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Evaluating in-plane hydraulic conductivity of non-woven geotextile and plastic drain by laboratory test

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ABSTRACT: In this study, the hydraulic conductivity associated with in-plane flow of geosynthetics was investigated in the laboratory. Three kinds of testing methods employed were; an in-plane hydraulic conductivity test for geosynthetics based on JGS T-932 (plan), a similar test on in-soil geosynthetics, and an in-plane flow test of geosynthetics in a triaxial cell. The examination focused on not only the effects of in-soil flow conductivity of geosynthetics, but also the effects of boundary conditions around the geosynthetics in the laboratory tests. It was successfully demonstrated the in-plane hydraulic conductivity was more stable against pressure for the plastic board drain than non-woven geotextiles, noting that the hydraulic conductivity of non-woven geotextiles was greatly reduced with the sustained pressure. It was also found that the triaxial apparatus was more suitable for measuring the hydraulic conductivity of plastic board drain that exhibited a high discharge rate.

1 INTRODUCTION

Geosynthetics made of synthetic resin such as planar non-woven geotextiles and strip plastic drains are often employed in earth fills and foundations so as to facilitate seepage water flow in the earth fill and also consolidation of the foundation soil.

It is expected that the drainage capacity of these geosynthetics in the horizontal direction, i.e., in-plane hydraulic conductivity, deteriorates to some extent owing to reduction in cross sectional area of the material when pressurized. In addition, such reduction in the hydraulic conductivity varies with the soil grading.

In practical design, it is thus important to evaluate quantitatively such deterioration of the material's conductivity. In so doing, it is urgently needed to establish rational testing method for assessing in-soil conductivity of geosynthetics. At present, in-plane hydraulic transmissivity of geosynthetics is usually evaluated by using an in-plane hydraulic conductivity testing system after the standard plan described by the Japanese Geotechnical Society, JGS T-932 (Plan). On the other hand, a similar testing method using a triaxial apparatus is presumably superior in a respect that it is capable of applying confining pressure uniformly to the specimen of geosynthetics.

Accordingly, the in-plane hydraulic transmissivity of non-woven geotextiles as well as a plastic board drain was measured by using two sets of apparatus; i.e., a device designed after the standard plan from the Japanese Geotechnical Society, JGS T-932 (Plan), and a modified triaxial apparatus. Discussion was made on the effects of the suspained pressure with and without the soil.

2 EXPERIMENTAL

In this paper, three types of test employed are tentatively called "***normal test***", "***in-soil test***", and "***triaxial-cell test***", respectively (Table 1).

"Normal test" employs an in-plane hydraulic conductivity testing device of geosynthetics after standard plan described by the Japanese Geotechnical Society, JGS T-932 (plan). As seen in Fig.1, the normal compressive stress was applied to the bare geosynthetic specimen by using an air-bag.

"In-soil test" was carried out in the same testing device in which the geosynthetic specimen was sandwiched in Toyoura sand. As seen in Photos 1 and 2, the geosynthetic specimen was covered with a Poly Vinyl den Chloride (PVDC) film so that the

Table 1. Testing method.

Test name	Description
"Normal test" (See Fig.1)	In-plane hydraulic conductivity test using bare geosynthetic after JGS T-932 (plan)
"In-soil test" (See Photo 1)	In-plane hydraulic conductivity test using in-soil geosynthetic after JGS T-932 (plan)
"Triaxial-cell test" (See Fig.2)	In-plane hydraulic conductivity test using bare geosynthetic in a triaxial cell

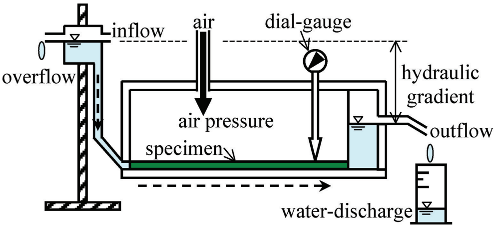


Figure 1. Configuration of *"Normal test"*.

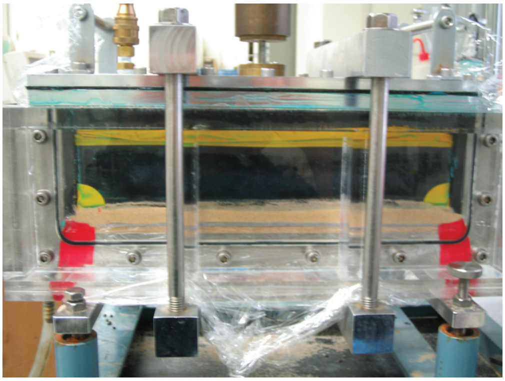


Photo 1. Snap for the *"In-soil test"*.

water flow in the soil can be separated from that in the geosynthetics.

"Triaxial-cell test" refers to a similar test performed in a modified triaxial apparatus. As shown in Fig.2, the bare geosynthetic specimen can be subjected to a uniform confining pressure through a flexible rubber membrane.

Table 2 shows three kinds of geosynthetics tested. Figure 3 shows the cross-sections of *"Non-woven geotextile"* and *"Non-woven geotextile reinforced fiber"*. Photo 3 shows *"Plastic board drain"*.

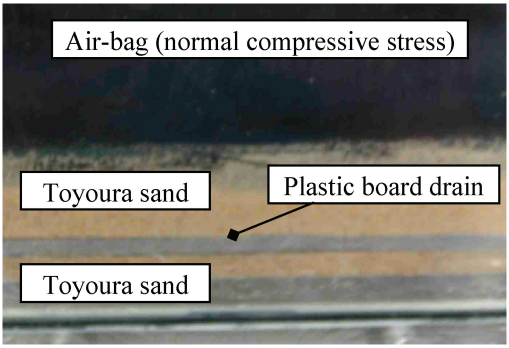


Photo 2. Geosynthetic specimen in the *"In-soil test"*.

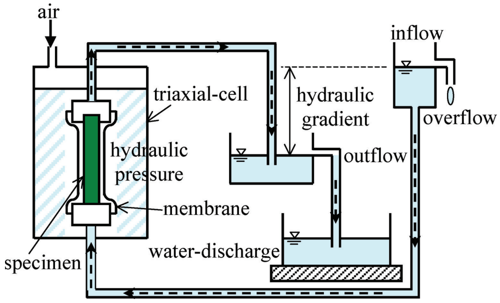
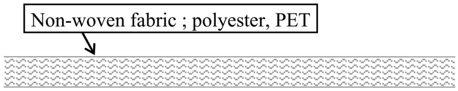


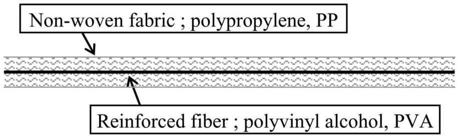
Figure 2. Configuration of *"Triaxial-cell test"*.

Table 2. Geosynthetics tested.

Name	Type of drainage materials
"NW"	non-woven geotextile (no reinforcement)
"NW-RF"	non-woven geotextile with reinforced fiber
"PD"	plastic board drain



(a) Cross-section of *"Non-woven geotextile"*.



(b) Cross-section of *"Non-woven geotextile reinforced fiber"*.

Figure 3. Cross-sections of *"Non-woven geotextile"* and *"Non-woven geotextile reinforced fiber"*.

In all the tests, the geosynthetic specimen was subjected to incremental pressures of 20, 40, 100, and 200 kPa. In tests using *"NW"* and *"NW-RF"*, the conductivity was examined at each stage by using the hydraulic gradients of 0.25, 0.5, and 1.0. On the other hand, the test using *"PD"* employed the values of hydraulic gradient of 0.025, 0.05, 0.1, 0.2, 0.25, 0.5 and 1.0 in each step.

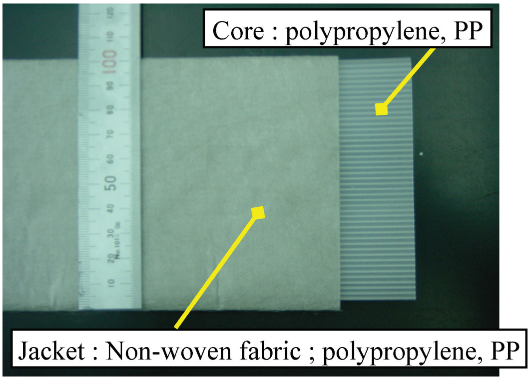


Photo 3. A snap for *"Plastic board drain"*.

3 RESULTS AND DISCUSSION

3.1 *Definitions for hydraulic conductivity*

The hydraulic conductivity in the plane of geosynthetics is characterized in terms of the coefficient of in-plane hydraulic transmissivity θ_h or in-plane permeability k_h.

$$\theta_h = \frac{Q}{W(\Delta h/L)} \quad \text{and} \quad k_h = \frac{Q}{W(\Delta h/L)H_g} = \frac{\theta_h}{H_g}$$

where Q is the rate of discharge, W and L are the width and length of the specimen in the flow direction, Δh is the total head loss in the geosynthetics, and $I(=\Delta h/L)$ is the hydraulic gradient in the geosynthetics, and H_g is the current thickness of the specimen. It should be mentioned that the H_g value was measured in a separate test in which the dead load was applied to the specimen.

3.2 *Comparison between "normal test" and "in-soil test"*

Figures 4, 5 and 6 show the relationship between the in-plane hydraulic transmissivity and the normal compressive stress P in *"in-soil test"* and *"normal test"* by using three kinds of geosynthetics of *"NW"*, *"NW-RF"* and *"PD"*, respectively. Figures 7, 8 and 9 show similar results in terms of the relationship between the in-plane hydraulic transmissivity and the hydraulic gradient in *"in-soil test"* and *"normal test"* for *"NW"*, *"NW-RF"* and *"PD"*, respectively.

In tests using *"NW"*, the transmissivity decreased considerably as the P increased, implying that the transmissivity in *"in-soil test"* was almost zero at $P = 200$ kPa (see Figs.4 and 7). Note also that the transmissivity in *"in-soil test"* was higher than *"normal test"* when P was less than say 40 kPa. However, the trend was reversed for $P > 100$ kPa. These observations may be attributed to an influence that the thickness of the geotextile decreased locally at around $P = 100$ kPa involved with intrusion of soil grains into the geotextile.

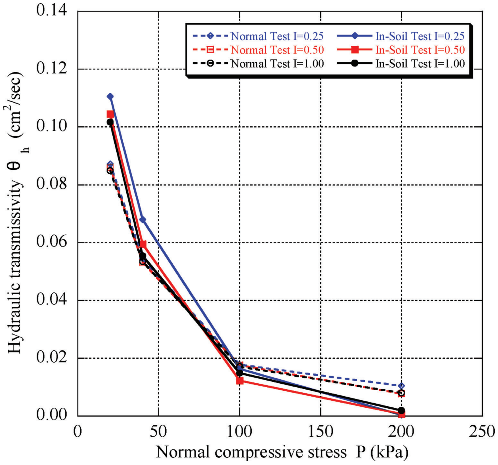


Figure 4. Relationship between hydraulic transmissivity and normal compressive stress for *"Non-woven geotextile"*.

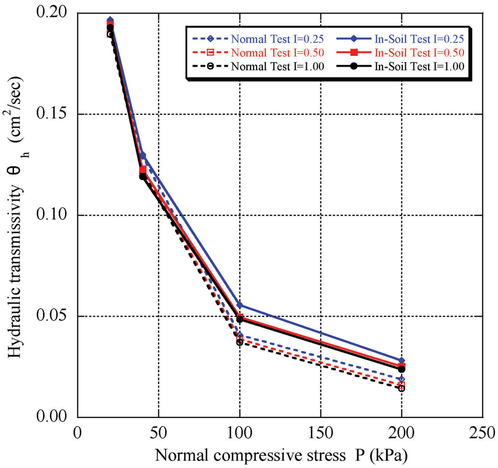


Figure 5. Relationship between hydraulic transmissivity and normal compressive stress for *"Non-woven geotextile reinforced fiber"*.

In comparative tests using *"NW-RF"*, the transmissivity in both of *"in-soil test"* and *"normal test"* steadily decreased when P increased in value. When P ranged between 20 kPa and 40 kPa, the transmissivity in *"in-soil test"* was approximately equal to *"normal test"*. However, when P was more than 100 kPa, the transmissivity in *"in-soil test"* was more than that of *"normal test"* (see Figs.5 and 8). The effect of reinforcement to the non-woven geotextile was obvious in that the hydraulic conductivity was improved at higher

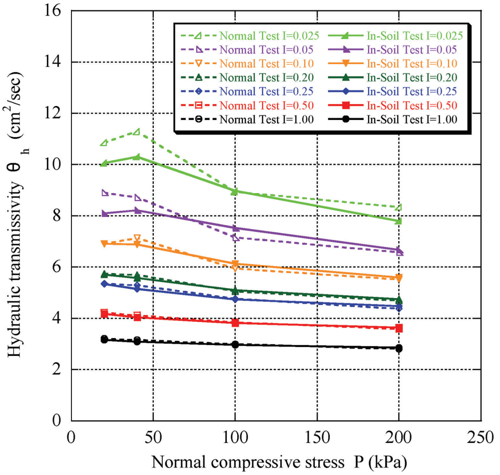


Figure 6. Relationship between hydraulic transmissivity and normal compressive stress for *"Plastic board drain"*.

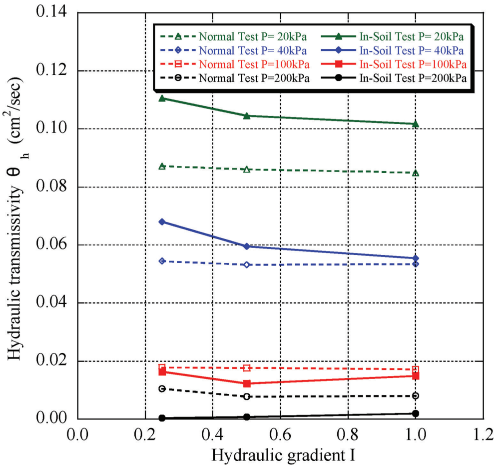


Figure 7. Relationship between hydraulic transmissivity and hydraulic gradient for *"Non-woven geotextile"*.

pressures since *"NW-RF"* prevented soil grains from penetrating into the material.

As seen in Figs.4 and 5 (or Figs.7 and 8), the result of *"NW"* and *"NW-RF"* for $P > 100$ kPa is opposite to each other between *"in-soil test"* and *"normal test"*. The difference may be attributed to the effects of reinforced fiber in *"NW-RF"*.

As seen in Figs.6 and 9, the transmissivity of *"PD"* was substantially larger by approximately ten-fold. Besides, it was virtually the same between *"in-soil test"* and *"normal test"*. Moreover, the transmissivity was unaffected by the normal compressive stress for the range of P examined. The rigidity of *"PD"* is much higher compared to non-woven geotextiles, which in turn may result in independence of transmissivity against P.

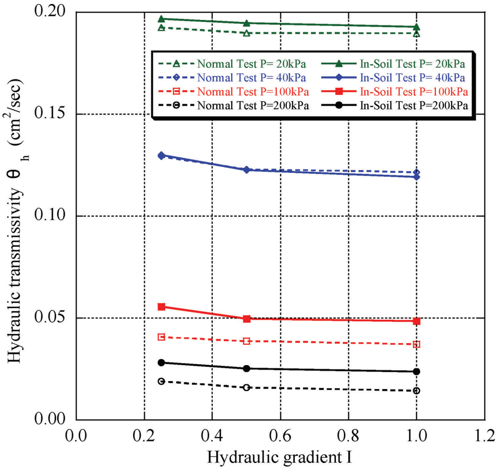


Figure 8. Relationship between hydraulic transmissivity and hydraulic gradient for *"Non-woven geotextile reinforced fiber"*.

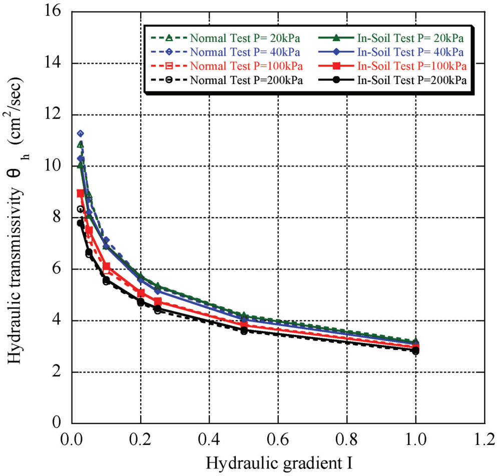


Figure 9. Relationship between hydraulic transmissivity and hydraulic gradient for *"Plastic board drain"*.

Effects of the hydraulic gradient in tests using non-woven geotextiles showing lower transmissivity were insignificant. Conversely, the transmissivity of the *"PD"* was significantly influenced by the hydraulic gradient in a manner that the transmissivity apparently decreased when the hydraulic gradient increased. This may be attributed to energy loss possibly due to turbulent flow in the testing system. Accordingly, the hydraulic gradient should be low enough to prevent any occurrence of turbulent flow in test using a high transmissivity geosynthetic like *"PD"*.

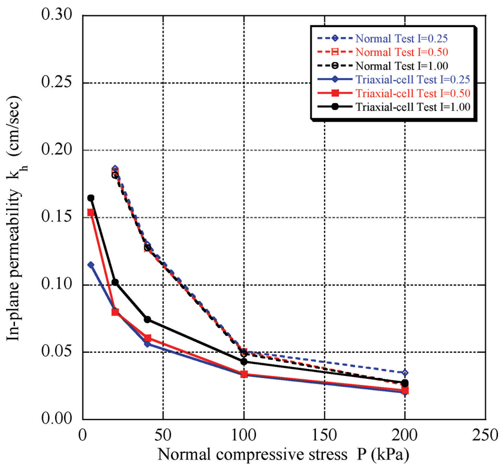


Figure 10. Relationship between in-plane permeability and *P* for *"non-woven geotextile"*.

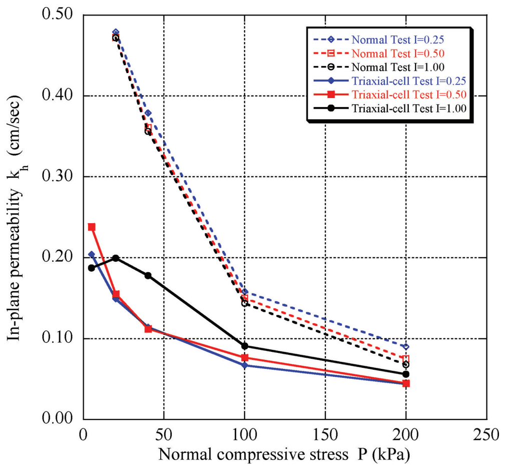


Figure 11. Relationship between in-plane permeability and *P* for *"non-woven geotextile with reinforced fiber"*.

In summary, the *"PD"* seems more efficient as a drain material when used in earth fill, since the transmissivity is higher, and unaffected by in-soil pressure as compared to non-woven geotextiles.

3.3 *In-plane permeability in two testing devices*

Figures 10, 11, and 12 show the relationship between in-plane permeability and *P* for *"NW"*, *"NW-RF"*, and *"PD"* as examined using *"triaxial-cell test"* and *"normal test"*.

As for *"NW"* and *"NW-RF"*, a trend was clear in both the tests that the permeability decreased as *P* increased. It may be attributed to the fact that the density of fiber in *"NW"* and *"NW-RF"* increased with *P* involved with decrease in the thickness of the geotextile. On the other hand, the permeability was unaffected by the hydraulic gradient applied, since no turbulent flow took place in these tests with relatively low rate of discharge. Note also that the permeability in *"normal test"* was noticeably higher compared to that in *"triaxial-cell test"* over a range of *P* from 20 kPa to 100 kPa. In *"normal test",* the normal pressure on the specimen may have been much less than the pressure applied in the air-bag possibly due to the effects of friction between the airbag and the sidewall. It is a potential drawback involved in *"normal test"* with the rigid boundary.

Conversely, in tests on *"PD"*, the permeability did not depend on the *P* very much, since the *"PD"* was stiff enough against the applied pressures over a range examined. However, the permeability of *"PD"* varied with the hydraulic gradient in a manner that the permeability decreased with the hydraulic gradient. The tendency was more significant in *"normal test"*.

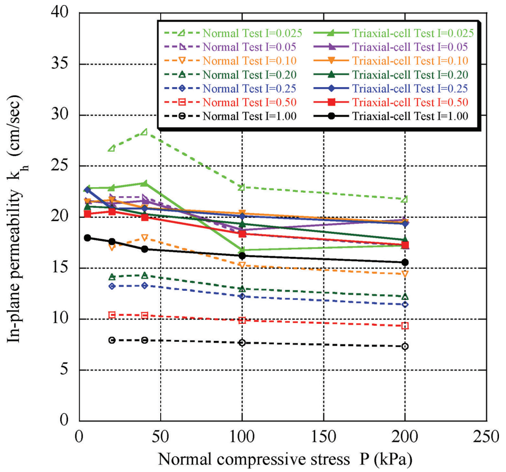


Figure 12. Relationship between in-plane permeability and *P* for *"plastic board drain"*.

Figure 13 shows the relationship between the in-plane hydraulic transmissivity of *"PD"* and *P* in *"triaxial-cell test"* and *"normal test"*. The transmissivity of *"PD"* is examined against the hydraulic gradient in Fig.14. As stated earlier, the transmissivity hardly varied with *P*, and varied significantly with the hydraulic gradient. As for the dispersion of the transmissivity against the hydraulic gradient, *"normal test"* was more significant compared to the results in *"triaxial-cell test"*. The transmissivity in *"triaxial-cell test"* hardly depended on the hydraulic gradient. On the other hand, the transmissivity in *"normal test"* varied greatly with the hydraulic gradient. Moreover, when the hydraulic gradient was relatively low, the

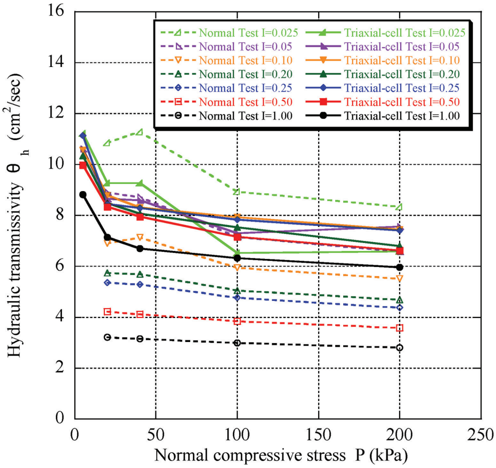


Figure 13. Relationship between hydraulic transmissivity and *P* for *"Plastic board drain"*.

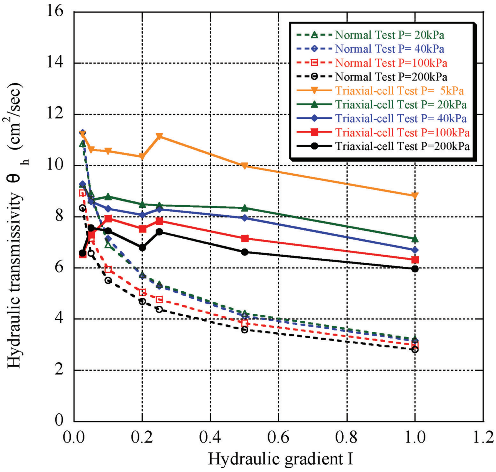


Figure 14. Relationship between hydraulic transmissivity and hydraulic gradient for *"Plastic board drain"*.

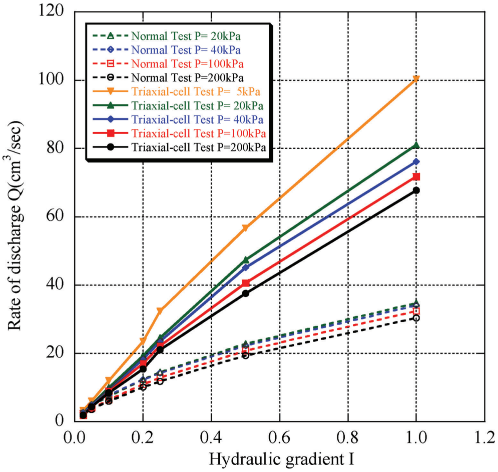


Figure 15. Relationship between the rate of discharge and hydraulic gradient for *"Plastic board drain"*.

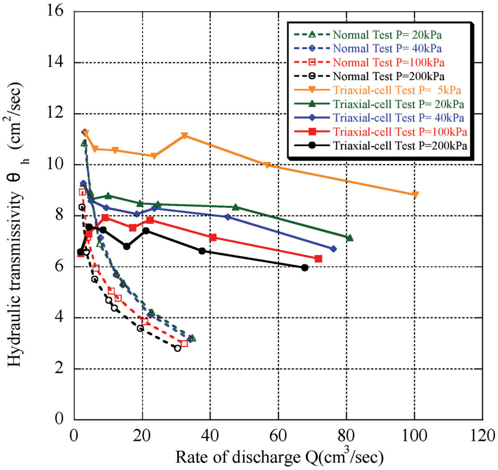


Figure 16. Relationship between the rate of discharge and hydraulic transmissivity for *"Plastic board drain"*.

transmissivity in *"normal test"* was approximately equal to that in *"triaxial-cell test"*.

Figure 15 shows the relationship between the rate of discharge and the hydraulic gradient for *"PD"*. The relationship between the in-plane hydraulic transmissivity and the rate of discharge in *"triaxial-cell test"* and *"Normal test"* is shown in Fig.16. As seen in these figures, the rate of discharge of *"PD"* was much lower in *"normal test"* than in *"triaxial-cell test"*, implying that the transmissivity was relatively low in *"normal test"*. Provided that the results of *"triaxial-cell test"* are correct, it may be surmised that some loss of discharge took place in *"normal test"* associated with the characteristic configuration of the testing device. The results suggest that the *"normal test"* is not suitable for measuring correctly the in-plane transmissivity of geosynthetics when the hydraulic gradient is relatively high (i.e. when the rate of discharge is relatively high).

4 CONCLUSIONS

i) The in-plane hydraulic transmissivity of in-soil non-woven geotextile decreased with the sustained normal compressive stress, reaching approximately to zero at 200 kPa. This may be attributed to the increase in fiber density.

ii) The behavior of "non-woven geotextile reinforced fiber" was slightly improved by showing slower decrease against P.

iii) The in-plane hydraulic transmissivity of "plastic board drain" was higher by ten-fold compared to those of the non-woven geotextiles. Moreover, due to a high stiffness of the "PD", it hardly depended on P as examined up to 200 kPa.

iv) iv) Therefore, the "plastic board drain" seems potentially more effective geosynthetic to promote drainage in the earth fill.

v) In tests using "non-woven geotextile" and "non-woven geotextile reinforced fiber", the in-plane permeability in *"normal test"* was higher than *"triaxial-cell test"* only when the normal compressive stress was relatively low, say less than 100 kPa,

vi) On the other hand, the in-plane conductivity of "plastic board drain" was lower in *"normal test"* than in *"triaxial-cell test"*, and it increased with the increase in the hydraulic gradient, i.e. the increase in the rate of discharge.

vii) When the rate of discharge is relatively high, *"triaxial-cell test"* seems superior to *"normal test"* for the purpose of measuring the in-plane conductivity of geotextiles correctly.

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