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Approximate Experimental Simulation of Clogging of Pervious Concrete Pile Induced by Soil Liquefaction during Earthquake

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Reference

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ABSTRACT

It has been reported by previous studies that the pervious concrete pile (PCP) has the advantages of high permeability and strength as a novel ground-improvement technology. However, during an earthquake, the liquefied soil particle is bound to migrate into the PCP under the excess pore water pressure because of dynamic stress. This leads to the clogging of PCP. In this study, a permeability test system for an approximate simulation of this clogging is presented. The experimental results obtained by employing this system were reported and validated. In order to gain insight into the clogging caused by earthquake, the effects of the porosity on pervious concrete were evaluated. Clogging that accounted for the acceleration peak, the frequency, and the duration of vibration were characterized. The thickness of the impervious layer of ground surface and the pile spacing on the clogging were studied as well. Results show that within the scope of this study, the clogging of PCP is significantly related to the aforementioned factors. In addition to the thickness of the impervious soil layer, the clogging becomes more obviously with the increase of the other five factors. However, the overlarge values of some factors, such as the porosity of pervious concrete, the acceleration peak, and the frequency/duration of vibration, cannot obviously aggravate the clogging of pervious concrete. Based on the experimental evidence, a preliminary dynamic clogging model is proposed, which is helpful for the design of PCP composite foundation.

Keywords

pervious concrete pile, clogging, permeability, earthquake

Introduction

The composite foundation technology, as a widely applied technology, can be used to enhance the bearing capacity of foundations and to reduce the settlement and liquefaction potential of the ground, according to Haldar and Babu,[1] and Ariyarathne, Liyanapathirana, and Leo.[2] Generally, vertical reinforcement of composite foundations can be divided into granular pile and rigid pile. In previous studies by Hughes and Withers,[3] Poorooshasb and Meyerhof,[4] Lee and Pande,[5] and Pinto and Rodrigues,[6] it has been found that granular pile is able to accelerate the rate of consolidation as well as reduce the liquefaction potential of sand or silt ground through higher permeability, which enables pore water to enter into the pile instead of accumulating in the soils and causing soil liquefaction. However, granular pile has a relative low stiffness and strength, which is also greatly influenced by the confining pressure of the surrounding soil according to Guetif, Bouassida, and Debats.[7] Thus, when granular pile is applied to soft clay or organic or peat soil, the shallow part of this pile is prone to expansion failure, and thus the bearing capacity of the ground sees little improvement. As to rigid pile such as low-grade concrete pile or cement fly-ash grave pile, it has the potential to overcome the weak bonding problem of granular pile based on the research by Yu, Huang, and Zhang,[8] Sariosseiri and Muhunthan,[9] Le Hello and Villard,[10] and Jia et al.,[11] but with poor permeability, which results in a slow ground consolidation rate.

Based on the above, an innovative ground improvement method using pervious concrete pile (PCP) was proposed by Suleiman, Raich, and O'Loughlin.[12] Because pervious concrete (also referred to as porous concrete) is a mixture of portland cement, gap-graded aggregate, and water with/without a small amount of fine aggregate, there is a large number of connective pores within the aggregate skeleton. Generally, the porosity of pervious concrete is between 15 and 25 %, and the permeability is typically between 2 and 6 mm/s, or even as high as 10 mm/s according to Pieralisi, Cavalaro, and Aguado,[13] Montes, Valavala, and Haselbach,[14] and Luck et al.[15] With high permeability, pervious concrete can also provide a compressive strength between 3.5 and 28 MPa, as detailed in the study by Schlüter and Jefferies.[16] Therefore, PCP has fast drainage and high bearing capacities, that is to say it has the advantages of both granular pile and rigid pile, according to Zhang et al.[17] Its fast drainage capacity can accelerate the dissipation of excess pore water pressure, thus consolidating the subsoil and the postconstruction settlement of upper construction such as road embankments. However, it is inevitable that PCP will suffer from vibration loads during its life cycle and cause soil liquefaction, such as in the following cases:

(1) When installing the vibrating sinking tube for PCP, silt sand or silt liquefaction often occurs. These silts facilitate PCP clogging by migrating fine soil particles into fresh concrete pile.
(2) During an earthquake, soil liquefaction can also cause PCP clogging.
(3) When PCP is used to reinforce the foundation of large machines, the vibration of the machine can also lead to PCP clogging.

In the literature (Kia, Wong, and Cheeseman,[18] Zhou et al.,[19] Brown and Borst,[20] Deo, Sumanasooriya, and Neithalath,[21] Haselbach, Valavala, and Montes,[22] Haselbach,[23] Reddi et al.,[24] and Kayhanian et al.[25]), a number of studies on clogging of permeable materials are available in regard to other drainage projects, such as gravel and pervious concrete. As with PCP, prefabricated vertical drain (PVD) is also used to accelerate the consolidation process, thus rapidly increasing the strength and stiffness of soil. Nevertheless, PVD clogging is also unsolved. For example, surrounding the PVD, fine soil particles may become entrapped within the fibers of the filter (i.e., the geotextile), which results in the clogging of filter sleeve pores, a reduction of PVD's discharge capacity, and the obstruction of the consolidation process (this is according to Rollin and Lombard,[26] and Basu and Madhav[27]).

To our knowledge, the PCP clogging due to vibration-induced soil liquefaction has not been given full attention yet until now, although the issue of clogging has been questioned since the technique of PCP was first proposed. Therefore, this study focuses on the approximate experimental simulation of PCP clogging caused by soil liquefaction during the postconstruction period. Herein, a clogging simulation system of pervious concrete under vibration load is developed. Using this new test setup, a series of laboratory simulation tests are conducted to demonstrate the effects of several important factors in PCP clogging.

Simulation Clogging Test

BASIC ASSUMPTIONS OF THE TEST

In order to approximately simulate the clogging of PCP under earthquake load, the assumptions in this study are addressed as follows:

(1) Thin piles with small spacing are good for the consolidation of soil. Thus, we chose micropiles with a 20-cm diameter and spacing of 40 to 80 cm to simulate PCP-drained piles in this work.
(2) We only simulate the free field reinforced by PCP without considering the effects of upper buildings.
(3) We choose shallow soil for this simulation work because it liquefies more easily than deep soil.
(4) The soil specimens are derived from the shallow layer of the newly deposited soil around the Jinan Yellow River Bridge of China. Because of the incomplete dissipation of the excess pore water pressure, we assume that the excess pore water pressure is 2 kPa in this soil.

CLOGGING SIMULATION SYSTEM

When the pores of PCP are clogged, the permeability is bound to decrease. In this study, a clogging simulation–coupled permeability measurement system is developed, see figure 1. Its functions mainly are: (1) to avoid leakage on the pervious concrete specimen sidewalls during tests by using waterproof daub and flexible rubber cushion;[28] (2) to approximately simulate the clogging induced by vibration; (3) to continuously record the changing processes of the permeability before and after clogging. Test procedures will be described in the latter section.

The soil column and pervious concrete specimen in figure 1 are equal to the zone in the red frame shown in figure 2 (a clockwise rotation of 90°). The height of the pervious concrete specimen is equal to the radius of the PCP, and the height of the soil column is equal to half of the pile spacing minus the pile radius. In figure 2, h_{in} is the height of the water inlet, h_{out} is the height of the water outlet, Δh is the water head difference, which represents the excess pore water pressure of underconsolidated foundation at a certain depth before the earthquake. In the test, Δh is 0.2 m, and the corresponding excess pore water pressure is 2 kPa.

In figure 2, the left side in the red frame is on a symmetrical plane, A-A, and no water flows through the symmetrical plane. To prevent the dissipation of excess pore water pressure during an earthquake, the thin circular rubber pad is placed on the surface of the soil column in the test; meanwhile, in order to ensure the water head difference (Δh) is constant during the clogging simulation test, there is a clearance of 2.5 mm between the edge of rubber pad and the sleeve wall.

In the test, the horizontal vibration is simulated by the vibration table, and the waveform of vibration is sine wave.

Test Material

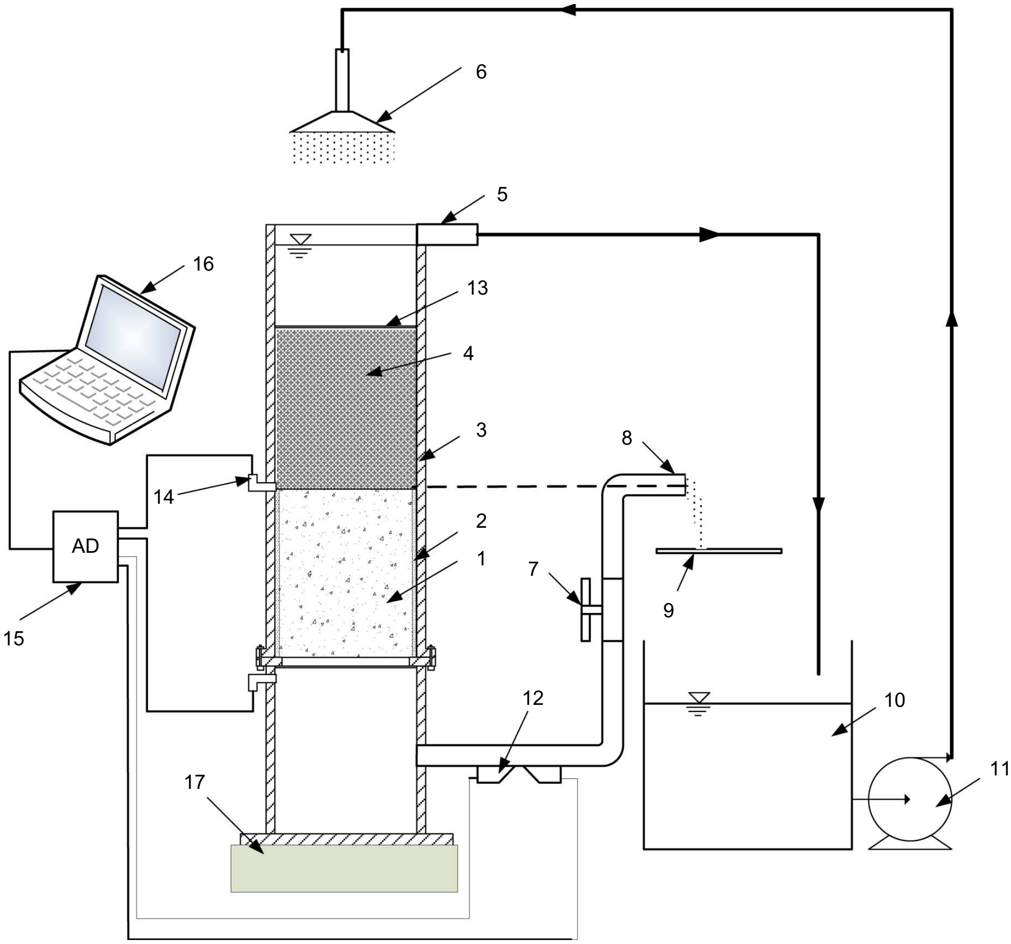
PERVIOUS CONCRETE

Pervious concrete mixtures are prepared using ordinary portland cement and coarse aggregates. Physical properties of this aggregate are presented in Table 1. Five target porosities (15, 17.5, 20, 22.5, and 25 %) are designed for the pervious concrete in this work, and the mix design method was originally proposed by Cui et al.[28] The mass proportions of pervious concrete are given in Table 2. The number of specimens needed to achieve the whole study were cast in 100×100 mm^2 cylindrical molds. Moreover, it is worth mentioning that sulphamate series super plasticizer was chosen to decrease water usage, thus ensuring good fluidity of the cement paste.

SOIL

According to Kishida,[29] the grading curve of soil used in this study is in the range of liquefiable soil, see figure 3. The nonuniform coefficient C_u of this soil is 5.43, so it is not piping soil.

FIG. 1 Diagram of the clogging simulation and permeability test system: 1. Pervious concrete sample; 2. Vaseline and rubber cushion; 3. Plexiglass sleeve; 4. Soil column; 5. Overflow (height adjustable); 6. Sprinkler; 7. Valve; 8. Outflow; 9. Filter; 10. Water container; 11. Pump; 12. Ultrasound wave flow meter; 13. Rubber cushion; 14. Pressure sensor; 15. Data acquisition system; 16. PC; 17. Vibration table.



Test

TEST PROCEDURE

Using our homemade clogging simulation system, the clogging tests of pervious concrete are carried out according to the following procedures:

(1) Tests on the initial permeability of pervious concrete.
After demolding, pervious concrete specimens were cured for 7 days in a standard curing room and then immersed in water for 24 hours, which helps specimens tend become fully saturated. Prior to being placed inside the plexiglass sleeve, the sample while in a surface dry state was glued with petroleum jelly and then jacked inside the flexible rubber cushion and fastened by the mounting bolts (see fig. 1). A pump was used to provide the required pressure to spray the water into the plexiglass sleeve, with valve 7 closed. When the water depth reached 10 cm with no bubble emission, valve 7 was opened. Once the water flow was stable, the permeability of a specimen could be measured by the head pressure and flow velocity. The average of the permeability of the last 10 minutes in Step 1 is regarded as the initial permeability of pervious concrete.

FIG. 2 Diagram of the simulated foundation.

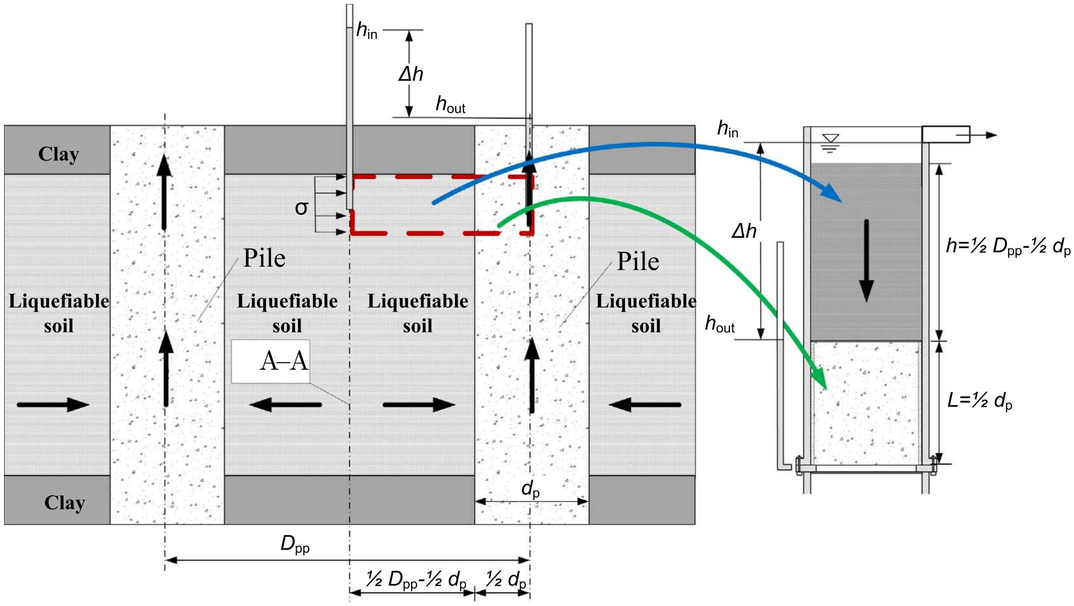


TABLE 1
Physical properties of aggregates in pervious concretes in this work

Size (mm)	Apparent Density (g/cm^3)	Stacking Density (g/cm^3)	Porosity (%)	Crushed Value (%)
4.75–9.5	.665	1.655	37.89	8.6

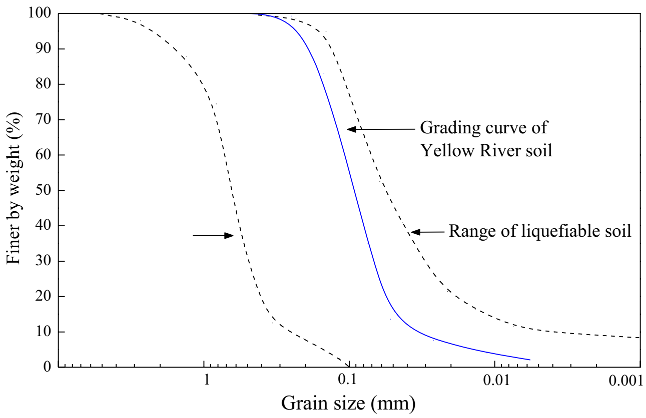
TABLE 2
Mix proportions per cubic meter of pervious concrete

Target Porosity (%)	Cement (kg/m^3)	Water (kg/m^3)	Aggregate (kg/m^3)	Water Reducer Dosage (%)
15	335	121	1,622	0.8
20	262	94		
25	189	68		

(2) Tests of clogging simulation during earthquake.
Firstly, the saturated soil was poured on top of the pervious concrete specimen to the desired height. After immersion in water for 8 hours, the soil specimen became completely consolidated and was then covered with the rubber pad and subjected to pump pressure to ensure a Δh of 20 cm. After experiencing a stabilization period of 10 minutes, the valve was opened just as mentioned above. When the stable water flow was available, the vibration was simulated by the vibration table (again, see fig. 1). At the end of the designated time, the vibration table was turned off. After the water flow became stable again, the valve was closed and the test stopped.
(3) Testing the permeability of the clogged specimen.
Following the simulation of vibration, the soil column and the pervious concrete specimen were disassembled from plexiglass sleeve (Location 3 in fig. 1); meanwhile, soil particles were also removed from the surface of the pervious concrete specimen. After this, they were placed in the plexiglass sleeve again,

FIG. 3

Gradation curve of Yellow River alluvial soil.



preparing for the measurement of clogged permeability by following the procedure described in Step 1. The average of the permeability of the last 10 minutes in Step 3 is regarded as the permeability of the pervious concrete after earthquake.

TEST CASES

As shown in Table 3, 24 test cases were proposed for studying the effect of pervious concrete porosity and the pile spacing on the clogging process. To be specific, five porosity (15∼25 %) and pile spacing (40∼80 cm) measurements were chosen, respectively. In addition, according to the height of the soil column, the pile spacing was 2, 2.5, 3, 3.5, and 4 times its diameter.

According to GB/T 17742-2008, *The Chinese Seismic Intensity Scale*, five acceleration peaks of vibration (1.5, 2.0, 3.0, 4.0, and 5.0 m/s^2) were selected to simulate the acceleration of an earthquake (see Table 4). To study the effect of the frequency of vibration on clogging, four frequencies of sine waves (5∼20 Hz) were chosen based on the statistics of the frequency of seismic wave. Of course, the duration of vibration is also a vital factor for the liquefaction of soil. So, five durations (5∼30 s) were investigated in this work. In addition, the effect of the thickness of the upper impervious layer on the clogging of PCP was also considered. Impervious layers were simulated by four iron blocks on the rubber cushion (Location 13 in fig. 1). The iron blocks prepared for this test measured 10 cm in diameter and 2∼12 cm in height (equivalent to 5∼30 cm impervious layer).

Results and Analyses

Figure 4 shows the permeability-time relationship of the pervious concrete specimens before and after earthquake simulation of Case 1. The result reflects the typical variation characteristics of the continuously recorded permeability during tests. It can be seen from figure 4 that for the permeability value both before and after an earthquake, there is a sharp increase at the beginning that then stabilizes at the second stage. The reason for the increase of permeability at the initial stage is that the water flow is unstable when Valve 7 is opened, which was described in the test procedure in the "Test Procedure" section. Once the water flow became stable, the permeability also stabilized, which is shown as the second stage in figure 4. In order to compare and analyze the permeability of pervious concrete before and after earthquake, a ratio of permeability before and after earthquake is used and defined as the normalized permeability (NP).

In this study, the excess pore pressure ratio from the study by Wang, Luna, and Yang[30] is used to describe the degree of soil liquefaction:

TABLE 3
Test cases

Case	Porosity of Pervious Concrete (%)	Height of Soil Column (cm)	Thickness of Impervious Layer (cm)	Acceleration Peak of Vibration (m/s^2)	Frequency of Vibration (Hz)	Duration of Vibration (s)
1	15	10	0	3.0	10	20
2	17.5	10	0	3.0	10	20
3	20	10	0	3.0	10	20
4	22.5	10	0	3.0	10	20
5	25	10	0	3.0	10	20
6	20	15	0	3.0	10	20
7	20	20	0	3.0	10	20
8	20	25	0	3.0	10	20
9	20	30	0	3.0	10	20
10	20	10	0	1.5	10	20
11	20	10	0	2.0	10	20
12	20	10	0	4.0	10	20
13	20	10	0	5.0	10	20
14	20	10	0	3.0	5	20
15	20	10	0	3.0	15	20
16	20	10	0	3.0	20	20
17	20	10	0	3.0	10	10
18	20	10	0	3.0	10	15
19	20	10	0	3.0	10	25
20	20	10	0	3.0	10	30
21	20	10	5	3.0	10	20
22	20	10	10	3.0	10	20
23	20	10	15	3.0	10	20
24	20	10	30	3.0	10	20

TABLE 4
Part of the seismic intensity table of China

	Damage Degree of Building		Horizontal Motion on the Ground	
Intensity	Damage Degree	Average Index of Damage	Maximum Acceleration (m/s^2)	Maximum Velocity (m/s)
VII	Light	0.11–0.30	1.25 (0.90–1.77)	0.13 (0.10–0.18)
VIII	Moderate	0.31–0.50	2.50 (1.78–3.53)	0.25 (0.19–0.35)
IX	Heavy	0.51–0.70	5.00 (3.54–7.07)	0.50 (0.36–0.71)

$$r_u = 1 - \frac{\sigma'}{\sigma'_0} = 1 - \frac{\sigma - (u_0 + u_d)}{\sigma'_0} \tag{1}$$

where σ is the total stress, σ'_0 is the initial vertical effective stress, σ' is the vertical effective stress, u_0 is the static pore water pressure, and u_d is the dynamic pore water pressure.

According to the principle of effective stress, when $\sigma' = 0$, namely $r_u = 1$, the soil is wholly liquefied. However, the engineering practice indicates that the soil liquefaction can happen when r_u is not up to 1.

Figure 5 shows some time history curves of the dynamic pore water pressure. It can be seen that r_u increases with the decrease of pervious concrete porosity, shown in **figure 5*A***. This is because smaller porosity may induce larger pore water pressure. By contrast, the increase of the acceleration peak and vibration frequency can increase pore water pressure because of the dynamic impacts.

FIG. 4 Time history curves of the permeability before and after earthquake simulation test in Case 1.

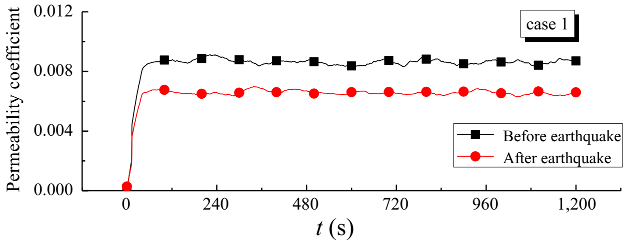
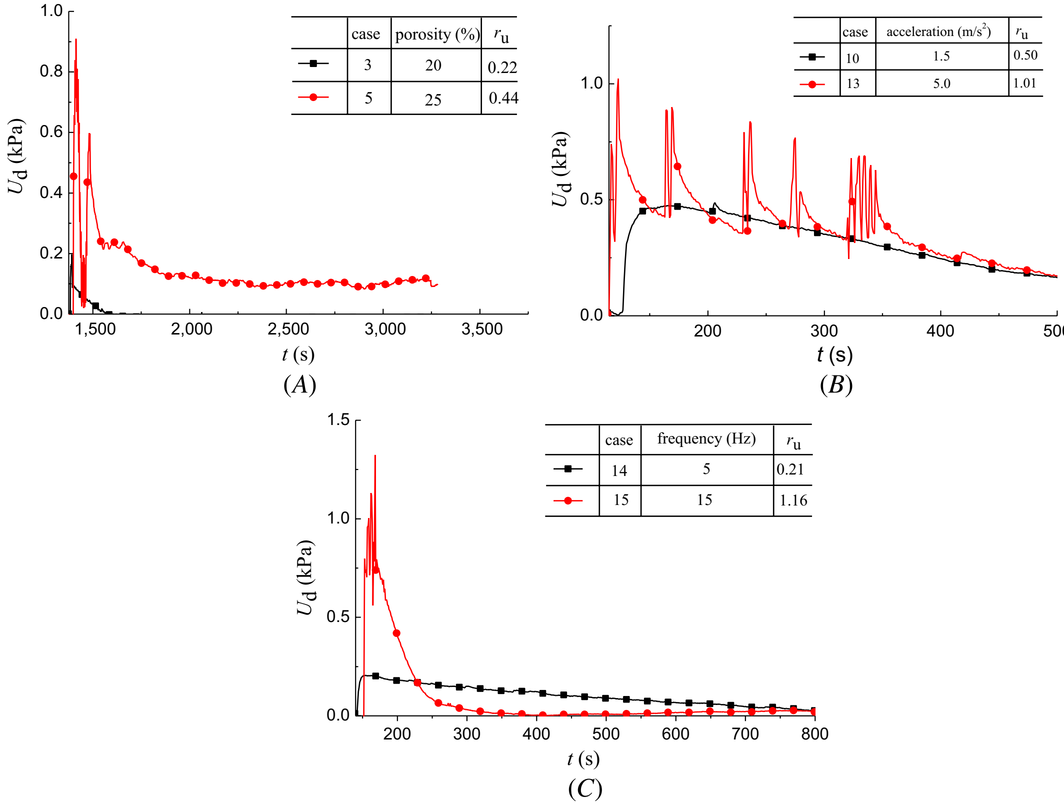


FIG. 5 Time history curves of the dynamic pore water pressure. (*A*) Porosity effect; (*B*) acceleration effect; (*C*) frequency effect.



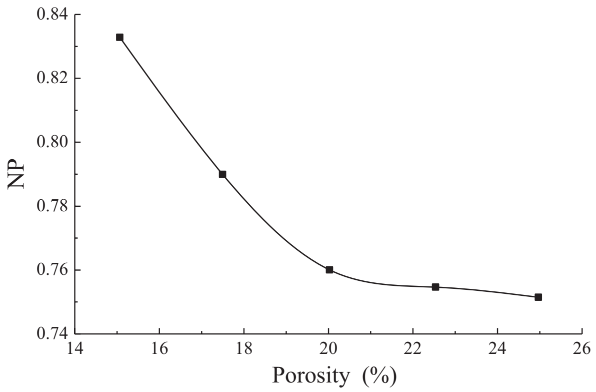
EFFECT OF PERVIOUS CONCRETE POROSITY ON CLOGGING

Figure 6 shows the variation curves of the NP of the pervious concrete with different porosities (Cases 1–5). It is not difficult to find that the bigger the porosity of pervious concrete is, the more severe the vibration-induced clogging is. The phenomenon relates to the rise of the excess pore water pressure induced by variation and the liquefaction of soil (flow state). Moreover, when the porosity of the pervious concrete increases, the suspending soil particles can migrate into the pervious concrete more easily, which induces many soil particles to clog the narrow portion of the pore channel ("pore throat") in pervious concrete.

Compared with a porosity of 15–20 %, the variation of NP is not obvious for the range of 20–25 %. This is due to the difference of the clogging mechanism between large pores and small pores. In the case of small porosity, the

FIG. 6

Variation curve of the NP with porosity.



clogging is generally considered to be a consequence of the blocking of surface channel by soil particles in pervious concrete, whereas in the case of large porosity, there is little resistance for soil particles in the large pore channel, and the clogging mainly occurs in the "pore throat," thus leading to stable permeability of pervious concrete.

EFFECT OF PILE SPACING ON CLOGGING

As mentioned above, the height of the soil column reflects the spacing of PCP. The relation between NP and the height of the soil column (Cases 3, 6–9) are plotted in figure 7. It can be observed that NP decreases notably with increasing pile spacing. This is because small pile spacing normally shares less soil volume than large pile spacing. So, the probability that soil particles migrate into the pervious concrete is minor when the pile spacing is smaller. This coincides with practical engineering: the PCP with smaller spacing has higher drainage efficiency and thus decreases the possibility of soil liquefaction as well as PCP clogging.

EFFECT OF THE VIBRATION ACCELERATION PEAK ON CLOGGING

The variation curves of NP with the vibration acceleration peak (Cases 3, 10–13) are shown in figure 8. It can be seen that the variation of NP differs with the seismic intensity. Firstly, in the seismic intensity range of VII, the clogging of PCP is not severe, and the decrease of drainage ability is not dramatic. Then, with the seismic intensity increasing from VII to VIII, the effect of acceleration peak is profound. The rapid decrease of NP represents the acceleration of clogging in PCP. However, in the seismic intensity range of IX, the soil liquefies completely, so

FIG. 7

Variation curve of NP with the height of soil column.

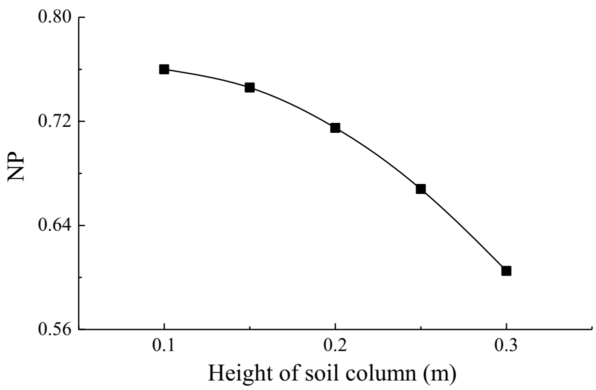
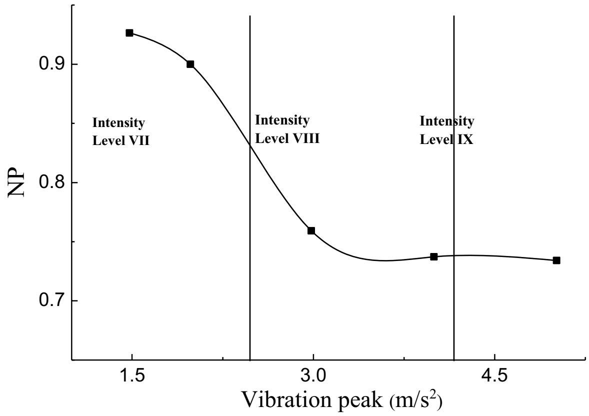


FIG. 8

Variation curve of the NP with the vibration acceleration peak.



the NP of pervious concrete reaches a relatively stable state, which reveals that the increase of acceleration has the most significant effect on PCP clogging.

EFFECT OF VIBRATION FREQUENCY ON CLOGGING

Figure 9 shows the change of NP with increasing frequency of vibration (Cases 3, 14–16). It is obviously that the PCP clogging gets more severe with increasing vibration frequency of up to 15 Hz. When vibration occurs beyond this value, the variation of NP becomes slow.

For the low frequency of vibration, there is enough time to dissipate the vibration-induced excess pore water pressure and even to mitigate the liquefied soil to some degree. On the other hand, the higher frequency makes the excess pore water pressure increase too fast to dissipate timely, which leads to the soil liquefying quickly. Or rather, when the soil is liquefied completely, the clogging of PCP is no longer sensitive to the increase of frequency.

EFFECT OF THE VIBRATION DURATION ON CLOGGING

The clogging of PCP is sensitive to the vibration duration within 20 seconds, as shown in figure 10. It can be interpreted as the increase of excess pore water pressure and the liquefaction of soil with increasing vibration time. However, after 20 seconds, the soil completely liquefies and the excessive duration of vibration cannot lead to the sustainable development of clogging.

FIG. 9

Variation curve of the NP with the frequency of vibration.

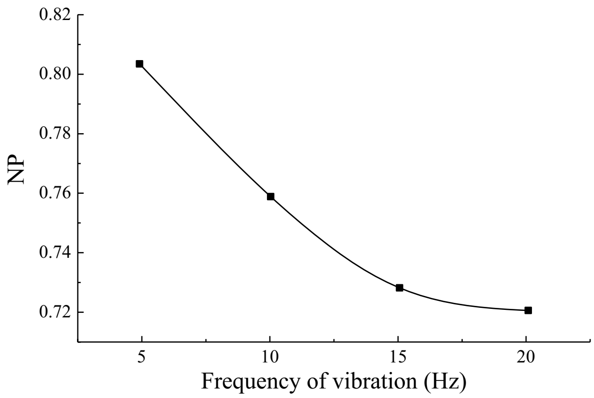
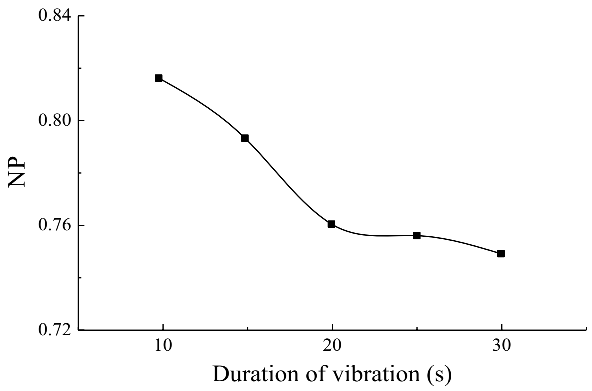


FIG. 10

Variation curve of the NP with the duration of vibration.



EFFECT OF THE THICKNESS OF IMPERVIOUS LAYERS ON CLOGGING

The thickness of impervious layers reflects the magnitude of confining pressure. Figure 11 shows that NP increases with the thickness of the impervious layer, which indicates that the clogging is more likely to happen in the shallow part of PCP. This is because the smaller the confining pressure is, the more easily the liquefaction happens.

VIBRATION-INDUCED CLOGGING MODEL OF PERVIOUS CONCRETE

Vibration-induced clogging is related to factors as follows:

$$k = f(k_0, P, D_{pp,} T_s, A, F, D, d_p, g) \tag{2}$$

where k is the permeability after clogging, and k_0 is the initial permeability; P is the porosity of pervious concrete; D_{pp} is the pile spacing; T_s is the thickness of the impervious layers; A is the vibration acceleration peak; F is the frequency of vibration; D is the duration of vibration; d_p is the pile diameter; and g is the acceleration of gravity.

We normalize the two sides of equation (2):

$$\frac{k}{k_0} = F\left(P, \frac{D_{pp}}{d_p}, \frac{T_s}{d_p}, \frac{A}{g}, F\sqrt{\frac{d_p}{g}}, D\sqrt{\frac{g}{d_p}}\right) \tag{3}$$

The normalized variables in equation (3) are shown in Table 5.

FIG. 11

Variation curve of the NP with the thickness of impervious layers.

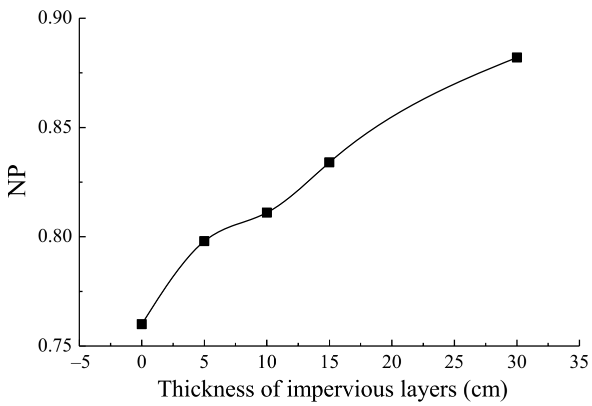


TABLE 5
Normalized variables in clogging tests

Case	k/k_0	P	$\frac{D_{pp}}{d_p}$	$\frac{T_s}{d_p}$	$\frac{A}{g}$	$F\sqrt{\frac{d_p}{g}}$	$D\sqrt{\frac{g}{d_p}}$
1	0.883	15.0	2.0	0.00	0.30	1.414	141.421
2	0.789	17.5	2.0	0.00	0.30	1.414	141.421
3	0.759	20.0	2.0	0.00	0.30	1.414	141.421
4	0.753	22.5	2.0	0.00	0.30	1.414	141.421
5	0.751	25.0	2.0	0.00	0.30	1.414	141.421
6	0.742	20.0	2.5	0.00	0.30	1.414	141.421
7	0.715	20.0	3.0	0.00	0.30	1.414	141.421
8	0.667	20.0	3.5	0.00	0.30	1.414	141.421
9	0.602	20.0	4.0	0.00	0.30	1.414	141.421
10	0.925	20.0	2.0	0.00	0.15	1.414	141.421
11	0.902	20.0	2.0	0.00	0.20	1.414	141.421
12	0.735	20.0	2.0	0.00	0.40	1.414	141.421
13	0.731	20.0	2.0	0.00	0.50	1.414	141.421
14	0.803	20.0	2.0	0.00	0.30	0.707	141.421
15	0.729	20.0	2.0	0.00	0.30	2.121	141.421
16	0.721	20.0	2.0	0.00	0.30	2.828	141.421
17	0.818	20.0	2.0	0.00	0.30	1.414	70.711
18	0.791	20.0	2.0	0.00	0.30	1.414	106.066
19	0.755	20.0	2.0	0.00	0.30	1.414	176.777
20	0.749	20.0	2.0	0.00	0.30	1.414	212.132
21	0.798	20.0	2.0	0.25	0.30	1.414	141.421
22	0.811	20.0	2.0	0.50	0.30	1.414	141.421
23	0.834	20.0	2.0	0.75	0.30	1.414	141.421
24	0.882	20.0	2.0	1.50	0.30	1.414	141.421

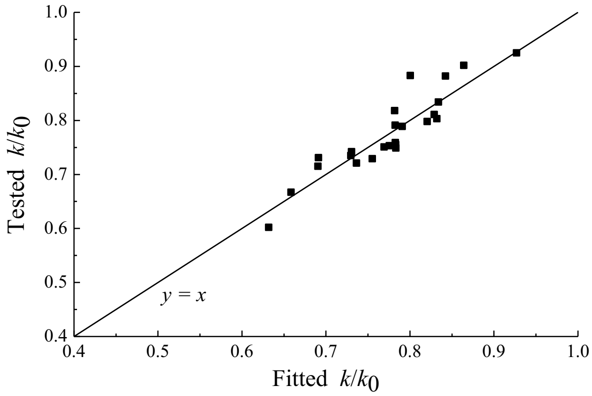
Using the regression analysis method, we can establish the relationship among the normalized variables, as shown in equation (4), with $r^2 = 0.94$ (r is the correlation coefficient).

$$\frac{k}{k_0} = \mathrm{NP} = p^{-0.33}\left(\frac{D_{\mathrm{PP}}}{d_{\mathrm{p}}}\right)^{-0.19}\left(\frac{T_{\mathrm{S}}}{d_{\mathrm{p}}}\right)^{-0.23}\left(\frac{A}{g}\right)^{-0.09}\left(F\sqrt{\frac{d_{\mathrm{p}}}{g}}\right)^{-0.07}\left(D\sqrt{\frac{g}{d_{\mathrm{p}}}}\right)^{0.03} \tag{4}$$

Figure 12 shows the fitting effect of the regression equation. It can be seen that the fitted values agree well with the tested value. With equation (4), engineers can approximatively estimate the permeability reduction of soil

FIG. 12

The relationship between tested and fitted k/k_O.



around PCPs after clogging. However, the applicability of this empirical relation proposed in equation (4) beyond the range of tests is not warranted.

Conclusions

In this study, a permeability test system was developed to approximately simulate the clogging of pervious concrete induced by soil liquefaction during earthquake. This system was used to conduct some experimental tests to study effects of pervious concrete porosity, the acceleration peak, the duration and frequency of vibration, as well as pile spacing on this clogging. Based on the test results, a preliminary dynamic clogging model was proposed, which will be helpful for engineers to estimate the permeability of PCP after an earthquake and the design of PCP composite foundation. The following conclusions were drawn as follows:

(1) The increase of the porosity, acceleration peak, frequency, duration of vibration, and pile spacing can cause a decrease in the permeability of the clogged pervious concrete, whereas the thickness of the upper impervious soil layer has a limited effect on the permeability of the clogged pervious concrete.
(2) The overlarge values of some factors, such as the porosity of pervious concrete, the acceleration peak, and the frequency/duration of vibration, cannot obviously aggravate the clogging of pervious concrete. Therefore, within the scope of this study, the aforementioned conditions cannot lead to the sustainable development of clogging.

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