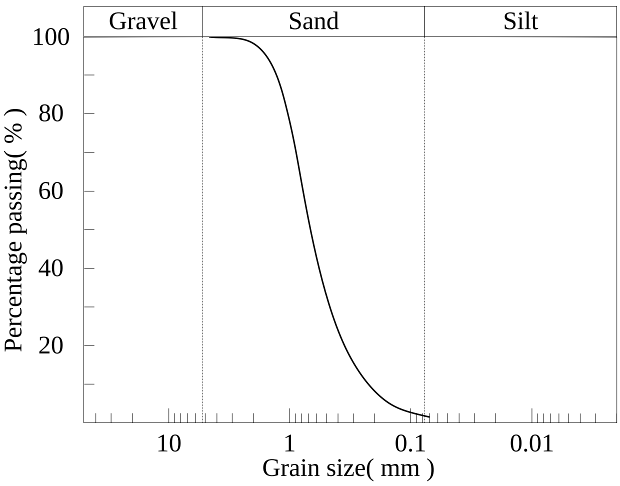


Parameters	Sand
Gravity(G_s)	2.64
D_{50}	0.68
e_{max}	0.91
e_{min}	0.63
Dry unit weight(kN/m^3)	14.70
Cohesion(c, kN/m^2)	0
Shear resistance angle(φ, °)	31°

Fig. 2 Properties of soil to use in test

As the bearing characteristics of the pile is mainly dependent on the flexural rigidity of the pile, the diameter of the model pile was determined by considering the following relative rigidity to secure the similarity between the model and prototype.

$$\lambda_{EI} = \frac{E_p I_p}{E_m I_m} \tag{1}$$

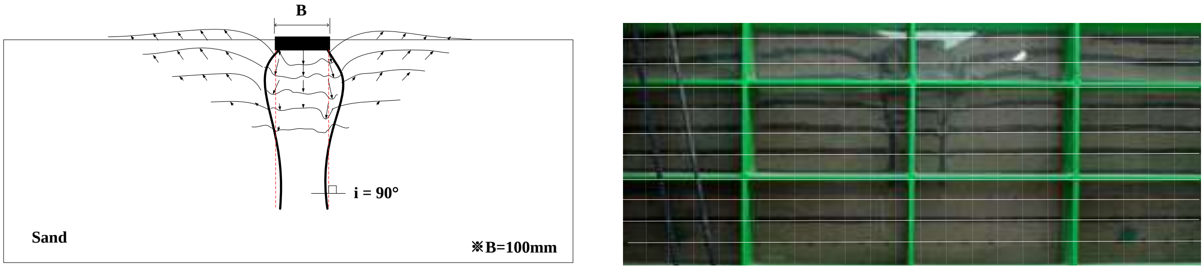
The subscripts p and m means the prototype and model respectively. According to Iai(1989), the λ_{EI} (bending rigidity scale factor) for the micropile is about 35. The model micropile simulates a prototype micropile with a diameter of 200 mm. To satisfy Eq.(4), the diameter of the model pile is set at 2 mm and the pile is made of steel. Soil particles are attached to the surface of the model micropile using glue as shown in Fig. 1(b) in order to introduce the frictional interface on the boundary surface between the soil and the micropile (Tsukada et al., 2006).

Model tests were conducted for the installation angle(i) of 45°, 60°, 75° and 90°. In each test, a load was applied until the ratio of vertical displacement to the width of the foundation, that is to say, the vertical strain, exceeded 10% which is considered as a state of failure (Han and Ye, 2006).

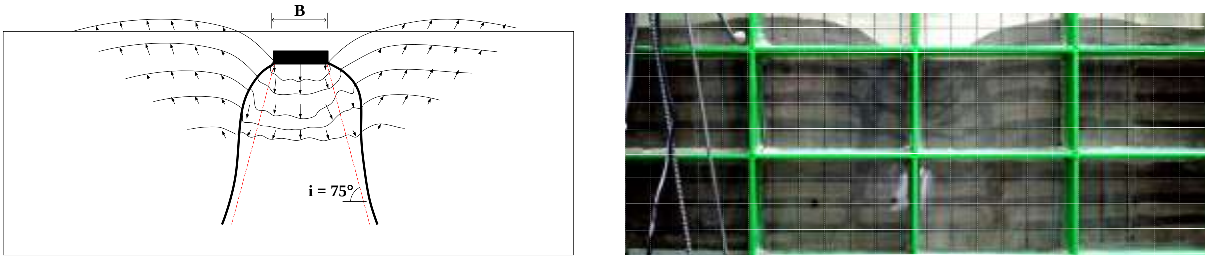
3. FAILURE MODES OF MICROPILED-RAFT

Fig.3 shows the failure mode of miropiled-raft with the installation angle after test. In results, the failure area showed a general shear failure mode similar to a shallow foundation, the failure zone of micropiled-raft varied depending on the installation angle. By comparing Fig.3(a) and Fig.3(b), it can be seen that the failure zone extended significantly in the battered installation comparing to the vertical installation.

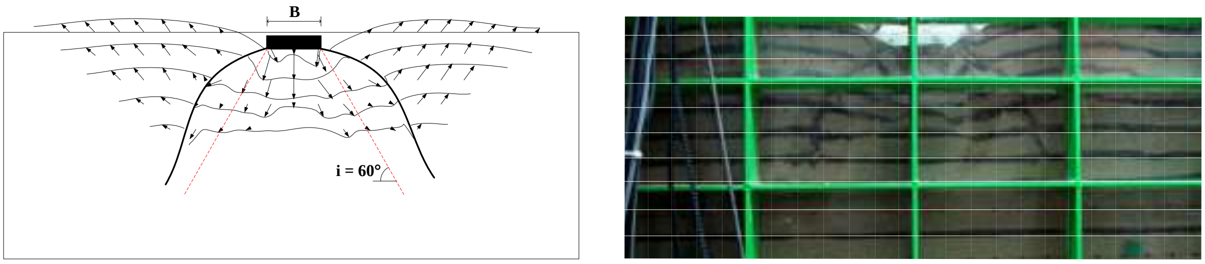
And the failure area in case of the battered pile conditions was extended as the installation angle derease. Especially, the failure area was significantly extended in the case of i = 60° comparing with the case of i = 90°. However it was similar to the case of i = 45°, as shown in Fig.3(c) and Fig.3(d).



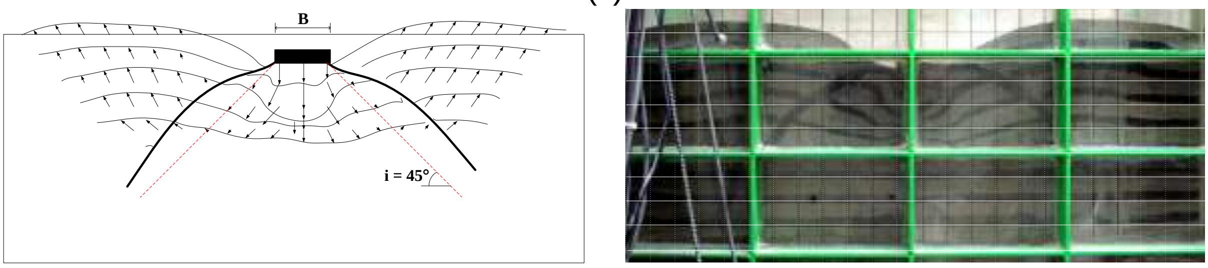
(a)



(b)



(c)

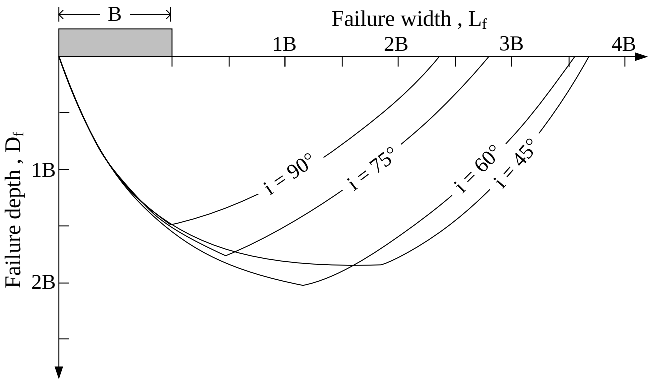


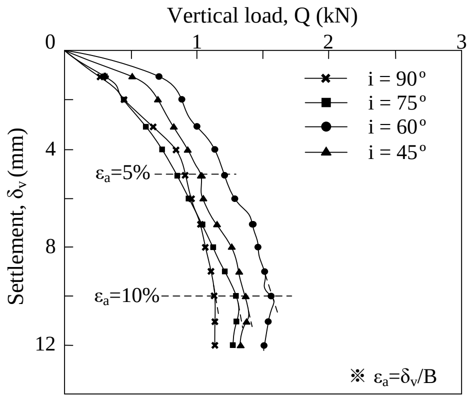
(d)

Fig. 3 Failure of micropiled-raft with the installation angle of micropile. (a) i = 90°, (b) i = 75° , (c) i = 60° , (d) i = 45°

Fig.4 compares the failure area and bearing capacity. In shows that, the failure width in the case of i = 90° was extended 2.3 times of B(= width of raft), and the failure depth was extended 1.5 times of B as shown in Fig.4(a). In the case of battered installation with i = 45° ~ 75°, it can be seen that the failure width and depth was extended considerably comparing with the case of i = 90°. Especially, the failure width and depth of the failure area in case of i = 60° were significantly extended. In comparing the case of i = 60° and i = 45°, the failure width was similar, while the failure depth for i = 45° decreased.

The load-displacement relationship for each test cases are shown in Fig.4(b). The maximum vertical load was about 1.15kN ~ 1.60kN, depending on the installation angles. And the vertical load in the case of i = 60° was greater than in other cases, while the load in the case of i = 90° was small. The results of model test confirmed that the bearing capacity of micropiled-raft is closely related to the failure area to be varied by the installation angle. Thus the installation angle is important factor in enhancing the bearing capacity.





(a) (b)

Fig.4 Comparison of test results. (a) failure area , (b) bearing capacity

Fig.5 shows the $L_{f(i < 90°)} / L_{f(i = 90°)}$ and $D_{f(i < 90°)} / D_{f(i = 90°)}$ - i relationship. Here, L_f and D_f is the failure width and depth, and the subscripts i = 90° and i < 90° represent the case of vertical and battered installation, respectively. The failure width ratio defined by $L_{f(i < 90°)} / L_{f(i = 90°)}$ increased as the installation angle decreased, and became constant when i is less than 60°. The maximum failure width for i = 60° was strongly extended, which is about 1.5 times comparing to the case of i = 90°. While the failure depth ratio defined by $D_{f(i < 90°)} / D_{f(i = 90°)}$ also increased as the installation angle decreased, but was decreased in exceeding i = 60°. In the case of i = 60°, the failure depth ratio was the maximum value, the failure depth is extended about 1.3 times comparing to the case of i = 90°.

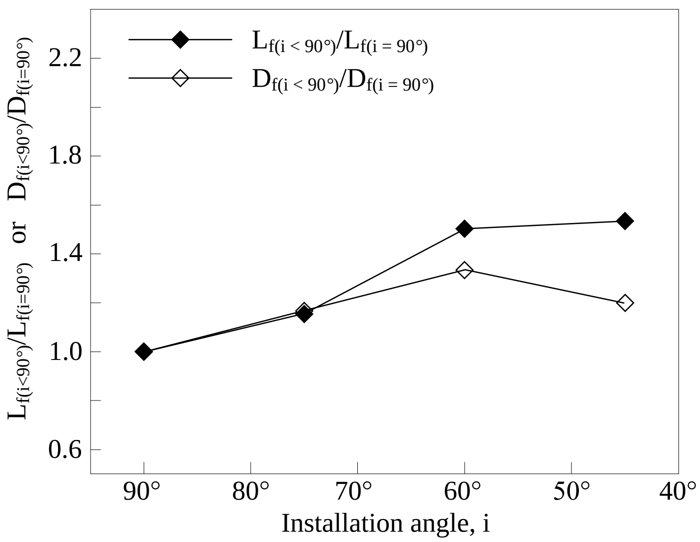


Fig.5 Effect of installation angle on the failure area

4. CONCLUSION

The failure modes of micropiled-raft with the installation angle were investigated by performing a model test. The results showed that the failure modes and bearing capacity were significantly influenced by the installation angle. It can be concluded that the failure mode and installation angle should be properly considered to enhance the bearing capacity of the micropiled-raft.

(a) The failure area of micropiled-raft in the case of battered installation is extended comparing with the case of vertical installation. The failure area is considerably extended with a decrease in the installation angle.
(b) The failure width increases as the installation angle decreases, and become constant when i is less than 60°. The failure depth also increase as the installation angle decrease, however it decrease when i exceed 60°.
(c) The failure width is the maximum in the case of i = 60°, and this is about 1.5times wider comparing to i = 90°. Meanwhile the failure depth is the maximum when i = 60°, and this is about 1.3times comparing to i = 90°.

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REFERENCE

FHWA(2005),"Micropile Design and Construction", United States Department of Transportation, No. FHWA NHI-05-039, December, pp.3-11~3-22.

Han, J. and Ye, S. L.(2006), “A Field Study on the Behavior of a Foundation Underpinned by Micropiles”, Canadian Geotechnical Journal, 43(1), pp.30~42.

Hoalley, P.J., Francis, A.J. and Stevens, L.K.(1969), “Load Testing of Slender Steel Pile in Soft Clay”, Proceeding of 7th International Conference Soil Mechanics and Foundation Engineering, 2, pp.123~129.

Holman, T.P.(2009), “Behavior and Mechanics of Micropiles in Rock”, Proceeding of the 17th International Conference on Soil Mechanics and Geotechnical Engineering, Alexadria, Egypt, 5-9 October 2009, pp.1349~1353.

Iai, S.(1989), “Similitude for Shaking Table Tests on Soil-Structure- Fluid Model in 1g Gravitational Field”, Journal of Soil and Foundation, 29(1), pp.105~111.

Lizzi, F.(1982),”Static of Monuments”, Sagep Publisher, Genoa, Italy, pp.78~144.

Madhira, R.M. and Sharma, J.K. and Sivakumar. V.(2009), “Settlement of and Load Distribution in a Granular Piled Raft”, Geomechanics and Engineering, 1(1), pp.97~112.

Meyerhof, G.G. and Yalcin, A.S.(1993), “Behavior of Flexible Battered Piles under Inclined Load in Layered Soil”, Canadian Geotechnical Journal, 30(2), pp.247~256.

Meyerhof, G.G.(1995), “Behavior of Pile Foundations under Special Loading Conditions”, Canadian Geotechnical Journal, 32(2), pp.204~222.

Pinyol, N.M. and Alonso, E.E.(2012), “Design of Micropile for Tunnel Face Reinforcement : Undrained Upper Bound Solution”, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 138(1), pp.89~98.

Poulos, H.G. and Davis, E.H.(1980), “Pile Foundation Analysis and Design”, John Wiley

& Sons, INC., New York, pp.71~142.

Randolph, M.F.(1994), “Design Method for Pile Groups and Piled Raft”, Proceeding of the 13th International Conference Soil Mechanics and Foundation Engineering, 5, pp.61~82.

Shu, S. and Muhunthan, B.(2010), “Influence of Sand State on Network Effect of Micropile”, Proceedings of the 10th International Society for Micropiles Workshop, Washington.

Sun, S.W., Zhu, B.Z., Wang, J.C.(2013), “Design Method for Stabilization of Earth Slope with Micropile”, Journal of Soil and Foundation, 53(4), pp.487~497.

Tsukada, Y., Miura, K., Tsubokawa, Y., Otani, Y. and You, G.(2006), “Mechanism of Bearing Capacity of Spread Reinforcing with Micropile”, Journal of Soil and Foundation, 46(3), pp.367~376.

You, G.L., Miura, K. and Ishito, M.(2003), “Behavior of Micropile Foundation under Inclined Loads in Laboratory Tests”, Lowland Technology International, 5(2), pp.16~26.