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Laboratory study of stability of punctured geotextile subjected to cyclic wave

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ABSTRACT: The alternating flow through the geotextile filter in coastal revetment creates a cyclic flow regime quite different from the uni-directional flow that has been extensively studied. Most of the filter design criteria and codes are based on tests from uni-directional flow conditions, which may not correctly reflect the in-situ conditions. A new bi-directional flow apparatus has been used to investigate the influence of the hydraulic conditions on the behavior of soil-geotextile interface and the stability of the revetment system. A series of tests were conducted on geotextiles specimens with pre-cut L-shaped holes, simulating the punctured holes on the geotextile filter resulted form its installation. Results show that geotextiles can still perform effectively with holes up to a certain critical size, if the soil arching is fully developed. Present of punctured holes in the geotextile filter does not imply failure of the revetment system if they are less than some critical size.

1 INTRODUCTION

Geotextile filters have been used in coastal revetment projects for many years; however, the performance of the geotextile filter represents an important design consideration that has not yet been clearly understood. In many classical design approaches, many mechanical parameters such as hydraulic drag forces, strength of the soil, the gravity and the cohesion (Giroud, 1985) were ignored. Other parameters, such as the density and the grain size distribution of the soil, were also neglected. The retention criterion depends only on geometrical parameters.

Most experimental studies conducted to evaluate the performance of geotextile filters concentrated on one-directional flow condition solely. However the alternating flow through the geotextile filter in coastal revetment creates a cyclic flow regime quite different from the uni-directional flow that has been extensively studied. The current design philosophy and methodology of the geotextile filter is based on research under the uni-directional flow, which may not reflect bi-directional flow of in-situ conditions.

In addition, geotextile damages due to installation were observed from time to time. The majority of the visible damage is in the form of puncturing, bursting or tearing and abrasion of geotextiles. Hence, the question on whether the geotextile filters would fail to function after prolonged cyclic wave action on geotextile filters with some punctured holes is real and need to be assessed.

There are many factors influencing the retention capability of geotextile filters and it is beyond the capabilities of present numerical methods to model such problems. Field observations and monitoring alone are very difficult to arrive at consistent conclusions due to the fact that there will be too many uncontrollable factors tangled together in the field. Meanwhile, the large variability of the soil in field conditions does not allow an easy comparison between various geotextile (Dierickx, 1996).

Laboratory research is the only feasible way to evaluate the performance of various geotextiles in a relatively short period. To evaluate the filtration behavior of geotextiles under cyclic wave load, a special laboratory equipment was built in National University of Singapore. It was developed with certain modifications to a perpendicular bi-directional flow set-up modeled by ENEL, Italy (Cazzuffi, et al., 1999). This apparatus is capable of simulating cyclic flow conditions normal to the soil-geotextile interface.

This paper presents the study on the key factors affecting the stability of geotextiles with punctured holes and aims to investigate the soil arching network phenomenon associated with it.

2 BI-DIRECTIONAL FLOW APPARATUS

The bi-directional flow apparatus system consists of mainly a two-way wave generator, a water reservoir and washout collector, and the steel sample chamber (Figure 1). The two-way wave generator activated by piston action is to simulate cyclic wave loadings applied on a seawater bank revetment. The test specimen cylinders consist of mainly 2 removable steel chambers: top and bottom chambers. The bottom chamber holds small rocks to simulate the armour layers in revetment. The top chamber holds the soil test sample representing the base soil, while sandwiched between these two layers is the geotextile filter. Figure 2 shows a detailed schematic view of the internal setup of chambers and test materials.

A pneumatic loading device is placed above the top chamber by four long supporting stumps. An overburden load is applied on the soil specimen to simulate the condition of effective stresses as imposed on a coastal revetment during its construction. In this series of tests, vertical pressure of 0, 25kPa, 110kPa were applied respectively. Three pore pressure transducers (PPT) are placed at assigned locations to monitor fluctuations in pore pressure (Figure 2). The PPTs are miniature pore pressure transducers type of PDCR 81 series with working range of 1 bar manufactured by Druck Limited.

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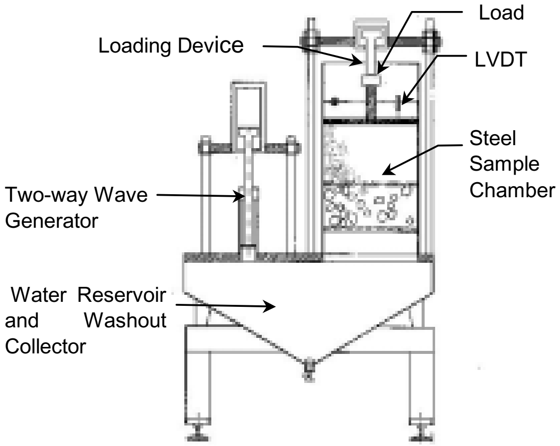


Figure 1. Schematic diagram of NUS bi-directional flow apparatus

The total pressure were measured by total pressure transducers (TPT), KD-5E type with working range of 5 kg/cm^2, manufactured by Tokyo Sokki Kenkyuio Co. Ltd., Japan.

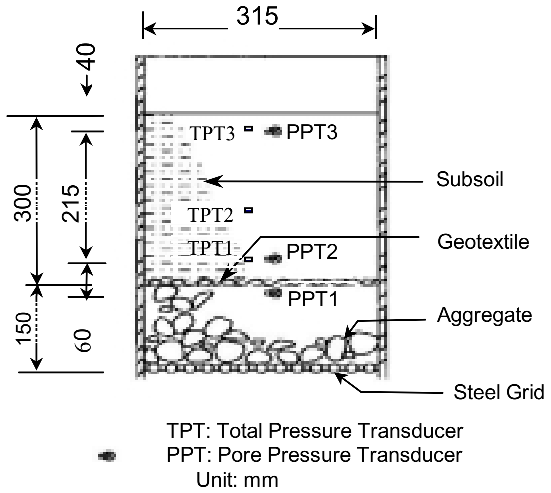


Figure 2. Detailed schematic view of the internal setup of chambers and test materials.

3 TEST PROGRAM

Test samples are subjected to a large number of simulated wave cycles. Two types of nonwoven geotextiles, NW1 and NW2, were used with their properties shown in Table 1. Typical reclamation sand is used as subsoil in this test series. The particles size distribution of sand used was shown in Figure 3.

Table 1. Index Properties of Geotextiles Tested

Properties	Test Standard	Geotextiles NW1	NW2
		Nonwoven	Nonwoven
Type		Nonwoven	Nonwoven
Polymer type		Polypropylene	Polypropylene
Code		F60	F80
Mass per unit area (g/m^2)	EN 965	400	800
Thickness @ 2kg (mm)	EN 964-1	3.5	6.5
No. of Constrictions		25	40
Opening size O_{90} (mm)	EN ISO 12956	0.1	0.09
AOS O_{95} (mm)	ASTM D 4751	0.08	0.08
Cone drop test (mm)	EN 918	12	7
Elongation at max. load MD/CD (%)	EN ISO 10319	85/85	85/85

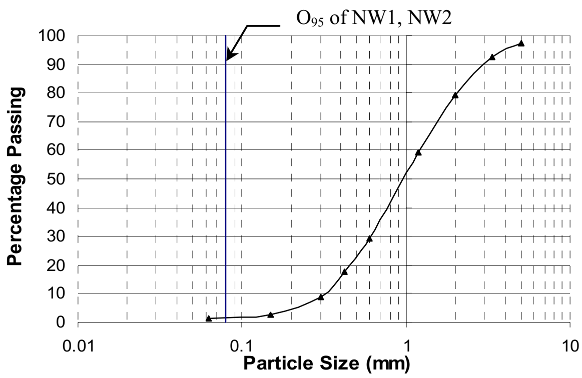


Figure 3. Soil particle size distribution and geotextiles opening sizes

To simulate the present of holes, geotextile samples were cut into "L" shape holes of different sizes as shown in Figure 4. The punctured hole size varies from 15mm to 65 mm. Period of cycle for every individual experiment was set at 2s, 5s, 7s and 10s respectively.

Figure 4. Picture of geotextiles with L-shape cut hole

4 TEST RESULTS

Tests are carried out under different wave periods and the pore pressure response at PPT1, 2 & 3 were recorded. Fig. 5 shows the typical variation of pore pressure for a cyclic wave load. It can be seen that there is a consistent phase lag between PPT1, PPT2 and PPT3 indicating satisfactory monitoring of pore pressure variation in the system. For all the tests conducted on both geotextiles, it was observed that the maximum and minimum pore pressure at all PPT locations became asymptotically constant after 3000 cycles. This implies that there are no more local variations in relative density, the soil mass and the filter system reach a dynamic equilibrium under the wave load.

Figure 5 also shows that the peak value of pore pressure decreases from the bottom of the sample (PPT1) to the top of the sample (PPT3). This kind of flow regime cannot be created by uni-directional flow.

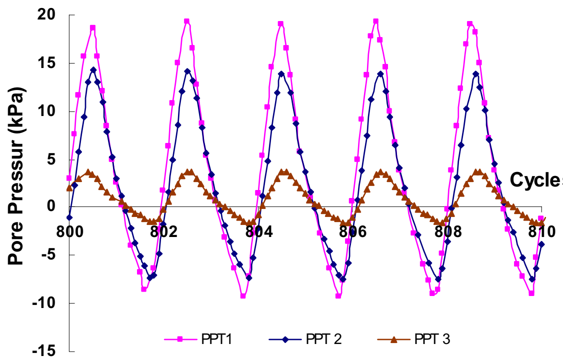
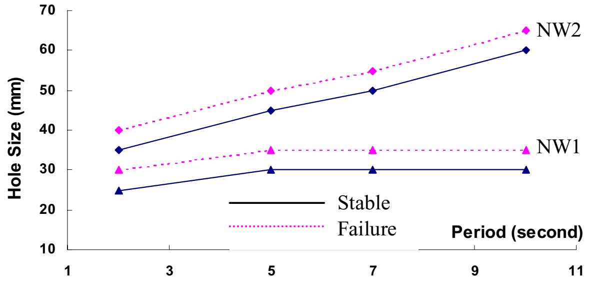


Figure 5. Pore pressure under different wave period (2s, NW2)

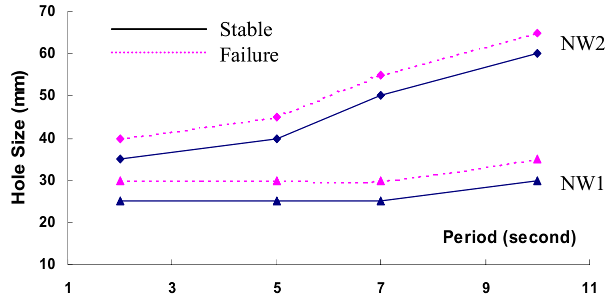
For the evaluation of the stability of soil-geotextile interface with puncture holes, there are no existing criteria for deciding if the structure is stable or unstable. In this series of test, a simple criterion is used to define the stability of soil-geotextile interface. That is, if there is excessive settlement during the cyclic test (due to piping and erosion), the soil-geotextile system would be treated as a failure case; otherwise, the system is considered as stable. Limitation settlement is set at 10% of the thickness of the sand sample.

Results on the stability of different geotextile at different wave period and different load were summarized in Figure 6. Figure 6 reveals that the critical hole size of the geotextile, i.e. the hole size of which failure initiated, is much larger in NW2 than in NW1 at every wave period and load conditions. Figure 6 shows that the system can still be stable even with some holes on geotextiles, as long as it does not exceed certain size at specific wave period and load, consistent with finding of Giroud (1999).

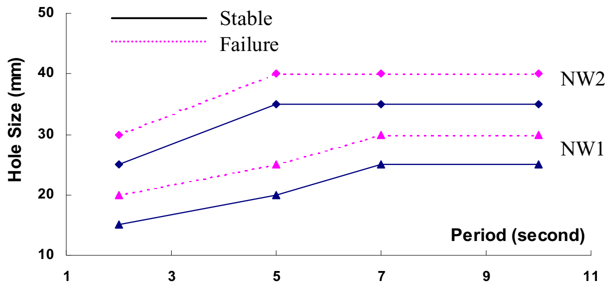
The factors affecting the stability of the soil-geotextile system with a puncture hole in the geotextile filter include the type of geotextile, the wave period, the load applied on geotextile filter and the size of puncture hole.



(a) At 110 kPa applied load



(b) At 25 kPa applied load



(c) With no applied load

Figure 6. Puncture hole size and the stability of geotextile at various wave period at different loading conditions

4.1 *Effect of Type of Geotextile on Stability*

The geotextile type has a significant effect on the performance of geotextile filter. NW1 and NW2 are basically the same geotextile with different thickness and strength (see Table 1). But under the same load and wave condition, the critical hole size is very different for these two geotextiles. The critical hole size is smaller in NW1 than in NW2. It indicates that thicker and stronger geotextiles can tolerate larger hole size probably due to its higher flexural stiffness (function of strength and thickness).

4.2 *Effect of Wave Period on Stability*

Figure 6 reveals that under the same load and the same geotextile, shorter wave period results in smaller critical hole size. This is because hydraulic gradient across the soil-geotextile interface is much larger when wave period is small (Zhao et al., 2000), thus, the high hydraulic gradient tends to increase the possibility of particle migration. Hence, it is more difficult for sand to build self-filtering system in shorter period wave, and resulted in erosion.

4.3 *Effect of Applied Load on Stability*

The result presented in figure 6 shows that greater the applied load is; more stable the soil-geotextile interface will be.

For both geotextiles, when applied loads increase from 0 to 25kPa, the critical hole size increases drastically. But when the applied load increases from 25kPa to 110kPa, there is no further increase in critical hole size for most of the cases (Figure 7). This is consistent for every wave period.

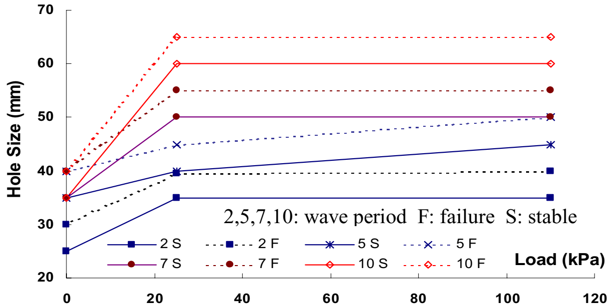


Figure 7. Critical hole size vs. load for NW2

The reason for the above observation is that greater load implies denser soil and more confinement on sand particles under the same wave drag force; thus it is more difficult for soil particles to move. However this effect of applied load on the soil-geotextile interface is limited to certain value of applied load. The critical hole size will not increase when the applied load increased beyond what is needed to confine the soil particles against the water drag force.

4.4 *Microscopic Explanations on Soil-geotextile Interface Stability*

From the test results, a conclusion can be drawn that punctured holes in geotextile filter do not necessarily imply failure of soil-geotextile interface. Under certain conditions, even if geotextile have been punctured with hole size up to 60mm, geotextile can still perform very well. This is due to the formation of some positive soil phenomena--arching.

In this series of tests it is impossible to observe the formation of arching directly. But some macroscopic phenomena, such as change in soil particle distribution, the soil sample settlement and washout mass, could give indication that the arching network was established under some conditions.

Figure 8 illustrates the sample settlement during the cyclic wave. For various wave periods, at the beginning of wave cycles, the settlement of sample increases rapidly. After certain number of cycles, the settlement increases very slowly and the system begins to stabilize. The result shows the amount of settlement at first 500 cycles is about 80% of settlement of 3000 cycles.

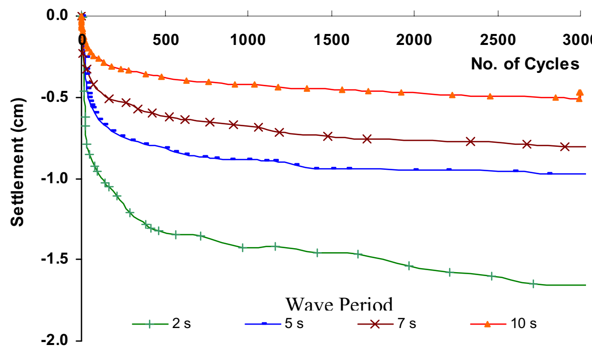


Figure 8. Settlement of soil sample under different wave period

The soil sample settlement could be due to the soil particles being re-arranged or/and some soil particle being washed out. However, the mass of fine particles being washed out is less than 100 gram in all the tests as shown in Figure 9. In most tests, it is even less than 50 gram while the settlement is in the order of 4.7mm to 16.6mm. Obviously, the soil particles rearrangement is the main cause for the soil sample settlement under wave action. Sand samples were also taken for sieve analysis before and after test. It was found that the sand near geotextile filter became coarser than before the test, and the sand far away from geotextile filter became slightly finer than before test.

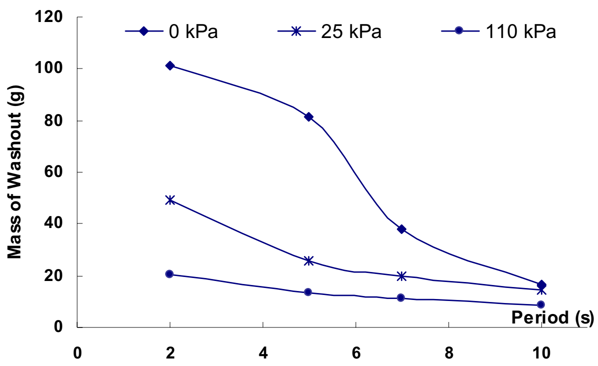


Figure 9. Amount of soil washed out after test (NW2)

In view of this macroscopic phenomenon, a conjecture can be made. At the beginning of wave cycle, the intensity of rearrangement of soil particles is very heavy. Some fine particles in the soil were washed out. The larger particles of the soil mass will then form an "arch" bridges over the hole, which in turn, filters smaller particles of soil, which then retains the soil and prevents piping. After some time, the moveable fine particles have been washed out almost completely and particle rearrangement has also completely developed. A stable arching network was formed. It is resulted in a critical hole size much larger than the sand particle size. For stable cases, the time required for arching built-up is not very long.

When a stable arching network is established, the self-filtering of sand mass will take place so that larger soil particles will restrain slightly smaller soil particles that will in turn restrain even smaller soil particles. The structure is safe with no more rearrangement and washout. Once the arching network is established in the subsoil, the resulting soil-geotextile interface is stable, and hence no erosion.

The arching built-up is influenced by the wave period, vertical loaded and the type of geotextile as explained earlier.

5 CONCLUSIONS

The newly developed bi-directional flow apparatus was able to simulate the cyclic wave regime at the geotextile filter in coastal revetment application. A series of tests were conducted with variation in wave period, applied load and the type of geotextiles to study the performance of geotextile filter.

The geotextile specimen were pre-cut with L-shaped hole of size up to 60mm simulating the punctured hole on the filter resulted from the installation. Results showed that:

a. The soil-geotextile interface can still be stable, even if there are punctured holes on geotextile, as long as they do not exceed certain critical hole size.
b. The stability of punctured geotextile filter can be explained by the formation of arching network behind the soil-geotextile interface. Under some conditions, sand particles rearrangement will take place and arching network will be established so that it will limit fines particles movement, and no clogging, blinding and erosion of fines through the filter. The soil-geotextile structure will remain to be stable. The extent, rate of formation and stability of the arching network are highly influenced by the magnitude of hydraulic gradients imposed on the soil-geotextile system, the type of the geotextile, the applied load, the puncture hole size and so on. Within certain limiting hole size, a stable and self-filtering arching network prevents the erosion of base soil and provides the retention function of geotextile filter.
c. The critical hole size for stronger geotextile is larger than that in weaker geotextiles due to its higher flexural stiffness.
d. Under the same vertical load, geotextile subjected to shorter wave period is found to have smaller critical hole size, thus represent the harsh environmental condition.
e. The greater the applied load, the larger the critical hole size the geotextiles filter can tolerate. However, beyond what is needed to confine the soil particles against the wave force, the increase in applied load does not increase the critical hole size.

The bi-directional flow tests can provide a better understanding of the performance of revetment geotextile filter and leading to an improved design. For a conservative design condition, geotextile NW1 subjected to 2-second wave with no applied load can tolerate punctured hole size in the order of 15mm, while a favorable condition of 110kPa loading with 10-second wave can tolerate punctured hole size up to 60mm if a stronger geotextile NW2 was used.

6 ACKNOWLEDGEMENT

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