2022「中技社科技獎學金」

2022 CTCI Foundation Science and Technology Scholarship

境外生生活助學金

Living Grant for International Graduate Students

Numerical Analysis on Response of Laterally Loaded Piles in a Coupled Poro-elastic Soil on Different Ground Conditions.

Alex Atanaw Alebachew (3rd year PhD Candidate), Meen-Wah Gui (Professor)

Department of Civil engineering , National Taipei University of Technology

Graduate Institute of Civil and Disaster prevention engineering

Abstract

The coupled hydro-mechanical analysis of laterally loaded single and group pile using finite element method were carried out in the homogeneous flat and slope ground using a commercial software COMSOL 2D and 3D Multiphysics interface. the generation of excess pore-water pressure to analyse the coupled problem in undrained soil , The deflection and bending moment at the maximum excess pore water pressure were computed in a 2D single pile analysis. The group effect of the pile was extended from the single pile in various parametric combinations. The p-y curve was developed to investigate the slope reduction factor of initial stiffness and bearing capacity of soil at different slope angle.

Research Focus

I. Response of single pile in various loading rates

Motivation

- ✓ **Soil pile interaction** is a complicated problem that needs a though investigation for the advancement of Civil work technology.
- ✓ However, simplified assumptions are mostly taken into account to ease of the complication .
- ✓ Thus, resulting non-representative out puts are extracted and cause a disaster.
- ✓ **Objective:** Design a coupled physics model for the complete analysis of soil structure interaction.

Proposed model and material

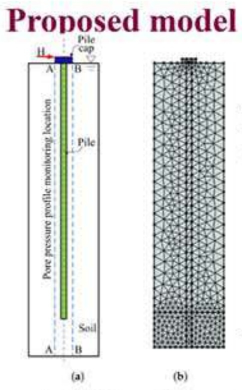

Table 1. Input parameters used in the analysis.

Constants	Value
Elastic modulus of soil	7.0 MPa
Poisson's ratio of soil	0.35
Density of soil	1690 kg/m³
Void ratio	0.6
Apparent cohesion c'	10.0 kPa
Angle of shearing ϕ'	13.3°
Saturated hydraulic conductivity	3.22 ×
Biot-Willis coefficient	1.0
Elastic modulus of concrete	30.0 GPa
Poisson's ratio of concrete	0.156
Density of concrete	2500 kg/m³

Figure 1. (a) Schematic layout of the study problem; (b) typical numerical mesh used in the analysis.

Governing equation

$$\frac{1}{M}\frac{\partial p}{\partial t}+\nabla\left[-\frac{k}{\mu}\nabla\left(p+\rho_f g z\right)\right]=-\alpha_B\frac{\partial}{\partial t}\varepsilon_{\text{vol}} \quad (2)$$

$$\frac{1}{M}=\frac{\alpha_B-n}{K_s}+\frac{n}{K_f} \quad (3)$$

$$k_n=\frac{E(1-v)}{d_s(1+v)(1-2v)} \quad (4)$$

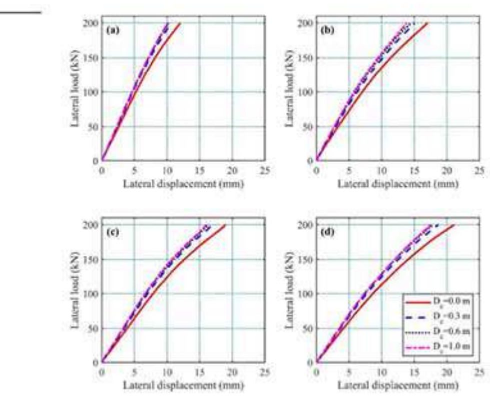

Figure 4. Effect of cap embedment depth on lateral displacement of pile cap: (a) undrained (loading rate = 2 kN/s); (b) partially drained (loading rate = 2 kN/h); (c) drained (loading rate = 2 kN/day); and (d) dry soil (loading rate = 2 kN/step).

Part of Result

Table I. Positioning performance with Various Evaluation Metrics

Loading Rates	Pile Responses (Maximum)	Elapsed Time					
2 kN/s (Undrained)		10 s	50 s	100 s	1 h	10 h	100 h
	Lateral displacement (mm)	1.10	5.68	12.40	15.69	21.46	22.42
	Bending moment (MNm)	5.86	31.90	67.82	80.74	87.04	87.67
2 kN/h (Partially-drained)		10 h	50 h	100 h	200 h	500 h	1000 h
	Lateral displacement (mm)	1.37	7.89	17.70	21.43	21.84	21.90
	Bending moment (MNm)	6.71	36.73	77.59	86.13	86.23	86.28
2 kN/day (Drained)		10 days	50 days	100 days	200 days	500 days	—
	Lateral displacement (mm)	1.64	8.73	21.37	21.77	21.77	—
	Bending moment (MNm)	6.77	36.83	85.22	85.87	85.87	

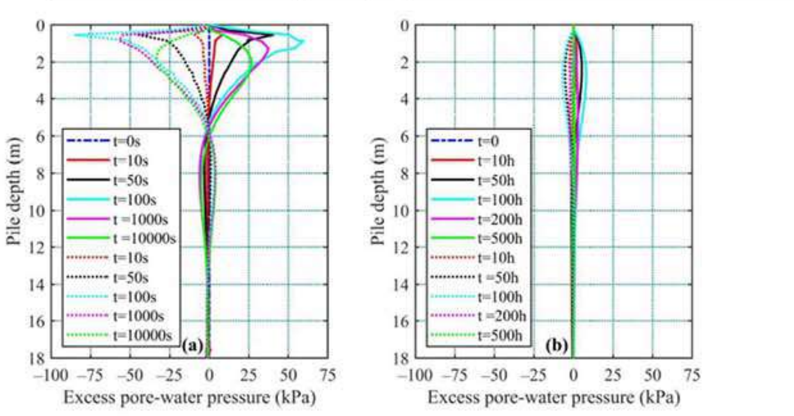

Figure 2. Generation and dissipation of excess pore water pressure at Sec. A-A and Sec. B-B (see Figure 1a) during the loading of the pile: (a) fast loading rate: 2 kN/s (undrained); and (b) slow loading rate: 2 kN/h (partially drained).

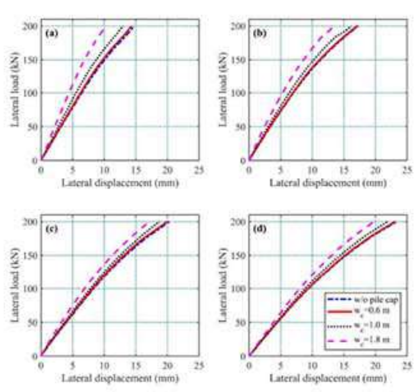

Figure 5. Effect of pile cap width on lateral displacement of pile cap: (a) undrained (loading rate = 2 kN/s); (b) partially drained (loading rate = 2 kN/h); (c) drained (loading rate = 2 kN/day); and (d) dry soil (loading rate = 2 kN/step)

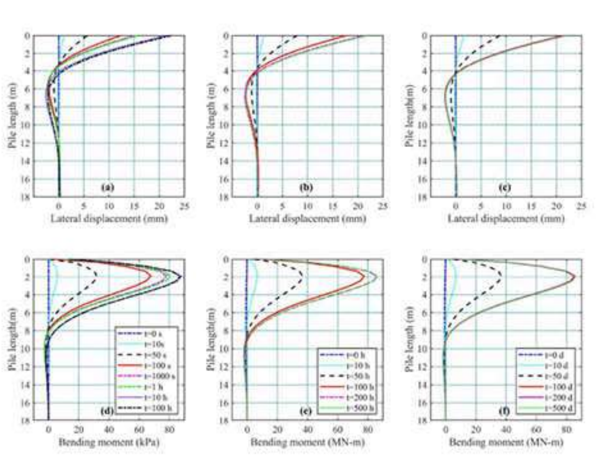

Figure 3. Responses of pile under various loading rates: lateral displacement under the rate of (a) 2 kN/s (undrained); (b) 2 kN/h (partially drained); (c) 2 kN/day (drained); bending moment under the rate of (d) 2 kN/s (undrained); (e) 2 kN/h (partially drained); and (f) 2 kN/day (drained).

Table 3. Effect of pile cap embedment depth on lateral displacement of pile cap under various loading conditions and in dry soil.

Cap Embedment (m)	2 kN/s (Undrained) (m)	2 kN/h (Partially-Drained) (m)	2 kN/Day (Drained) (m)	2 kN/Step (Dry) (m)
0.0	12.0	17.0	19.0	21.1
0.3	10.6	15.0	16.9	18.7
0.6	10.2	14.6	16.4	17.9
1.0	10.1	13.8	16.0	17.5

Table 4. Effect of cap width on displacement of pile cap under various loading conditions and in dry soil.

Cap Width (m)	2 kN/s (Undrained) (m)	2 kN/h (Partially-Drained) (m)	2 kN/Day (Drained) (m)	2 kN/Step (Dry) (m)
w/o cap	14.8	17.2	20.2	23.3
0.6	14.3	17.1	19.9	23.1
1.0	13.0	16.1	18.7	21.9
1.8	10.2	13.4	17.1	19.8

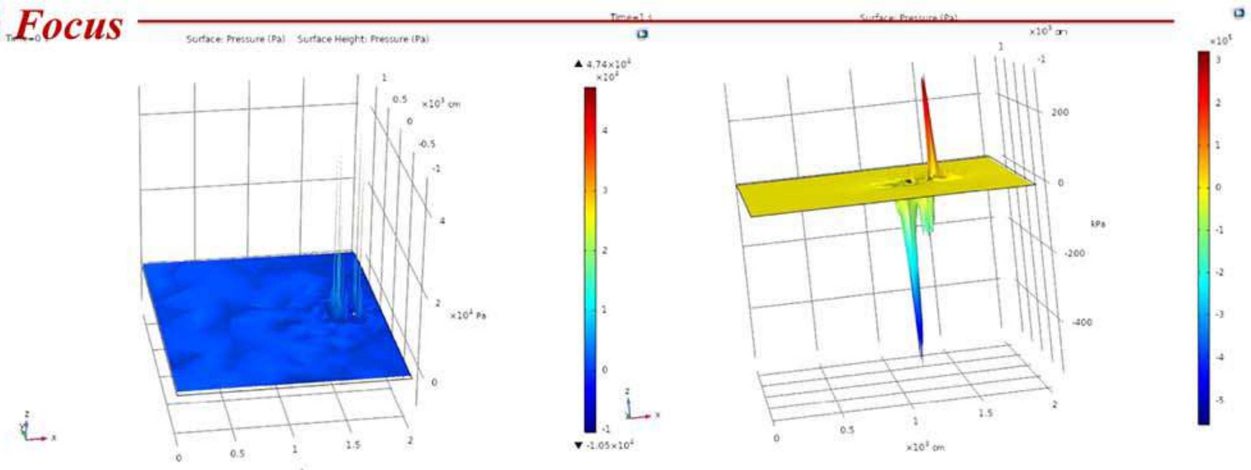

Fig 4. The distribution of excess pore water pressure from hydrostatic pressure to a value with quick loading

II. Group response of pile on slope ground

Motivation

Group pile response

- ✓ Capable to do a complete analysis of static pile design.
- ✓ Can be able to set the proper configuration of the group on a slope ground .
- ✓ Enable to hydro-mechanical coupling of soil subjected by lateral load to analyze group response of pile and develop the p-y curve to analyze the initial soil stiffness and soil bearing capacity.

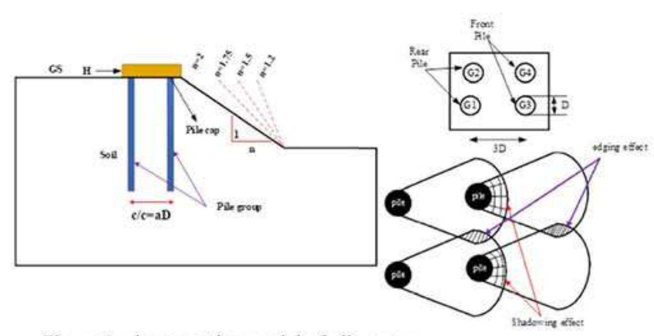

Figure 1. planar section model of pile group

➢ **Objective:** To extend the response of the single pile to an interactive group effect on slope ground .

$$p=\frac{k_{ini}y}{1+\frac{k_{ini}y}{p_u}}$$

$$p=\frac{a_k k_{io}y}{1+\frac{a_k k_{io}y}{a_p p_u}}$$

Parametric values

- Rate of loading
- Pile group spacing
- Setback distance
- Slope angle variation

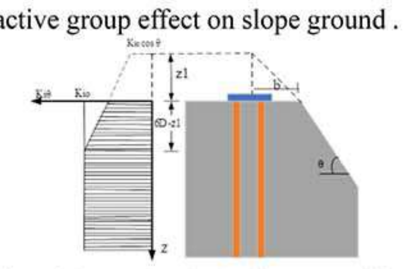

Figure 6. Effect of slope angle and edge distance on stiffness

$$a_k=\frac{K_i}{K_o}=\cos\theta+\frac{z}{6D}(1-\cos\theta)\le 1$$

$$a_k=\frac{K_i}{K_o}=\cos\theta+\frac{1-\cos\theta}{6D}\left[\frac{z}{6D}+(\frac{s}{D}-0.5)\tan\theta\Big)\right]\le 1$$

Part of Result

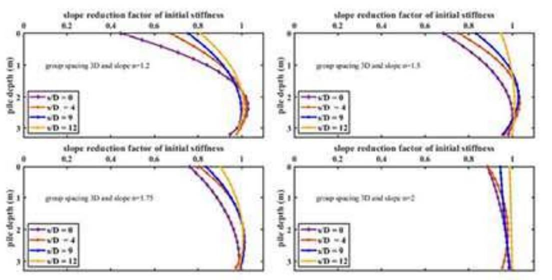

Figure 5 Stiffness reduction of slope in variation of group interaction

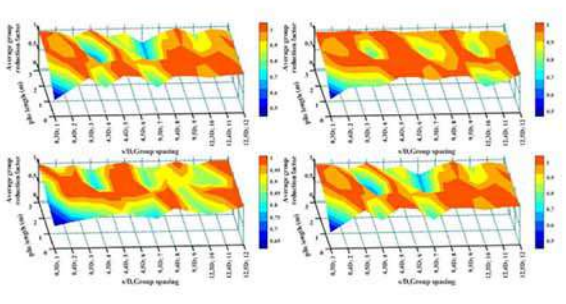

Figure 8. Group reduction factor effect on slope ground

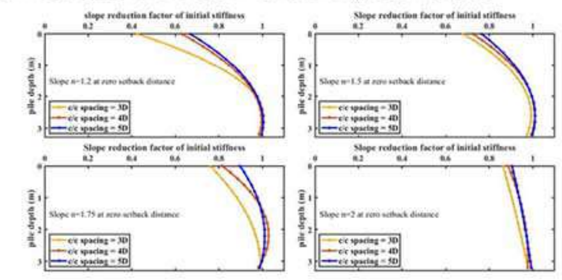

Figure 7. Edge distance effect on stiffness of group pile

Conclusion

The groundwater table plays a critical role in soil–structure interaction problems; however, most of the studies on laterally loaded single piles were seldom performed using the coupled hydromechanical governing equations or considering the soil as a porous media.

Publications

1. Gui, M.-W.; Alebachew,A.A. Responses of Laterally Loaded Single Piles Subjected to Various Loading Rates in a Poroelastic Soil. Appl. Sci. 2022, 12, 617. https:// doi.org/10.3390/app12020617.