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Effects of drainage by the sheet pipe on the suction and volume water content of subsurface layer

Les effets du drainage par la pipe de feuille sur l'aspiration et le volume d'eau contenu de couche Sub-surfacique

H. Matsuda
Yamaguchi University, Ube, Japan

K. Tamura
Kyouwa Construction Industry Co., Ltd., Hagi, Japan

B. I. Setiawan, S. K. Saptomo
Bogor Agricultural University, Bogor, Indonesia

ABSTRACT: A high density polyethylene rolled-band sheet with a width of 180mm and having perforated drainage small holes is transformed into a drainage pipe with 50mm in diameter at the construction site, just before inserting into the subsurface soil layer.

To confirm the efficiency of the sheet pipe, by using the newly developed Miniature-Type Model Soil Box, firstly the drainage capacity of the sheet pipe was compared with those of pipe-shaped drainage pipes, secondly, to find the characteristics of saturated–unsaturated flow in the subsurface soil layer when drained through the sheet pipe, the changes of water head and the matric potential were measured with time and thirdly, the applicability of sheet pipe as a drainage pipe was confirmed by the field tests.

The main conclusions are as follows. 1) By comparing the drainage capacity of the sheet pipe with four other pipe-shaped drainage pipes which are commercially used in Japan, the drainage capacity of the sheet pipe was confirmed to be effective for a soil with a relatively high coefficient of storage.2) Effects of the ground water level lowering by the sheet pipe drainage on the matric potential and volume water content were observed. 3) Efficiency of the sheet pipe was confirmed in a full scale field test.

RÉSUMÉ: Les feuilles de polyéthylene haut densité, 180 mm de largeur, ayant des petits trous perforés, sont emporté au chantier en form de rouleau. Le rouleau est placé au point de départ de l'installation du tuyau et il est attiré dans la couche de sol sous la surface continuellement et installé à une profondeur de 500mm avec une forme de tuyau par Mole Drainer. (Machine spéciale d'installation de tubes en feuille) La feuille est transformée en tuyau par le coffrage moulé placé à côté du rouleau, dont le diamètre est de 50 mm. La longueur du rouleau est d'environ 100 m.

L'efficacité des tuyaux polyéthylene est confirmé par Méthode Soil Box New, nouvellement développée Miniature-Type Model Soil Box. Tout d'abord, la capacité de drainage de ce tuyau a sera comparé avec des autres types, deuxièmement pour trouver les caractérisitiques de l'écoulememt d'eau staturé ou non staturé, les changements de tête de l'eau et du potentiel matriciel de l'écoulement en sousterrain a été mesuré avec le temp, troisièmement l'applicabilité de drainer de ce tuyau a été confirmé par les résultats des essais sur place.

Les principaux conclusions sont les suivants. 1) Au point de vue de drainage, en comparant la capacité de ce tuyau avec des autres tuyaux populaires au Japon, ce tuyau (sheet pipe) est efficase pour un sol ayant des eau intérieur non-couleé. 2) L'abaissement du niveau de l'eau souterrainne dans le couche mouillé, les effets par ce tuyau a été contents. 3) L'efficience de ce tuyau a été confirmé par des essais totalement sur le chantier.

Keywords: Ground water; Drainage; Seepage; Matric potential; Volume water content

1 INTRODUCTION

Drainage from the subsurface soil layer is important for the improvement of play ground, park, golf course and a plant field, etc., and also useful when improving the soft soil ground.

The sheet pipe is transformed by the pipe-shaping equipment from a high density polyethylene rolled-band sheet at the construction site and drawn into the soft soil layer by the Mole Drainer without trenching and keeping the pipe level horizontal. Because of such an installation of drainage pipe, the construction cost becomes very low and this method has been mainly adopted in Japan for expanding the multi-purpose farmland, especially in the paddy fields.

In this study, to evaluate the drainage capacity of the sheet pipe, by using the newly developed Miniature-Type Model Soil Box (hereinafter designated as MT-MSB), firstly the drainage capacity of the sheet pipe was compared with those of standard types of pipe-shaped drainage pipes, secondly to find the characteristics of saturated–unsaturated flow in the subsurface soil layer when drained through the sheet pipe, the changes of water head and the matric potential were measured with time and the changes of the volume water content were observed, and thirdly, by checking the gradient of the water flow in the pipe and by the results of field tests, the applicability of the sheet pipe was confirmed.

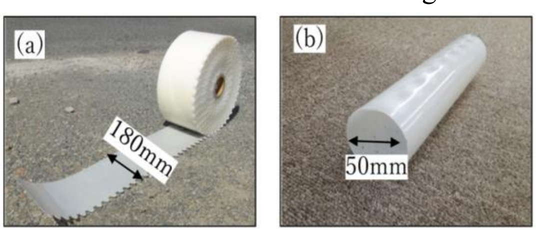


Figure 1. (a)Rolled-band sheet with the perforated drainage holes, (b)Sheet pipe transformed from the rolled sheet

2 SHEET PIPE INSTALLATION BY MOLE DRAINER

2.1 Process of insertion of the sheet pipe into the subsurface layer

The rolled-band sheet which is shown in Figure 1 (a) has perforated drainage holes with 2.0mm in diameter and the dimension is 180mm in width, 1.0mm or 0.7mm in thickness, and 100m in length per roll. This rolled-band sheet is transformed into the sheet pipe of 50mm in diameter as shown in Figure 1(b) by the Piper (pipe-shaping equipment) which is shown in Figure 2.

Then the sheet pipe is inserted into the subsurface soil layer at a predetermined depth D_p by connecting the leading bullet with 100 mm in diameter, which is horizontally drawn into the ground by the Mole Drainer. The process of insertion of the sheet pipe into the subsurface

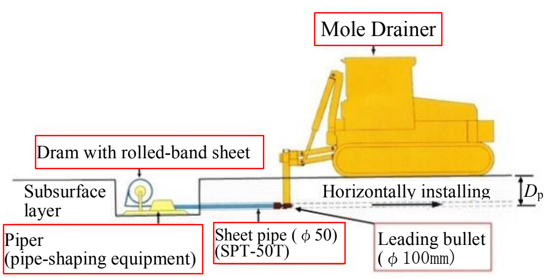
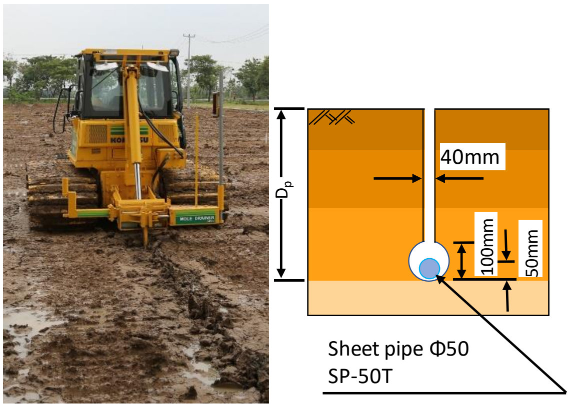


Figure 2. Process of insertion of the sheet pipe into the subsurface layer



(a) (b)

Figure 3. (a)Sheet pipe is under drawn into the ground, (b) Cross section of subsurface layer after the insertion of sheet pipe

layer is shown in Figure 2. Figure 3(a) shows the Mole Drainer which is under installing the sheet pipe and the cross section of the subsurface layer after the insertion of the sheet pipe is shown in Figure 3(b).

2.2 Advantages of drainage by using the sheet pipe

There are some advantages of using the sheet pipe. Firstly, since the sheet pipe is installed by the Mole Drainer without excavation and refilling, the construction period can be shorten about 1/4 of those for the conventional construction method and also the construction cost can be reduced approximately 50%. Secondly, as shown before, since the sheet pipe is transformed from the rolled-band sheet at the construction site, the packing size is very compact ($0.04m^3/100m$) and is 1/15 volume of the pipe-shaped drainage pipe. So, the transportation cost is very low. Thirdly, since the sheet pipe is installed horizontally, without making slope toward the drainage outlet, it is possible to use even in places where the height differences between the land and the drainage canal are relatively small.

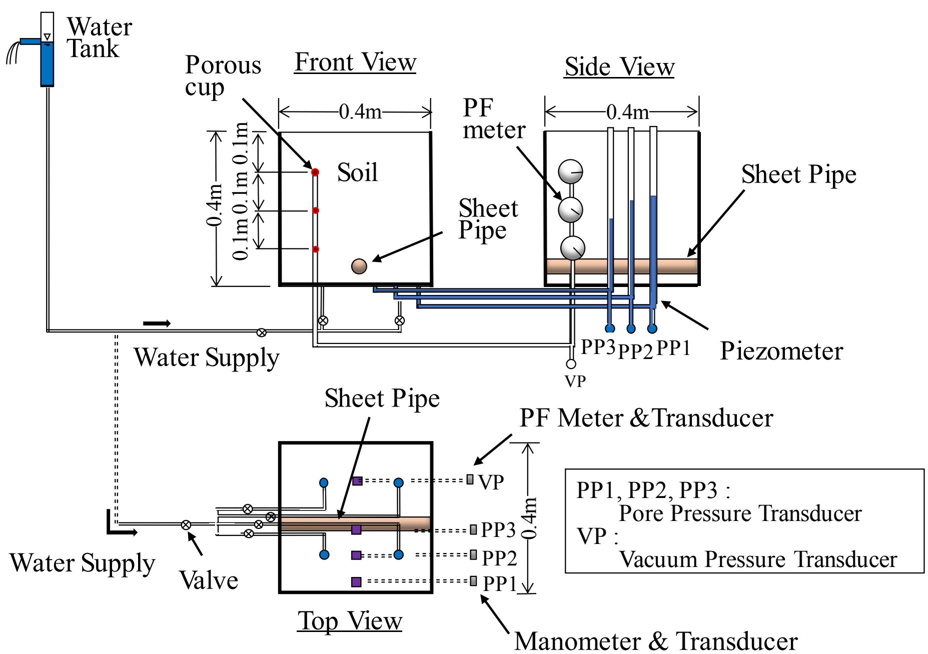


Figure 4. Outline of the Miniature-Type Model Soil Box (MT-MSB)

3 DRAINAGE CAPACITY OF SHEET PIPE

3.1 *Miniature-Type Model Soil Box*

To evaluate the drainage capacity of the sheet pipe, the Miniature-Type Model Soil Box (MT-MSB) as shown in Figure 4 was newly developed. Dimensions of MT-MSB are 0.4m×0.4×0.4m and polycarbonate plates with the thickness of 10mm were used for the box wall and the base plate. The center of the drainage pipe is placed at 75mm upper from the base plate, and through small holes on the base plate which are placed at a distance 30mm (PP3), 100mm (PP2) and 170mm (PP1) from the center of the drainage pipe, water heads and the atmospheric pressure were measured by using the high sensitive pressure transducers (PGM-02KG:max=20kPa). As for the change of the matric potential during the drainage test, the porous cup column was set horizontally at a depth 0.1m, 0.2m and 0.3m from the top surface of MT-MSB and the positive and negative pressure were measured by the pressure transducer (PGM-1KG: max=±100kPa). When supplying the water to MT-MSB after finishing the drainage test, the water was led from the constant head water tank to the four small holes of the base plate. The accumulation of the water drained through the sheet pipe was measured by the volume-correlated load transducer.

3.2 *Investigation on the drainage capacity of sheet pipe*

3.2.1 *Soil used in the drainage capacity test*

Used sample is Toyoura sand which was taken at Toyoura area in Yamaguchi prefecture, Japan.

The grain size distribution curve is shown in Figure 5 and physical properties are shown in Table 1, in which ρ_s is particle density, e_{max} and e_{min} are the maximum and minimum void ratio, D_r is the relative density and k is the coefficient of permeability. In the sheet pipe-used drainage tests, soil deposit was prepared by the pluviation method in which de-aired Toyoura sand was poured into MT-MSB.

Table 1. Physical properties of Toyoura sand

ρ_s (g/cm^3)	e_{max}	e_{min}	k (m/s) Dr=60%
2.641	0.975	0.604	2.9×10^{-4}

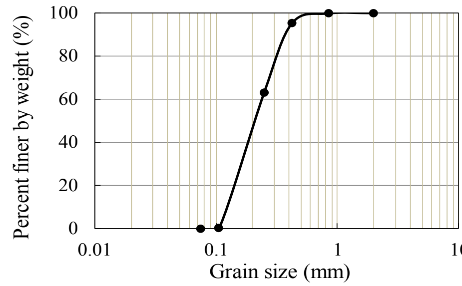


Figure 5. Grain size distribution curve of Toyoura sand

3.2.2 *Comparison of drainage capacities of sheet pipe with those of pipe-shaped drainage pipes*

To confirm the applicability of the sheet pipe, the drainage capacity of the sheet pipe was compared with those of four pipe-shaped drainage pipes which are commercially used in Japan. The outside diameter of each pipe is shown in Table 2 and the dimensions of perforated drainage holes are in the range from 2 to 8mm.

In the experiments, to prevent the sand particle from eroding through drainage holes, all the drainage pipes were covered with the stainless mesh. This is because the diameter of the perforated drainage holes on every pipe is larger than the maximum size of sand particle. To clarify the effect of the stainless mesh on the permeability, the constant head permeability test was carried out and the negligible effects were confirmed.

Table 2. Diameters of drainage pipes

Drainage pipe	Pipe A	Pipe B	Pipe C	Pipe D	Pipe E
Diameter (mm)	50.5	60.0	59.6	60.4	55.6

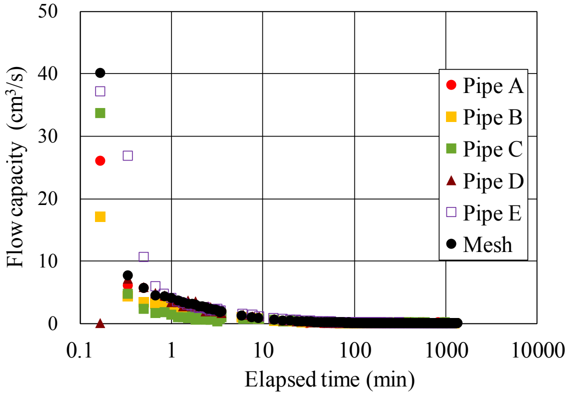


Figure 6. Changes of flow capacity with elapsed time

After installing the drainage pipe in MT-MSB, the sand was poured into the box with keeping Dr=60%. Then to prevent the air from remaining inside the drainage pipe, the drainage valve was opened and the water level of the downstream was kept the same as those in MT-MSB.

Figure 6 shows the change of flow capacity with time for each drainage pipe. At 10 sec after opening the drainage valve, the flow capacity reaches 40cm^3/s and 26 cm^3/s for the case of only mesh and pipe A (sheet pipe), respectively.

Based on the relationships between the flow capacity and the elapsed time, the coefficient of drainage capacity C_d which is defined as the ratio of the volume of discharged water through the drainage pipe to those only through the mesh was obtained on every drainage pipe. In Table 3, the coefficients of drainage capacity for each

Table 3 Coefficient of drainage capacities for each drainage pipe

Time (min)	Coefficient of drainage capacity				
	Pipe A	Pipe B	Pipe C	Pipe D	Pipe E
200	0.79	0.63	0.85	0.95	0.93
300	0.83	0.65	0.87	0.94	0.92
400	0.86	0.67	0.88	0.94	0.92
500	0.89	0.68	0.89	0.93	0.91
600	0.92	0.69	0.91	0.93	0.91
700	0.94	0.69	0.92	0.93	0.91
800	0.97	0.70	0.93	0.93	0.91
900	0.98	0.70	0.95	0.94	0.92
1000	1.00	0.71	0.97	0.94	0.92

drainage pipe are shown at a prescribed time. It is seen that at the time of 600min, C_d shows over 90% for pipes A, C, D and E, and that at 1,000min, pipe A reaches 100%. By these results, the drainage capacity of the sheet pipe is satisfied.

4 EFFECT OF DRAINAGE BY SHEET PIPE ON THE WATER HEAD, MATRIC SUCTION AND VOLUME WATER CONTENT

As mentioned before, at the base plate of MT-MSB, the pore water pressure were measured at PP1, PP2 and PP3. In Figure 7, the changes of the water head which is obtained from the pore water pressure are shown with time. It is seen that the decrease of the water head at PP2 or PP1, which position from the center of sheet pipe is farther than PP3, is apparently delayed. In Figure 8, the

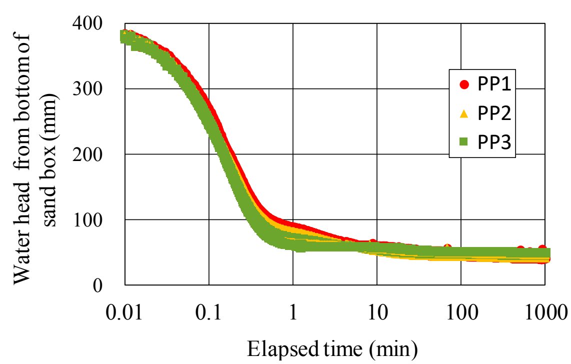


Figure 7. Lowering of water head by the Pipe

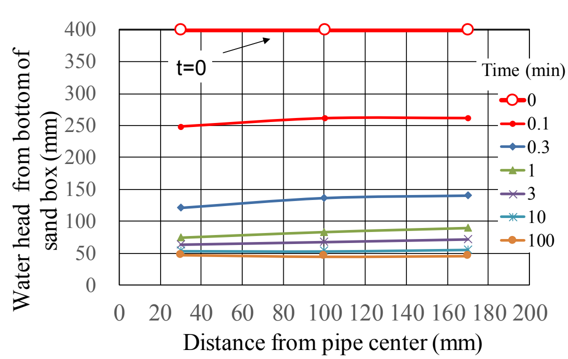


Figure 8. Distribution of water head

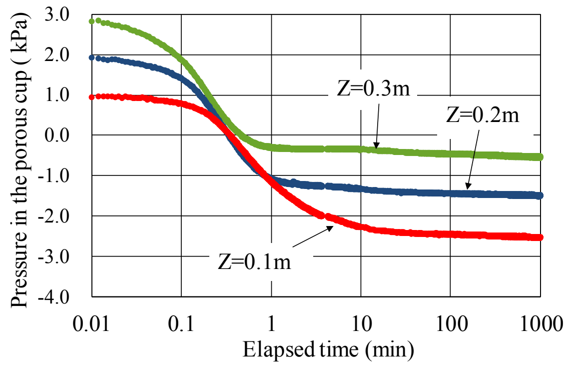


Figure 9 Pressure in the porous cup

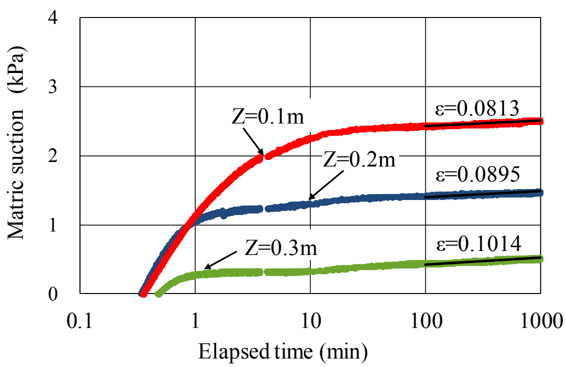


Figure 10. Change of matric suction in the soil

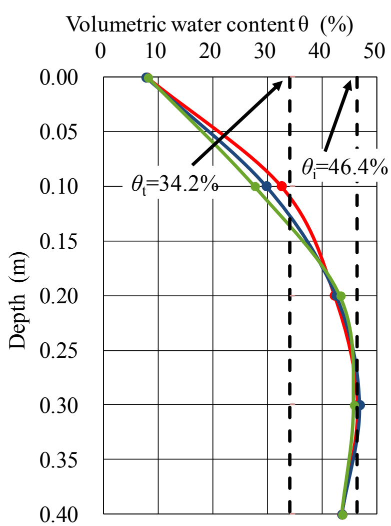


Figure 11. Distribution of volumetric water content

distributions of the water head for PP1, PP2 and PP3 are shown. t=0 in the figure means the initial water head. After starting the drainage test, it is seen that the water head quickly drops and the gradient of phreatic surface changes with the distance from the center of the drainage pipe. This results are useful for analyzing the seepage flow.

As mentioned before, to measure the matric suction in the soil layer, the porous cup was placed at the depth Z=0.1m, 0.2m and 0.3m from the top surface of MT-MSB. Relationships between the pressure in the porous cup and elapsed time are shown in Figure 9. Based on the result of Figure 9, the changes of matric suction S_u were obtained as shown in Figure 10. For every depth, it is seen that after 100 min the matric suction increases linearly with the elapsed time. So, the gradients of S_u to the logarithm of time defined as $\varepsilon = \Delta S_u/\Delta(log t)$ are shown in Figure 10 for the time between 100min and 1000min. Apparent tendencies that the gradient ε decreases with the level of matric suction are seen.

After finishing the drainage test, the water contents were measured at the position of 30mm, 100mm and 170mm from the center of the drainage pipe and also at the depth as Z=0.1m, 0.2m and 0.3m.

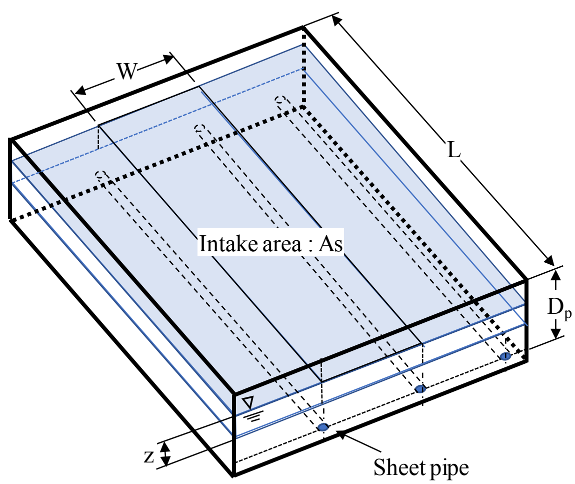


Figure 12. Intake model for the sheet pipe drainage

Figure 11 shows the distribution of volume water content θ which is defined as $\theta = \gamma_d / \gamma_w \times w$, where γ_d is the dry unit weight, γ_w is the unit weight of water and w is the water content. At the surface of the soil layer and at the depth of 0.3m, the volume water contents are about 8% and 46.4%, respectively. In this case, the coefficient of storage is obtained as S=12.2%.

5 APPLICABILITY OF SHEET PIPE BASED ON THE HYDRAULIC GRADIENT

5.1 *Flow capacity*

Figure 12 shows the intake model for the subsurface drainage, where A_s: intake area, W: spacing of sheet pipe, L: length of sheet pipe, D_p: depth of sheet pipe installation, S: coefficient of storage and z: lowering plan of ground water table.

Then, the intake volume of water V and the flow capacity are obtained as follows. (The Japanese Society of Irrigation, Drainage and Reclamation Engineering. 1980)

$$V = A_s \cdot z \cdot S \tag{1}$$

$$Q = v \times A \tag{2}$$

$$v = \frac{1}{n} \times R^{\frac{2}{3}} \times i^{\frac{1}{2}} \tag{3}$$

Where v: velocity, i: hydraulic gradient, A: flow area and $A = \frac{1}{4} \times \pi \times D^2$, D: diameter of the sheet pipe, R: hydraulic mean depth, $R = \frac{A}{P}$, P: wetted perimeter, and n: Manning's coefficient of roughness and n=0.010 was obtained for the

Table 4. Hydraulic gradient required for sheet pipe

Soil	*S* (%)	*Q* (×10^{-3}) (m^3/s)	*Hydraulic gradient* (%)
Soil 1	20.0	0.093	0.0077
Toyoura sand	12.2	0.056	0.0028

sheet pipe.

5.2 *Drainage capacity by the sheet pipe based on the hydraulic gradient*

To confirm the efficiency of the sheet pipe, the hydraulic gradient in the sheet pipe was calculated under the conditions of z=100/day, D=50mm, L=100m, W=4.0m, n=0.010 and S=0.122.

For the given conditions, the flow capacity Q=0.0056×10^{-3}m^3/s is obtained and by applying the diameter D=50mm, the hydraulic gradient i =0.0028% is obtained. For the drainage based on the ground water table lowering plan, to discharge the water without fulfilling the sheet pipe, the following equation is satisfied,

$$i = 0.0028\% \ll \frac{5}{10{,}000} = 0.05\% \tag{4}$$

The hydraulic gradient for Soil 1 (Uno, 1973) with different coefficient of storage is also shown in Table 4, in which it is seen that even for the soil 1 with higher coefficient of storage as S=20%, the sheet pipe satisfies the condition required for the drainage from the subsurface layer.

6 CASE STUDIES ON THE DRAINAGE BY USING SHEET PIPE

Installation of sheet pipe was performed at the Pilot Project Area in West Java Province, Indonesia. As shown in Figure 13, the test field with the area of 1,000m^2 is divided into two areas, a sheet pipe installed area (SP-area) and non sheet pipe area (NSP-area). In SP-area, the sheet pipe was installed by the Mole Drainer at a depth of D_p=0.45m and with the installation spacing of W=4.0m.

Figure 14 shows the outline of sheet pipe installation at SP-area and Nos.1-8 in the figure show the bore holes at which the changes of ground water level were measured. Table 5 shows the physical properties of sample obtained

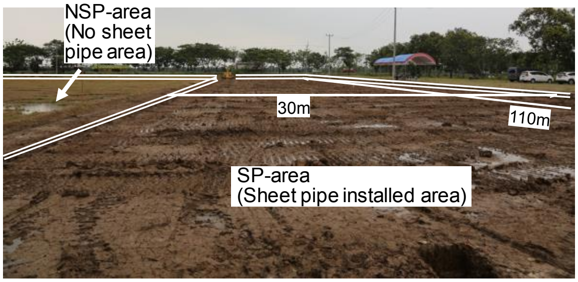


Figure 13. Pilot project area of 1,000m^2. In the SP-area, sheet pipe is under installing

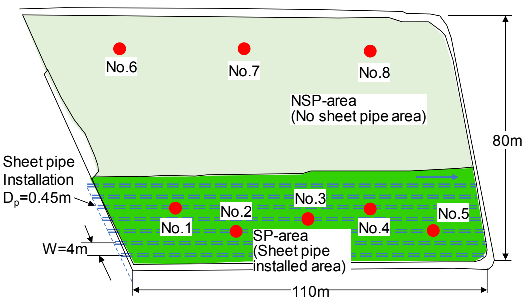


Figure 14. Outline of the test site

at Nos.1-5 and the coefficient of permeability observed by the tube method. It is seen that all the soils are classified as CH (Inorganic clay of high plasticity) and the permeability is very low compared with the soil used in the MT-MSB test.

In Figure 15, the changes of the ground water level (GWL) observed at Nos.1-5 in SP-area and Nos.6-8 in NSP-area are shown. Although the sheet pipe installation was started on March 12, 2018 and also the effect of the site preparation

Table 5. Physical properties of sample (0.0-0.5m)

Bore Hole	**No.1**	**No.2**	**No.3**	**No.4**	**No.5**
Clay(%) <0.005mm	69.10	80.75	67.06	61.82	57.77
Silt(%) <0.075mm	29.76	19.25	29.72	36.02	39.43
Fine sand(%) <0.420mm	1.14	0.00	3.00	2.16	2.12
w(%)	29.85	37.45	36.14	39.52	34.37
Gs	2.540	2.535	2.544	2.531	2.493
PI	32.77	45.37	44.18	32.97	37.80
Void ratio	0.76	0.96	0.93	1.01	0.87
k (cm/sec)	3.75×10^{-6}	1.98×10^{-5}	1.47×10^{-5}	5.91×10^{-7}	3.09×10^{-5}

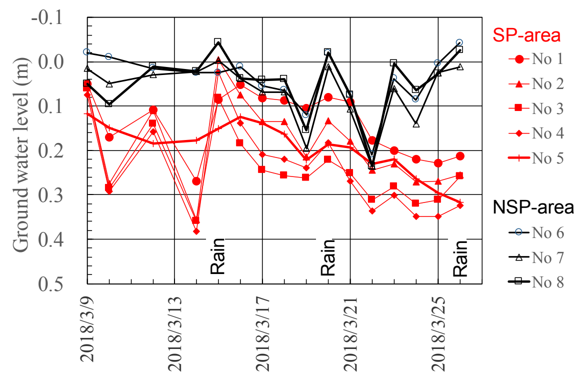


Figure 15. Effect of sheet pipe drainage on the ground water level lowering at the test site

remains, when comparing the GWL at SP-area with those of NSP-area, the apparent efficiency of the drainage by the sheet pipe is seen.

7 CONCLUSIONS

To confirm the drainage capacity of the sheet pipe, laboratory tests and the field tests were carried out.

The main conclusions are as follows.

1) By comparing the drainage capacity of the sheet pipe with four other pipe-shaped drainage pipes, the sheet pipe was confirmed to be effective for a soil with a relatively high coefficient of storage.
2) Effects of the ground water level lowering by the sheet pipe drainage on the matric potential and volume water content were observed.
3) Efficiency of the sheet pipe was confirmed by the full scale field test.

8 REFERENCES

Uno Takao. 1973. Seepage and drainage based on the characteristics of moisture retention of soil, Tsuchi to Kiso, JSSMFE, 21, 8, 21-25. (in Japanese)

The Japanese Society of Irrigation, Drainage and Reclamation Engineering. 1980. Handbook of Agricultural Engineering. (in Japanese)