YONSEI UNIVERSITY

Combined Effects of Embedded Angle and Pile Spacing on Load Responses of Micropiles in Sand

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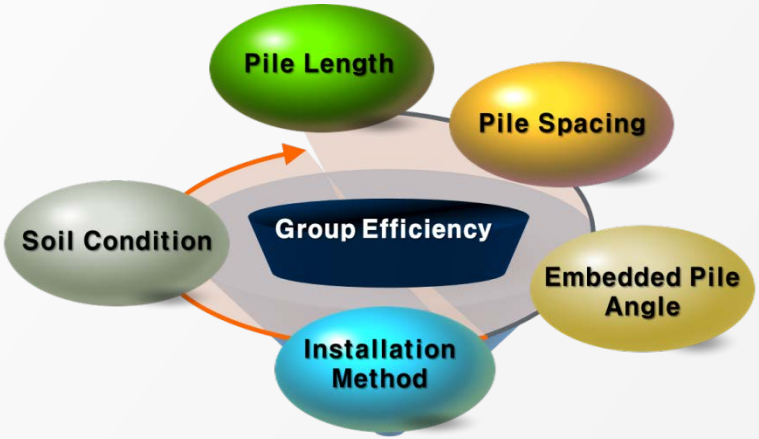
1. Introduction

Micropile

- Introduced by Lizzi in 1950s
- D < 300 mm

Group micropiles

- How to consider the group efficiency ?



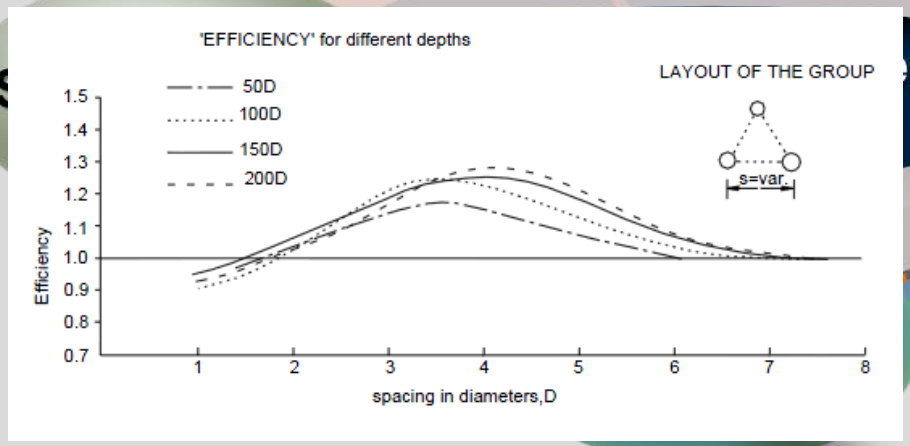
Many researchers had experimental tests to investigate the group efficiency !

Group efficiency

◈ **Lizzi et al 1985**

- L= 50D, 100D, 150D, 200D
- S = 1D – 8D

➡ Positive group efficiency (S=2D-7D)

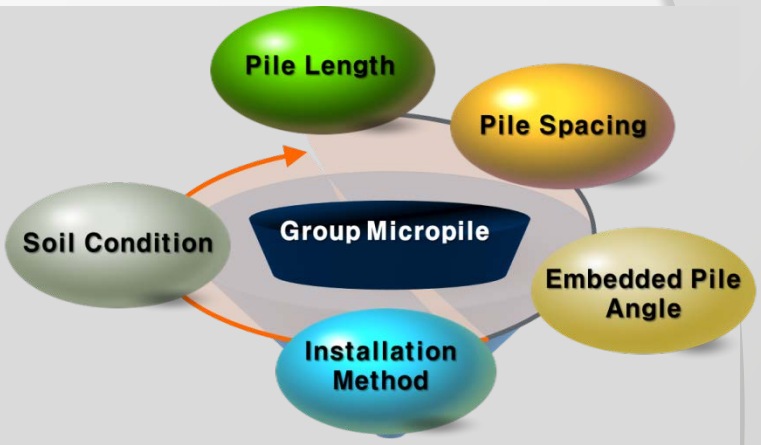


Group efficiency

◈ Lee 1991

- Retriculated micropile
- Pile spacing and pile length

➡ highest group efficiency on S=8D



◈ Forever 2002

- Several full-scale and reduced-scale models

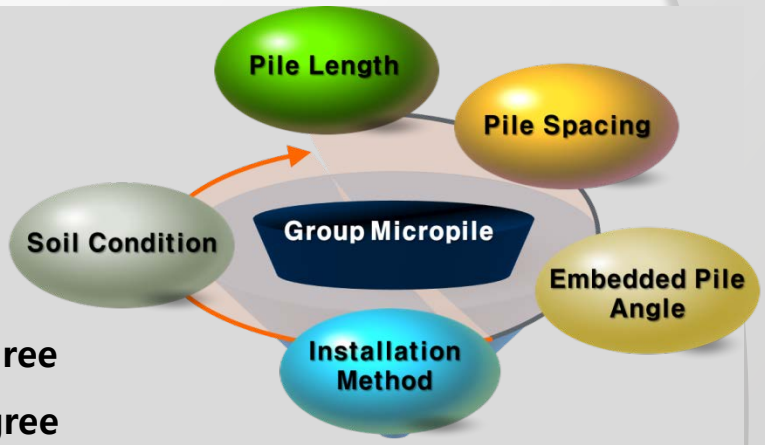
➡ group efficiency ≤ 1

➡ group efficiency > 1 : large number of micropiles

Group efficiency

◈ Tsukada 2006

- Pile rigidity, pile embedded angle, soil condition
  - ➡ Effective pile embedded angle 15 to 30 degree
  - ➡ More effective pile embedded angle 15 degree on large settlement



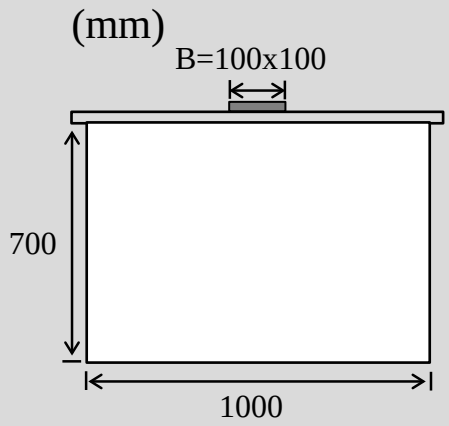
◈ Present study

- Combined effect of pile spacing & embedded pile angle
- Consider the pile spacing (S=3D, 5D, 7D)
- Consider the embedded pile angle (Θ=0°, 15°, 30°, 45°)

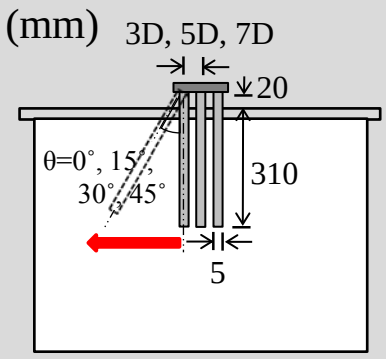
Test types and conditions

◈ Test types

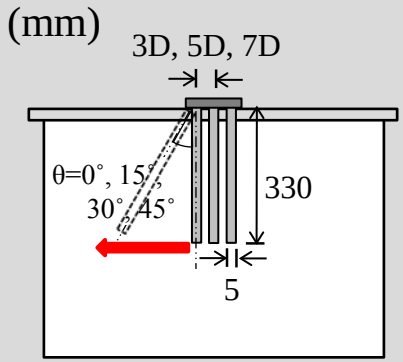
- 3 types of tests : unpiled raft, group micropile, micropiled-raft



Unpiled raft



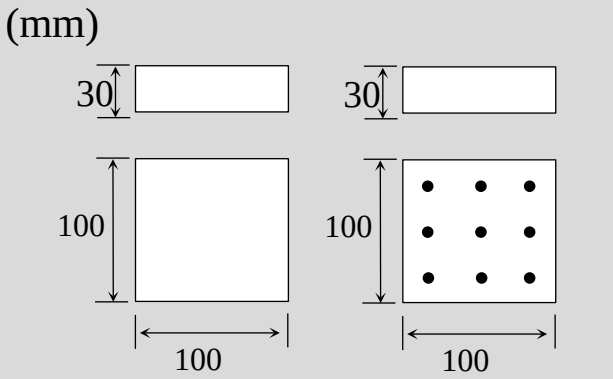
Group micropiles



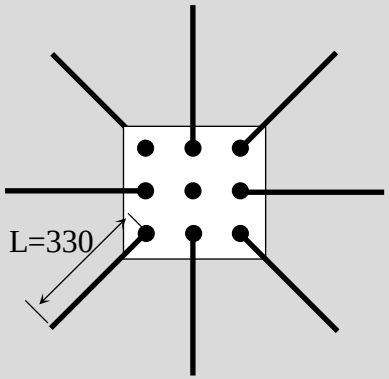
Micropiled-raft

Test types and conditions

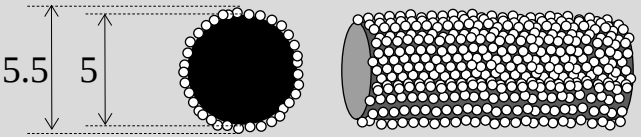
◈ Model configurations



Model raft and micropiled-raft



Top view of typical micropiled-raft



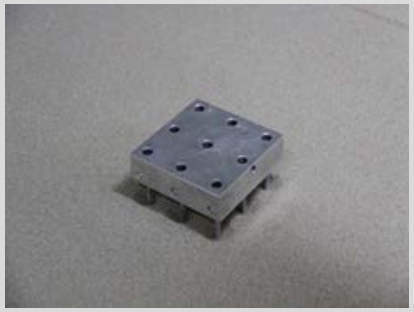
Model micropile

Test types and conditions

◈ Procedure of axial load test

Making the model specimen

Installation of micropiles



Completion of group micropile

Performance of axial load tests

2. Testing Program

Test types and conditions

◈ Soil conditions

- **Jumunjin sand (clean silica sand)**
- **Friction angle obtained by Triaxial tests**

$$\phi' = 0.034 \cdot D_R + 37.03$$

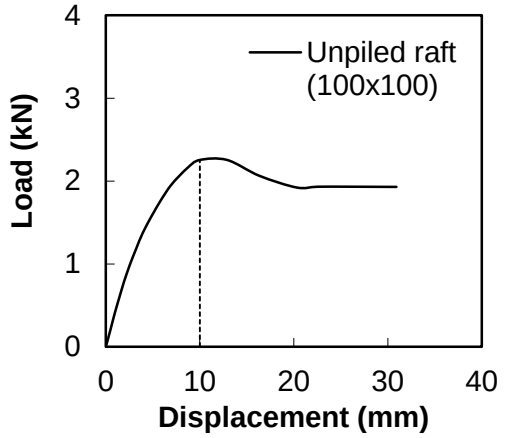
◈ Basic properties of test sand

Max. void ratio (e_{max})	0.927
Min. void ration (e_{min})	0.591
Specific gravity (G_s)	2.65
D_{10} (mm)	0.335
D_{50} (mm)	0.525
Uniformity coefficient (C_u)	1.73
Curvature coefficient (C_c)	0.97
Max. dry unit weight (kN/m^3) (γ_{max})	16.34
Min. dry unit weight (kN/m^3) (γ_{min})	13.49
Soil type (USCS)	SP

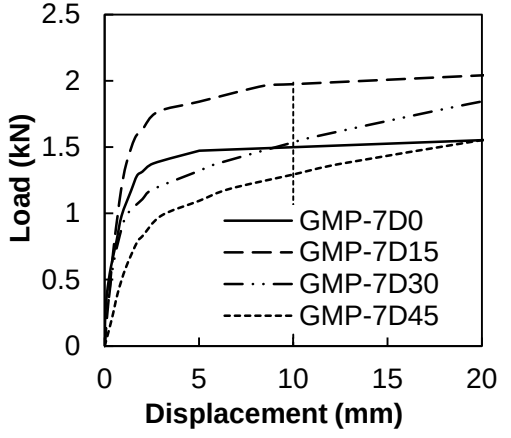
3. Test Result and Analysis

Variation of load capacity

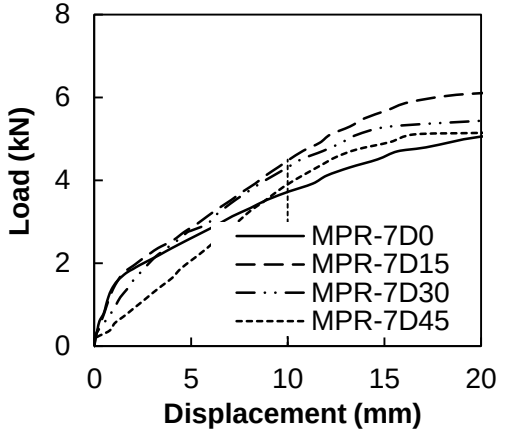
◈ Unpiled raft



◈ Group micropile



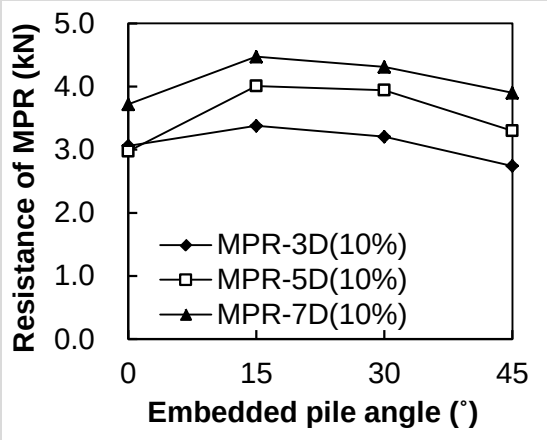
◈ Micropiled-raft

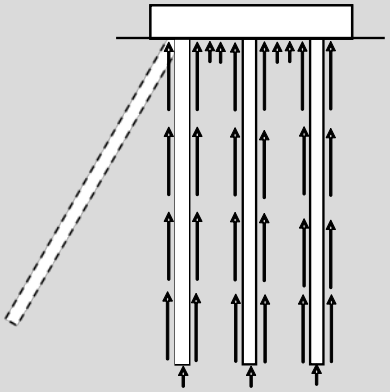


- **Load capacity : 10% width of unpliled raft**
- **Same criteria applied on GMP and MPR**

Variation of load capacity

◈ Resistance of MPR

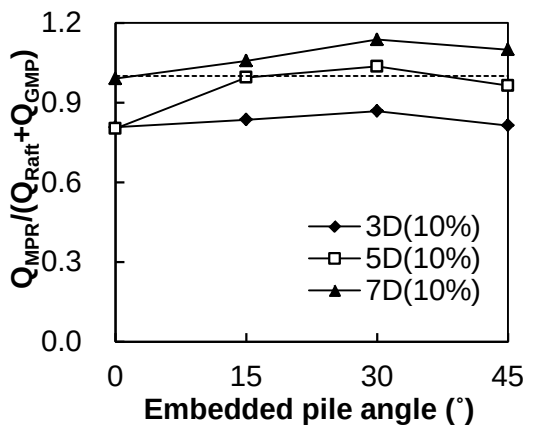


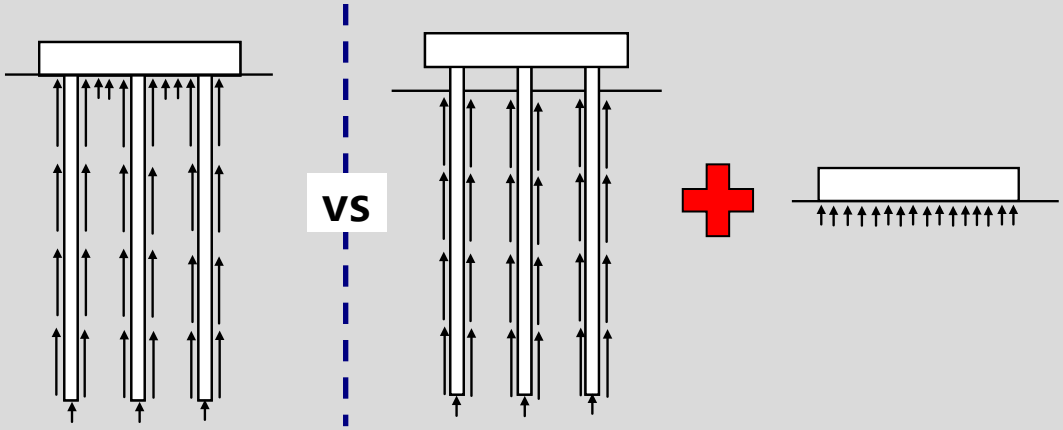


- Resistance change with pile spacing and embedded pile angle
- Resistance increase with pile spacing
- Highest resistance measured on 15 degree of embedded pile angle

Variation of load capacity

◈ Resistance efficiency of MPR

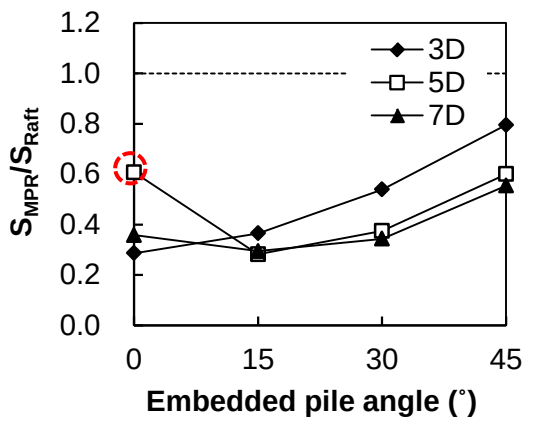




- Resistance efficiency of MPR change with pile spacing and embedded pile angle
- 3D : $Q_{MPR} \approx 0.8(Q_{Raft} + Q_{GMP})$
- 5D : $Q_{MPR} \approx 1.0(Q_{Raft} + Q_{GMP})$
- 7D : $Q_{MPR} > 1.0(Q_{Raft} + Q_{GMP})$
- Highest resistance efficiency measured on 30 degree of embedded pile angle

3. Test Result and Analysis

Settlement reduction of micropiled-raft



- Standard load : Ultimate load for unplied raft (10% width of unpiled raft)
- Settlement reduction increase with pile spacing
- Settlement reduction decrease with embedded pile angle
- 0˚ : $S_{MPR} \approx 0.3 \sim 0.4\ S_{Raft}$ (except MPR-3D0)
- 15˚ : $S_{MPR} \approx 0.3 \sim 0.4\ S_{Raft}$
- 30˚ : $S_{MPR} \approx 0.38 \sim 0.6\ S_{Raft}$
- 45˚ : $S_{MPR} \approx 0.6 \sim 0.8\ S_{Raft}$

4. Conclusion

1 **In presents study, increase resistance and settlement reduction for using the micropiles were investigated with pile spacing and embedded pile angle**

2 **The resistance increase with pile spacing and the highest resistance of MPR was measured in 15 degree of embedded pile angle.**

3 **The resistance efficiency of MPR increase with pile spacing and the highest value measured in 30 degree of embedded pile angle.**

4 **The settlement reduction increase with pile spacing and decease with embedded pile angle, the highest settlement reduction measured in 0 or 15 degree of embedded pile angle**

Thank you

Q & A