and changing frequency. During the test, pore water pressure, cell pressure, axial strain and axial stress will be read and noted continuously. The testing procedure is illustrated as below:

- **Saturation method step**: Using back pressure (σ_{back}) of 90 kPa and cell pressure σ_{cell} of 100 kPa
- **Consolidated step:** The sample is consolidated with cell pressure (σ_{cell}) of 170 kPa; back pressure (σ_{back}) of 130 kPa and the effective stress (σ_3') of 40 kPa.
- **Shearing step:** Dynamic loading will be applied

Table 2 The cyclic triaxial test for samples

Sample	Freq (f)	Cell pressure σ_3 (kPa)	Back pressure σ_b (kPa)	Eff stress σ'_c (kPa)	Stress amplitude (kPa)	Cyclic stress Ratio CSR
B01	1	170	130	40	32	0.4
B02	1	170	130	40	24	0.3
B03	1	170	130	40	16	0.2
B04	1	170	130	40	8	0.1
B05	1	170	130	40	16	0.2
B06	1	170	130	40	24	0.3
B07	1	170	130	40	8	0.1
B08	2	170	130	40	8	0.1
B09	3	170	130	40	8	0.1
B10	1	170	130	40	8	0.1
B11	2	170	130	40	8	0.1
B12	3	170	130	40	8	0.1
B13	1	170	130	40	16	0.13
B14	1	170	130	40	16	0.1
B15	1	170	130	40	16	0.2
B16	3	170	130	40	16	0.13
B17	8	170	130	40	16	0.1
B18	1	170	130	40	24	0.16
B19	3	170	130	40	24	0.2
B20	8	170	130	40	24	0.2
RS-S01	1	170	130	40	8	0.1
RS-S02	1	170	130	40	8	0.1
RS-S03	1	170	130	40	16	0.13

2.3.3. Type of testing

The cyclic triaxial test was conducted with two types of samples including sea sand samples (B01-B20) and 3 river sand samples (**RS- S01** to **RS- S03**). To study the failure mechanism of sea sand sample, the several dynamic loading tests were conducted with difference amplitude (8-12kPa), corresponding to the maximum value that can be reached for fill embankment location at 1.5 depth which is below pavement surface. The dynamic loading caused by vehicle is calculated according Vietnamese standard as shown equation below:

$\Delta\sigma_a = \alpha.P_x = 0.5$ x16 = 8 kPa

where:

- α : loss dynamic stress factor from road surface to the sand layer at 1.5m depth with $\alpha = 0.5$
- Px: calculated vehicle loading, Px is taken as 16 kN/m^3

Thus, the effect of stress amplitude and frequency were considered with the following conditions:

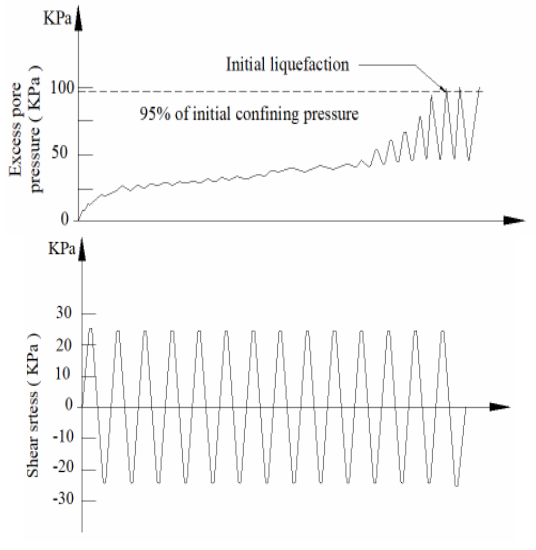
- Effect of stress amplitude on liquefaction:
  - ✓ Samples B1-B6 and Frequency f= 1Hz
  - ✓ Change of Stress amplitude range: 8± 32(kPa)
- Effect of frequency on liquefaction:
  To determine the stability of material when the vehicles moving on the road with difference speed with change of frequency but stress amplitude remains constant.
  - ✓ Frequency f (Hz) = 1-8 Hz
  - ✓ Change of Stress amplitude $\Delta\sigma_a = \pm 8$(kPa)

The shear strength of sand when liquefied is evaluated by conducting cyclic triaxial test in undrained test condition. In this test, the sand sample is saturated and consolidated under constant cell pressure and amplitude repeated stresses until the sample is deformed, or the pore water pressure reaches similar value with initial cell pressure. In this state, the sample can be considered at unstable dynamic state, and then the liquefaction occurred. Normally, the liquefaction phenomena can be determined by 2 ways (Figure 1):

(1) The increase of pore water pressure reaches 95 % of initial stress,

(2) or (2) The development of large deformation, are described with amplitude corresponding with 5% of axial strain.

For establishing the liquefaction of specific sample (up to 95% pore water pressure or 5% amplitude axial strain), the number of cycles must be indicated in one specify case with the uniform dynamic loading amplitude. It is noted that to reach the liquefaction stage corresponding to the 95 % of pore water pressure ratio and 5% of axial shear strain could not occur at the same time, then two separate curves can be drawn.



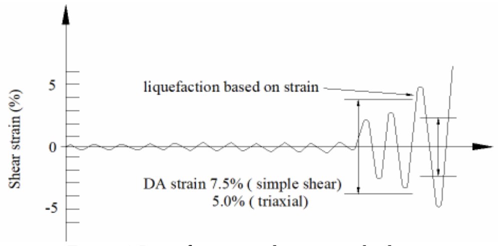


Figure 1 Liquefaction evaluation method

3. RESULTS AND DISCUSSION

3.1 Physical properties of sand

Figure 2 shows particle size distribution of sea sand and river sand. It is observed that the particle sizes of river sand samples are larger than those of sea sand samples.

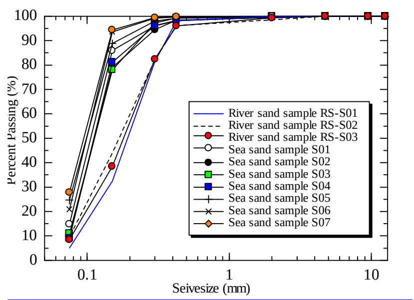


Figure 2 Particle size distribution of sea sand and river sand samples (S01 to S07 are group name of sea sand samples, see in Table 1)

3.2 Effect of stress amplitude on liquefaction capacity

To study the failure mechanism of sea sand sample, the number of dynamic loading tests were conducted with difference amplitude (8-12kPa), corresponding to the maximum value that can be reached for fill embankment location at 1.5 depth which is below pavement surface.

In case of amplitude value increasing from 8 to 32 kPa with the frequency (f) of 1Hz, the results are presented in Fig. 3 to 8. From Table 3, conclusions are given following:

- ✓ Samples with R95 are not liquefied even the sample B01 having the large vibration amplitude of 32 kPa.
- ✓ Samples with R90 are not liquefied even the sample B04 having the vibration amplitude of 8 kPa.

However, it is observed that the sea sand samples were liquefied for R90 samples at amplitude of 16 and 24 kPa (see Figure 7 and 8).

Table 3: Test result of various amplitude

Sample	Density index	f (Hz)	σ_a (kPa)	Ru	Comment
B01	0.95	1	32	77.5	Not liquefied
B02	0.90	1	24	95.0	Liquefied
B03	0.95	1	16	21.0	Not liquefied
B04	0.90	1	8	13.5	Not liquefied
B05	0.90	1	16	100.0	Liquefied
B06	0.90	1	24	100.0	Liquefied

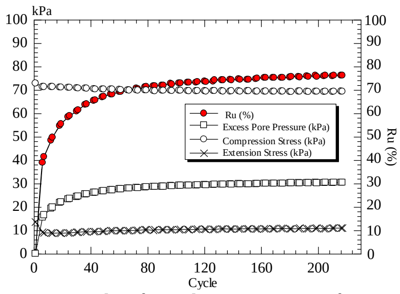


Figure 3: Test results of sample B01, SR = 0.4; f = 1HZ, stress amplitude σ_a =32 kPa

Comment [ln1]: Đường mầu xanh bên dưới bị lỗi
Ngoài ra đường ký hiệu em cho thưa ra (khoảng cách giữa dấu tròn hoặc dấu tam giác cho thưa ra)

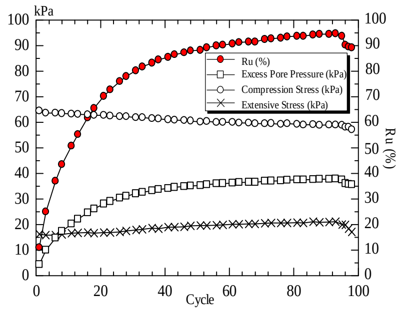


Figure 4: Test results of sample B02, SR = 0.3; f = 1HZ, stress amplitude σ_a =24 kPa

Comment [ln2]: Đường màu xanh bị lỗi

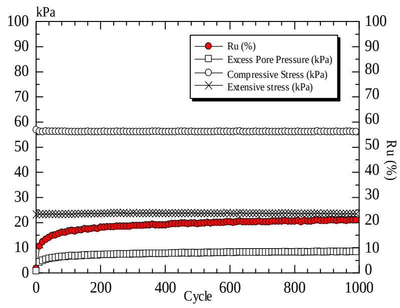


Figure 5: Test results of sample B03, SR = 0.2; f = 1HZ, stress amplitude σ_a = 16kPa

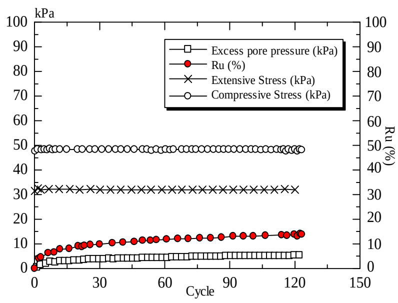


Figure 6: Test results of sample B04, SR = 0.1; f = 1HZ, stress amplitude σ_a = 8 kPa

Comment [ln3]: Vẽ lại theo phần mềm

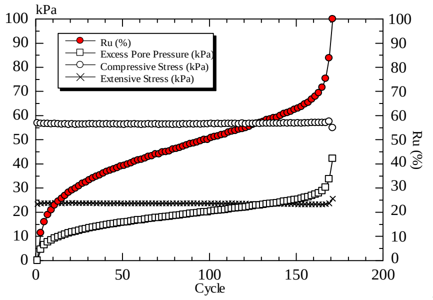


Figure 7: Test results of sample B05, SR = 0.2; f = 1HZ, stress amplitude σ_a = 16 kPa

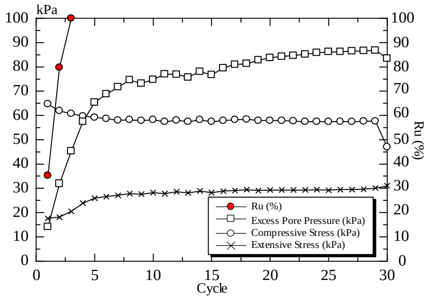


Figure 8: Test results of sample B06, SR = 0.3; f = 1HZ, stress amplitude σ_a = 24 kPa

3.2 Effect of frequency on liquefaction capacity

The vibration amplitude is remained constant in this case, to study vehicles capacity moving on the road with difference velocity, the frequency f will be changed to check the liquefaction capacity corresponding to the samples having R90 and R95. The test results in this case are shown from Figure 9 to Figure 24.

From the test results shown in Table 3 and 4, it is clear that in the case of the amplitude remained constant to 8 kPa, the frequency varies from 1 to 3 Hz, the pore pressure ratio is less than 95%, all the sea sand samples are not liquefied.

Table 4: Test result in case of different frequency of vehicles

Sample	Density index	f (Hz)	σ_a (kPa)	R_u	Comment
B07	0.90	1	8	4.5	Not liquefied
B08	0.90	2	8	4.0	Not liquefied
B09	0.90	3	8	74.3	Not liquefied
B10	0.95	1	8	13.0	Not liquefied
B11	0.95	2	8	13.3	Not liquefied
B12	0.95	3	8	17.0	Not liquefied
B13	0.95	1	16	100.0	Liquefied
B14	0.90	1	16	100.0	Liquefied
B15	0.95	1	16	100.0	Liquefied
B16	0.95	3	16	100.0	Liquefied
B17	0.95	8	16	41.5	Not liquefied
B18	0.95	1	24	100	Liquefied
B19	0.95	3	24	68	Not liquefied
B20	0.95	8	24	100	Liquefied

Table 5: Test result for river sand

Sample	Density	f (Hz)	σ_a (kPa)	Stress ratio	R_u	Comment
RS-01	0.95	1	8	0.1	32	Not liquefied
RS-02	0.9	1	8	0.1	8.25	Not liquefied
RS-03	0.90	1	16	0.2	60	Not liquefied

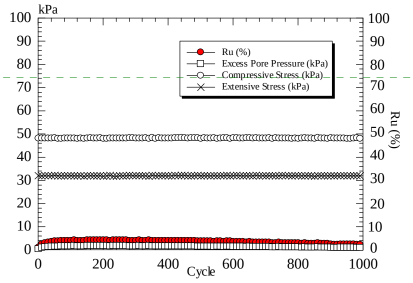


Figure 2: Test results of sample B07, f = 1 HZ, R90

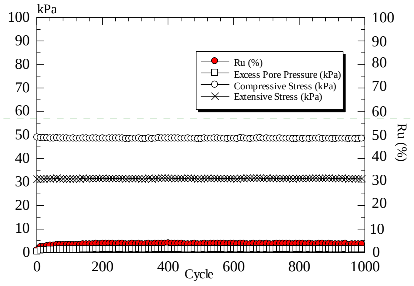


Figure 3: Test results of sample B08, f = 2 HZ, R90

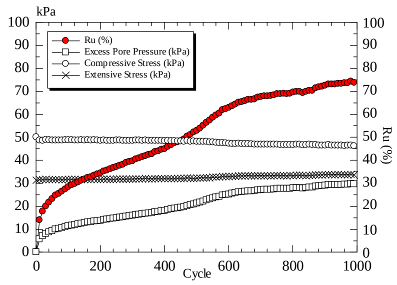


Figure 4: Test results of sample B09, f = 3 HZ, R90

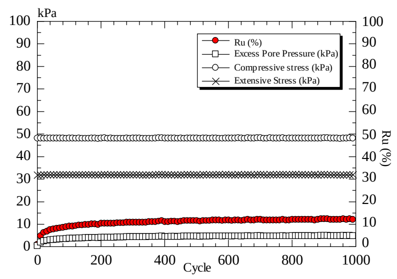


Figure 5: Test results of sample B10, f = 1 HZ, R95

Comment [ln4]: Đường màu xanh bị lỗi

Comment [ln5]: Đường xanh lá cây bị lỗi

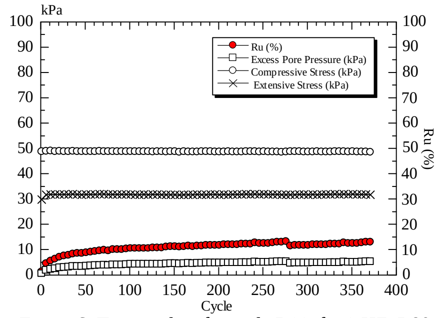


Figure 6: Test results of sample B11, f = 2 HZ, R90

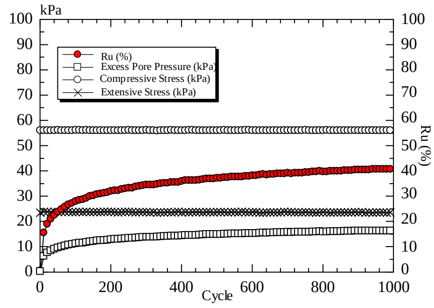


Figure 10: Test results of sample B15, f = 1 HZ, R95, Amplitude 16 kPa

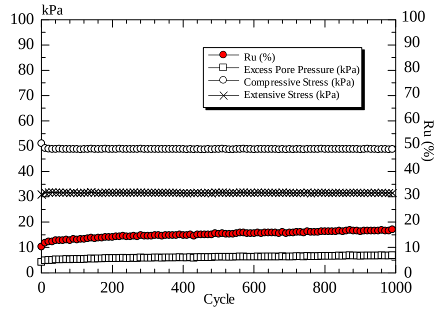


Figure 7: Test results of sample B12, f = 3 HZ, R95

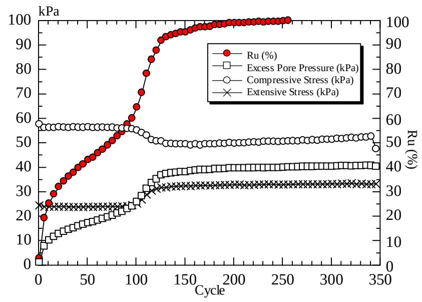


Figure 11: Test results of sample B16, f = 3 HZ, R95, Amplitude 16 kPa

Comment [ln7]: Đường màu trắng và xanh nước biển bị lỗi

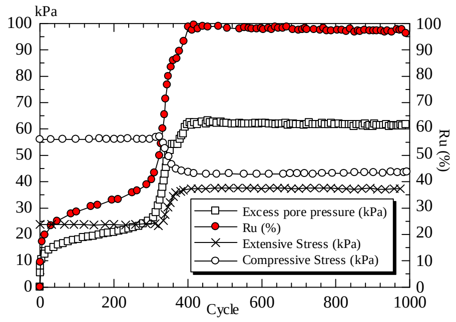


Figure 8: Test results of sample B13, f = 1 HZ, R95

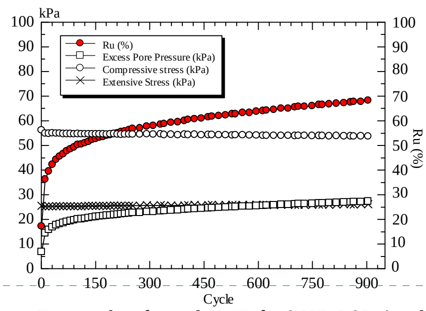


Figure 12: Test results of sample B17, f = 8 HZ, R95, Amplitude 16 kPa

Comment [ln6]: Vẽ lại theo phần mềm

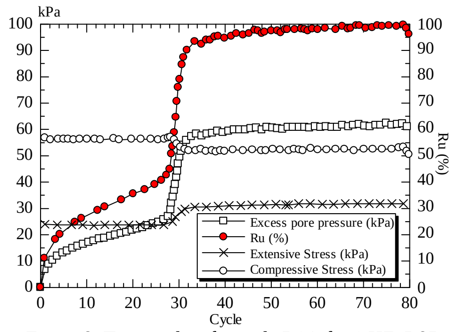


Figure 9: Test results of sample B14, f = 1 HZ, R95

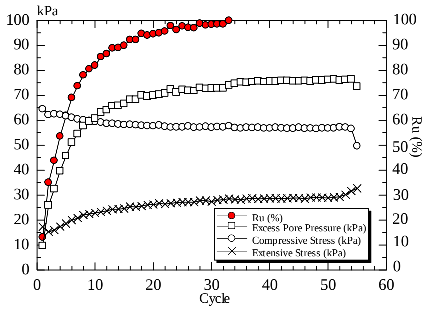


Figure 13: Test results of sample B18, f = 1 HZ, R95, Amplitude 24 kPa

Comment [ln8]: Lỗi đường màu trắng, xanh

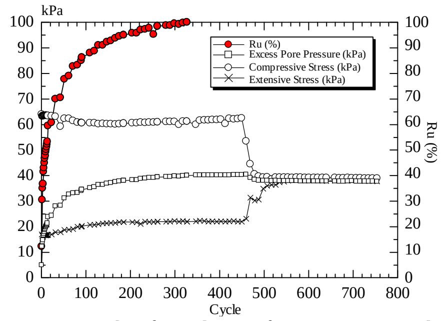


Figure 14: Test results of sample B19, f = 3 HZ, R95, Amplitude 24 kPa

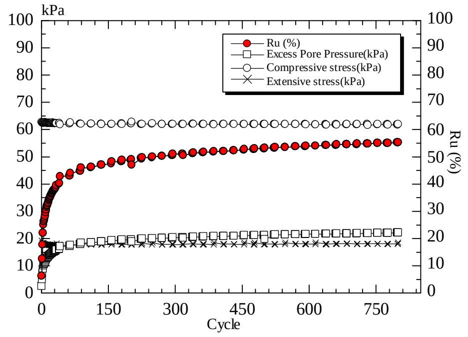


Figure 15: Test results of sample B20, f = 8 HZ, R95, Amplitude 24 kPa

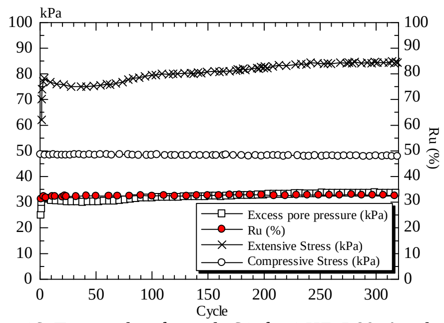


Figure 16: Test results of sample S1, f = 1 HZ, R90, Amplitude 8 kPa

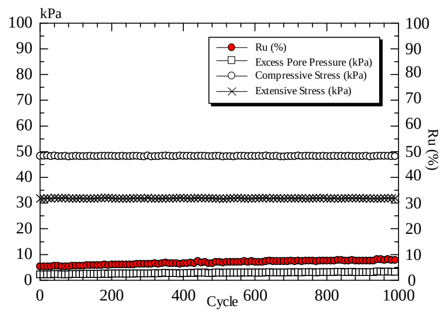


Figure 17: Test results of sample S2, f = 1 HZ, R90, Amplitude 8 kPa

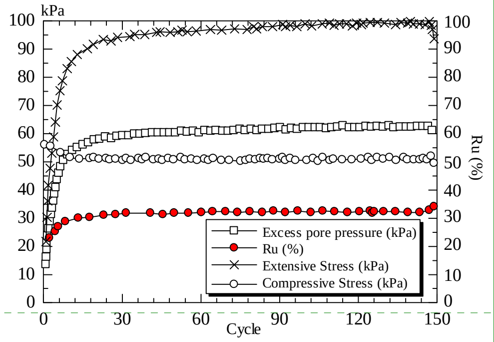


Figure 18: Test results of sample S3, f = 1 HZ, R90, Amplitude 16 kPa

3.3 Comparison of test results between sea sand and river sand.

Sea sand and river sand samples are compared based on the cylic triaxial test results which corresponding to frequency of 1HZ and density ratio of R90, and R95.

From the test results shown in Table 4 and Table 5, some discussions are given as below.

- All sea sand and river sand samples were not occur liquefied under normal condition of vehicle moving on the road (With stress amplitude (σ_a) of 8 kPa and frequency (f) of 1Hz)
- River sand samples could be subjected under condition that the vibration amplitude is twice higher than those in normal condition of vehicle moving on the road.
- Sea sand samples are liquefied when the vibration amplitude is twice higher than those in normal condition of vehicle moving on the road.

Liquefaction state are occurred corresponding to some conditions:

- Sample with R90 and vibration amplitude of 16 kPa
- Sample with R90 and R95 and the stress value is of 16, 24 kPa for B13, B14, B15 and B18 samples.

Thus, in the case of embankment having compaction ratio larger than 95% corresponding to normal amplitude or the value of amplitude is twice higher than normal conditions, the embankment will not occur liquefaction state. Therefore, sea sand material can be used to replace for river sand to fill embankment.

4. CONCLUSION

Based on the test results, conclusions are drawn following:

- All of sea and river sand samples are not liquefied under normal vehicle moving condition (f-1Hz; stress amplitude σa = 8 kPa).
- Sea sand samples are liquefied under the vibration amplitude is twice higher than normal condition of vehicle moving
- It is recommended that in case of embankment having compaction ratio R90 and R95, the embankment will not be liquefied under normal amplitude value (σa = 8 kPa).
- Thus, the sea sand can be used to replace river sand for embankment fill.

Comment [ln9]: Lỗi hình màu xanh

Comment [ln11]: Dung phần mềm

Comment [ln10]: Lỗi hình

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