Evaluation of permeability and mechanical property of permeable column material

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ABSTRACT: Under the stormy weather condition such as typhoon, onshore and offshore facilities are sometimes damaged not only by the water pressure on the structures but also by the instability of seabed foundation. Wave-induced cyclic loading of water pressure on seabed surface causes the cyclic change in both pore water pressure and effective stress, and then the associated reduction in stiffness and load bearing capacity of the seabed enhances the damage on the structures. In order to stabilize the seabed and reduce the damage on the structures, a method called “Permeable Column Method” was proposed by the authors. In this method, highly permeable columns, whose main material is made of polypropylene and polyester, are installed vertically into seabed with an appropriate interval and depth. Since permeable columns can propagate the water pressure change on seabed surface into the depth in the seabed, the distribution of excess pore water pressure is smoothened and upward seepage force is suppressed. As a result the seabed is stabilized with sufficient stiffness and load bearing capacity. In order to examine the efficiency of permeable column, a series of laboratory tests is conducted: uniaxial compression tests, bending tests, permeability tests and microscope observations. In this paper the result of the experiment is explained.

1 INTRODUCTION

Various types of seashore, offshore structures, port and harbor facilities such as breakwater, shore protection, quay wall and tower, are often damaged by wave loadings under stormy weather condition. The impact of water pressure on the structures induced by the sea wave loading is one of the major factors influencing the instability and/or destruction of the structures. At the same time, the water pressure is applied to the surface of seabed which bears the structures as a foundation ground. Since the surface of the water pressure induces the fluctuating excess water pressure and shear stress in the seabed, the wave loading sometimes causes the instability of the structures, as well as the seabed foundation ground.

Asahara et al. (2008) proposed the seabed stabilization method called “permeable column method”, where the columns consisted of highly permeable material are installed vertically into seabed with an appropriated interval and depth. In this method, fluctuating water pressure at seabed surface is propagated into the seabed directly through the permeable columns. Since the distribution of excess pore water pressure is smoothened in the seabed, the upward seepage force is suppressed, and the seabed is stabilized so as to retain sufficient load bearing capacity for the overlying structures.

A field observation of the response of seabed to wave loading was conducted by Miura et al. (2008) in Ishikari Bay New Port, Hokkaido, Japan. In the field observation the pore water pressure change in the seabed was monitored by using the two vertical arrays of pore water pressure cells; one of the array was surrounded by the permeable columns, but the other was not. It was found that the permeable columns were effective on the stabilization of the seabed.

In this study a series laboratory tests were conducted on the specimen extracted from the permeable columns; the permeability and mechanical properties were examined. The laboratory tests were conducted on the specimens from used permeable columns as well as intact ones. The microscopic observation was also conducted on the specimens from the intact and used permeable columns, to sight the sand particles invading into micro-pores of the specimens.

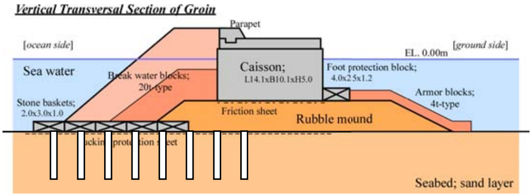


Figure 1. Example of the application of permeable column method.

2 PROFILE OF PERMEABLE COLUMN

The performance requirements for the permeable column are as follows:

・It is hollow cylindrical in shape, and has sufficient stiffness against compression and bending for making it easy to penetrate into seabed.

・It is highly permeable enough to propagating pore water pressure through them, and has filtration function so as to prevent the clogging of fine sand particles.

・It is sufficiently resistant to corrosion with seawater.

The material selected for permeable column referring the required performance, was the hollow cylindrical material consisted with polypropylene fibers; its circumference is wrapped with polyethylene mesh. The material was originally developed as a filter for purifying water. No adhesives are used, and the fibers are heated under high compression to form stable matrices with the fibers. Due to the microstructure, the column material showed high elastic deformability even with large strain of several percent, and excellent durability under impact forces.

The specification of the permeable column material is listed in Table 1.

Table 1. The standards of permeable column

Product Name	CP-150
Material	Polypropylene(50%)、Polyethylene(50%)
Section Size	(External diameter)65mm×(Internal diameter)30mm
Length	L = 1500mm, 750mm, 500mm

Figure 2. Permeable columns

Two types of samples of permeable column are examined in this study. One is “intact sample”, and the other is “used sample”. The intact sample is from totally new one, and the used sample was from the used permeable column which was installed and left in seabed and collected after the one-year seabed response observation. It was apparent that the surface of the used column material was dirty with sandy particles, and small fraction of them has invaded into micro pores inside the column material. Density of the samples was measured and porosity was calculated neglecting the existent sand particles.

The results are shown in Table 2. It shows that porosity of the used sample was rather small, compared with intact product.

Table 2. Porosity of permeable column

Type	Unit Volume (cm^3/m)	Fiber Density (g/cm^3)	Fiber Volume (cm^3/m)	Porosity of Permeable Column
Intact Sample A	2,611.4	0.935	894	65.8
Intact Sample B			898	65.6
Used Sample A			1,169	55.2
Used Sample B			1,152	55.9

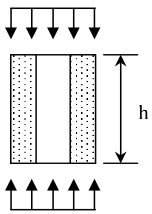
3 MECHANICAL PROPERTIES

In order to clarify the fundamental mechanical properties of the permeable column material, compression test and the bending loading test both were conducted. The specimens were compressed both in axial and radial directions: axial compression test and radial compression test.

The five hollow cylindrical specimens were prepared from both intact samples (Case1) and used samples (Case 2), respectively for each of the axial compression, radial compression, and bending loading tests.

3.1 *Axial compression test*

In the axial compression test, axial force is applied to the specimens through the top and bottom platens under a constant strain rate. The test condition of the test is shown in Fig.3.



External Diameter	65mm
Internal Diameter	30mm
Height	130mm
Section Area	0.0026m2
Loading Condition	Strain Control

Figure 3. Condition of an axial compression test

A typical behavior observed in the axial compression test is shown in Fig.4, where stress-strain curve is plotted throughout the loading. The stress-strain curve shows an elasticity behavior of the specimen at the early stage of loading (elastic region), and then it shows an inelastic behavior when a certain strain level is reached, where the specimen yields.

Elastic modulus and maximum compression stress were determined on the stress-strain curve such as shown in Fig.4; the elastic modulus was defined as the slope of the straight part of the stress-strain curve, and the maximum stress was defined as the peak stress within the yield region.

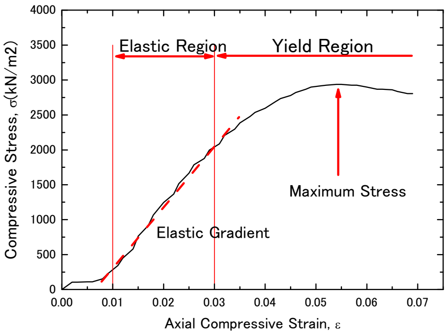


Figure 4. Stress-strain curve of an axial compression test

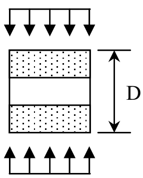
The experimental results of the axial compression tests are listed in Table 3. In the comparison between the results for intact specimens (Case 1) and used specimen (Case 2), the averaged value of elastic modulus was 10 to 20% higher for used specimen than for intact specimen. The maximum stress was also higher for used specimen than for intact specimen in average. The invasion of sand particles might cause the difference; however, the difference is not so large to be discussed more.

Table 3. Results of an axial compression test

	Case1 (Intact Sample)		Case2 (Used Sample)	
	Maximum Stress (kN/m^2)	Elastic Mudulus (kN/m^2)	Maximum Stress (kN/m^2)	Elastic Mudulus (kN/m^2)
1	2,447	60,941	2,507	73,552
2	2,939	87,498	2,501	73,388
3	2,375	75,500	2,459	70,572
4	2,315	60,199	3,095	94,079
5	2,537	75,927	3,227	98,814
Average Value	**2,523**	**72,013**	**2,758**	**82,081**

3.2 *Radial compression test*

In the radial compression test, line force is applied to the specimens in radial direction through the top and bottom platens under a constant strain rate. The test condition of the test is shown in Fig.5.



External Diameter	65mm
Internal Diameter	30mm
Height	60mm
Section Area	0.0026m2
Loading Condition	Strain Control

Figure 5. Condition of a radial compression test

The result is shown in Table 4. The applied force was divided by the maximum cross-section area of the specimen as shown in Fig.5, to calculate the stress.

The stress-strain relationship observed in the radial compression test was similar to that in the axial compression test. However, the value of the elastic modulus and the maximum stress at the time of destruction was approximately 40 % of the value obtained in the axial compression test.

In the comparison between the intact specimens and used specimens, the similar tendency can be seen that the stiffness and strength both are higher for used specimens than for intact specimens. It can be said that the exposition of the permeable columns under seafloor for long time may not perceptively deteriorate the mechanical properties of the permeable column material.

Table 4. Results of radial compression tests

	Case1 (Intact Sample)		Case2 (Used Sample)	
	Maximum Stress (kN/m^2)	Elastic Mudulus (kN/m^2)	Maximum Stress (kN/m^2)	Elastic Mudulus (kN/m^2)
1	1,277	32,125	1,217	36,843
2	1,053	25,601	1,187	33,067
3	926	23,030	1,187	29,049
4	1,060	25,449	1,344	38,879
5	971	21,749	1,277	35,465
Average Value	**1,057**	**25,591**	**1,242**	**34,661**

3.3 *Bending loading Test*

In the bending loading test the long specimens were supported at tow ends and loaded vertical forces at two points, where the span was divided into three equal lengths. The length *L* of span was 1.2m as shown in Fig 6.

The test was carried out on three specimens only from intact samples.

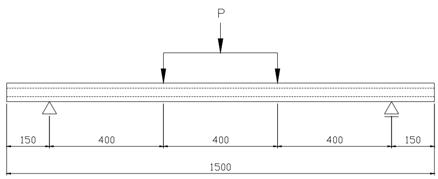


Figure 6. structural diagram of a bending test

The load-deflection curve observed in the bending test is shown in Fig.7. There was a similar tendency in all three cases; the maximum load was about 600N at the deflection amount of 225mm.

The bending strength σ_t was calculated by the formula as follows.

$$\sigma_t = M / Z \quad (1)$$

where M is bending moment, and Z is a section modulus. The result of bending test is shown in Table 5.

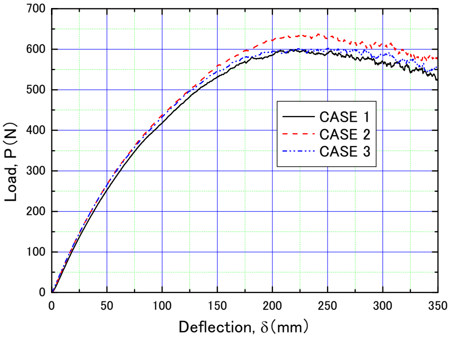


Figure 7. Load-deflection curve of bending test

Table 5. Results of bending tests

Span	L =	1.2	m
Loading Point Distance	L1 =	0.4	m
Maximum Load	P =	0.6	kN
Bending Moment	M =	0.12	kN･m
External Diameter	Dout =	65	mm
Internal Diameter	Din =	30	mm
Section Second Morment	I =	1.338E-05	m^4
Section Modulus	Z =	4.118E-04	m^3
Maximum Bending Stress	σ =	291	kN/m^2

4 PERMEABILITY

In order to examine the permeability of a permeable column, a series of permeability tests was conducted on the specimens from intact and used samples of the permeable column. The permeability was measured both in axial and radial direction: the axial permeable test and the radial permeable test.

4.1 *Axial permeability test*

In the axial permeability test water flew only in axial direction of the specimen; outer and inner circumferences were coated to prevent inflow or outflow of water through the circumferences. The test apparatus used in the test is shown in Fig.8.

According to the Darcy's Law, the coefficient permeability k is derived from the formula (2).

$$k = Q \cdot L / (A \cdot t \cdot \Delta H) \qquad (2)$$

where Q, L, A and t are flow volume, drain length, sectional area, and duration time, respectively, and △H is water head difference. The duration time t was fixed to be 600 sec. and test was conducted on the same specimen with different water head differences △H.

The test case and the test results are shown in Table 6.

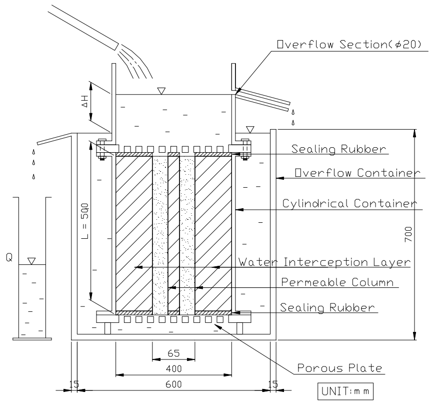


Figure 8. Axial permeability test

Table 6. Results of axial permeability test

Type	Test Case	Water Head Difference, ΔH(cm)	Flow Volume, $Q(cm^3)$	Coefficient of Permeablity, k(cm/sec)
Intact Sample	1-1	11.95	380	1.01×10^{-1}
	1-2	17.95	579	1.02×10^{-1}
	1-3	38.25	1,263	1.05×10^{-1}
Used Sample	2-1	11.95	769	2.05×10^{-1}
	2-2	17.95	1,138	2.02×10^{-1}
	2-3	38.25	2,513	2.10×10^{-1}

The Table 6 shows that the calculated value of permeability coefficient was in dependent of the water head difference. From the comparison between the intact and used specimens, the permeable coefficient is about two times higher for used specimen than for intact specimen. Since some sand particles invaded into micro pore in the used specimen, the permeability was first expected to be lower compared with that for intact specimen. Nevertheless the permeability was not lower for the used specimens.

4.2 *Radial permeability test*

In the radial permeability test water flew only in radial directions of the specimen; the both ends were coated to prevent the flow of water in axial direction. The test apparatus used in the test is shown in Fig.9.

In the test apparatus water flows from outer into inner spaces through the wall of hollow cylindrical specimen of permeability column. The height of specimen is 100mm.

The drain distance L of a sample is 35mm, and the cross-section area is given the effective radius of the permeable column as 47.5mm that is average of an outer diameter and an inner diameter. The duration time was fixed to be 60 sec. the permeability coefficient was calculated from the measured flow volume Q through Formula (2).

The test was carried out on intact specimens (case 3) and used specimens (case 4) the same as the axial permeability test. The water head difference Δ H was 57.5mm, 78.0 mm, or 96.5 mm.

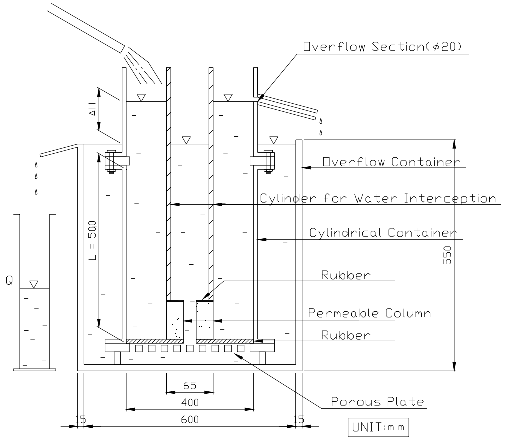


Figure 9. Radial permeability test

The test cases and test results from radial permeability tests are shown in Table 7.

Table 7. Results of radial permeability test

Type	Test Case	Water Head Difference, Δ H(cm)	Flow Volume, Q(cm^3)	Coefficient of Permeablity, k(cm/sec)
Intact Sample	3-1	5.75	4,095	1.55×10^{-1}
	3-2	7.80	5,303	1.48×10^{-1}
	3-3	9.65	6,413	1.44×10^{-1}
Used Sample	4-1	5.75	3,171	1.20×10^{-1}
	4-2	7.80	4,500	1.25×10^{-1}
	4-3	9.65	5,950	1.34×10^{-1}

There was no big dispersion at each examination case. Similarly, the large difference to the value of the coefficient permeability between intact material (case 3) and used material (case 4) was not seen. Compared with the test results of case 1 and case 2, it can be said that the reduction of permeability during one-year exposition of permeable columns under seafloor was fairly small disregarded.

The results of all the test cases show that the permeability coefficient was no less than $k=1.0x10^{-1}$ (cm/sec).

5 MICROSCOPIC OBSERVATION

In order to clarify the microscopic structure in the permeable column material, and the flat cross sections of both the intact and used materials were observed using an electro microscope: 200-fold magnification. after used at seabed, observation by an electron microscope was performed.

Figures 10 and 11 show the enlarged cross sections of the intact material and used one, respectively. Fibers can only be seen in the case of the intact material. On the other hand same minute particulates can be seen in the case of used material, especially in Textile Division. Since the particle diameter estimated from the photograph is approximately 10μm - 50μm, it seems that invasion of these particles are sparse and pores are not stuffed with the sand particles.

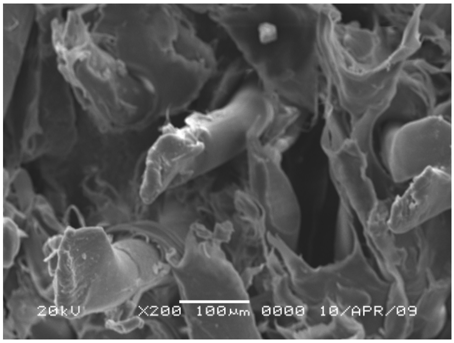


Figure 10. Intact material (x200)

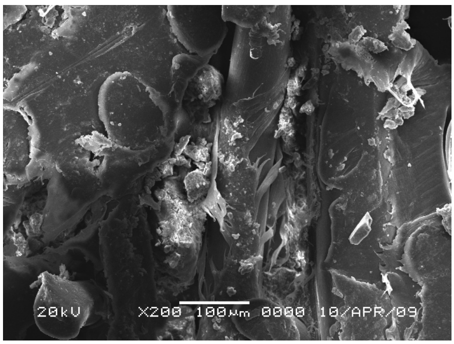


Figure 11. Used material (x200)

6 CONCLUDING REMARKS

To clarify the mechanical properties and permeability of permeability column material, a series of laboratory tests were conducted on the specimens prepared from intact and used permeable columns. The mechanical properties were examined in axial compression test, radial compression test and bending loading test. The permeability was examined in axial permeability test and radial permeability test. Also micro structures were observed by using an electro microscope. From the comparative examination of the test results, the following summary was drawn with the effect of the exposition of permeable columns under seafloor taken into account.

- All the specimens showed the rather elastic deformation behavior at an early stage of loading under axial load or lateral load. The behavior becomes inelastic and the specimen yielded, when the amount of strain exceeded about 3%. Axial elastic modulus was $E=2.5\text{x}10^3 kN/m^2$, and axial compressive strength was $\sigma=7.0\text{x}10^4 kN/m^2$.
- In the bending loading tests, maximum deflection was 225mm with span length of 1,200mm; high flexibility of the material was also seen under bending deformation. The bending strength was $\sigma=3.0\text{x}10^2 kN/m^2$.
- In all the specimens examined in permeability test, the permeability coefficient was no less than k= $1.0\text{x}10^{-1}$ (cm/sec). And it turned out that the influence of water flow direction and water head difference on coefficient permeability is so small that it can be disregarded.
- Microscopic observation of the cross sections the specimens showed that the particles whose diameter is about 10μm - 50μm have invaded into the pores of permeable column material during the exposition under seafloor. The result of the permeability test, however, showed that the influence of the particles on the permeability was so small that the effect may be minor and can be disregarded.
- The effect of the one-year exposition of permeable columns under seafloor was fairly small. The notable reduction in mechanical properties and/or permeability was not seen in any laboratory tests conducted in this study.

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