Journal of Zhejiang University-SCIENCE A

Reliability-based optimization of laterally loaded piles with necking defects

Yang YU, Bo SHI, Qing LÜ, Chaofeng WU

Cite this as: Yang YU, Bo SHI, Qing LÜ, Chaofeng WU, 2025. Reliability-based optimization of laterally loaded piles with necking defects. *Journal of Zhejiang University-SCIENCE A*, 26(11):1021-1033.
https://doi.org/10.1631/jzus.A2400484

The problem

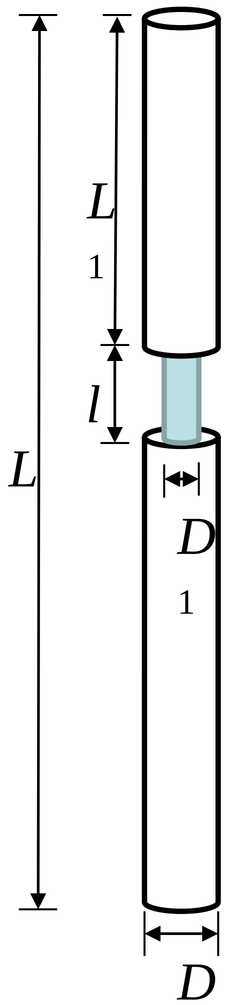

Fig. 1 Schematic of the necking defect of a laterally loaded pile.

- Laterally loaded piles are commonly used in sandy stratum foundations.
- These piles are particularly susceptible to necking defects during cast-in-place installation due to borehole collapse risks.
- These construction-induced geometric imperfections substantially compromise pile safety under lateral loading conditions.

The contributions of this research

1. A spreadsheet method is established to evaluate responses of laterally loaded piles with necking defects. Uncertainties of necking defects and soil parameters are considered in the proposed design method.

Δz_1	$r\Delta z$	Design Parameters	L (m) / D (m)	20 / 1	P_h (kN)	M_h (kN×m)	Equilibrium: P_h-P_0	Equilibrium: M_{z0}-M_0	maxdiff = y_0-y_{prev0}
0.4	1.033053429				160	0	0	7.77E-14	7.36E-08

i	z_i (m)	E_pI_p (kN×m^2)	y_i (m)	y_i' (m)	k secd	p_i (kN/m)	Q_i (kN)	M_i (kN×m)	y_{prev} (mm)	D (m)	φ (°)	γ (kN/m^3)
0	0	1262753.122	0.0047032	-0.001614	0.03601039	-0.000169	160	-7.77E-14	4.702646	1	35	16.8
1	0.4	1262753.122	0.0040576	-0.001604	12705.5744	-51.55353	149.689261	62.6252302	4.057095	1	35	16.8
2	0.813	1262753.122	0.0033989	-0.001574	21613.7923	-73.46382	123.859342	119.455063	3.398538	1	35	16.8
3	1.24	1262753.122	0.0027355	-0.001526	28733.3339	-78.60019	91.4028182	165.478591	2.735177	1	35	16.8
4	1.681	1262753.122	0.0020752	-0.001463	34928.6272	-72.48484	58.0893543	198.341732	2.074964	1	35	16.8
5	2.137	303187.024	0.0014252	-0.001263	47809.7878	-68.13859	26.0577411	217.433833	1.425004	0.7	35	16.8
6	2.607	303187.024	0.00091	-0.000922	54670.2714	-49.74945	-1.6827183	222.830154	0.909849	0.7	35	16.8
7	3.093	303187.024	0.0005487	-0.000569	60813.7443	-33.36815	-21.887757	216.777741	0.548595	0.7	35	16.8
8	3.596	1262753.122	0.0003529	-0.00035	55744.9206	-19.67412	-35.207983	202.151723	0.352859	1	35	16.8
9	4.115	1262753.122	0.0001931	-0.000271	60450.8811	-11.67335	-43.34031	181.594824	0.193056	1	35	16.8
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
25	15.18	1262753.122	5.23E-06	5.00E-07	132323.996	-0.692214	1.76348995	-2.5025619	5.23E-03	1	35	16.8
26	16.08	1262753.122	4.88E-06	-8.19E-07	136985.435	-0.667958	1.15016102	-1.190382	4.88E-03	1	35	16.8
27	17.02	1262753.122	3.70E-06	-1.40E-06	141692.412	-0.524854	0.59451952	-0.3880178	3.70E-03	1	35	16.8
28	17.98	1262753.122	2.21E-06	-1.56E-06	146447.919	-0.324151	0.18595992	-0.0279268	2.21E-03	1	35	16.8
29	18.97	1262753.122	6.52E-07	-1.56E-06	151254.839	-0.098599	-0.0242004	0.03390761	6.52E-04	1	35	16.8
30	20	1262753.122	-9.33E-07	-1.54E-06	156115.959	0.145721	0	0	-9.33E-04	1	35	16.8

Notes: (1) the Excel solver is applied to reach the equilibrium; (2) Boxed cells contain equations; (3) The yellow highlighted cells are initially set to 0; (4) The blue highlighted cells are the necking section of the cast-in-place pile.

Fig. 2 Spreadsheet method for a laterally loaded pile with a necking defect. The Excel solver is applied to reach the equilibrium; boxed cells contain equations; the yellow highlighted cells are initially set to 0; the blue highlighted cells are the necking section of the cast-in-place pile.

The contributions of this research

2. Optimal design parameters for the piles with necking defects are obtained considering safety, cost and design robustness.

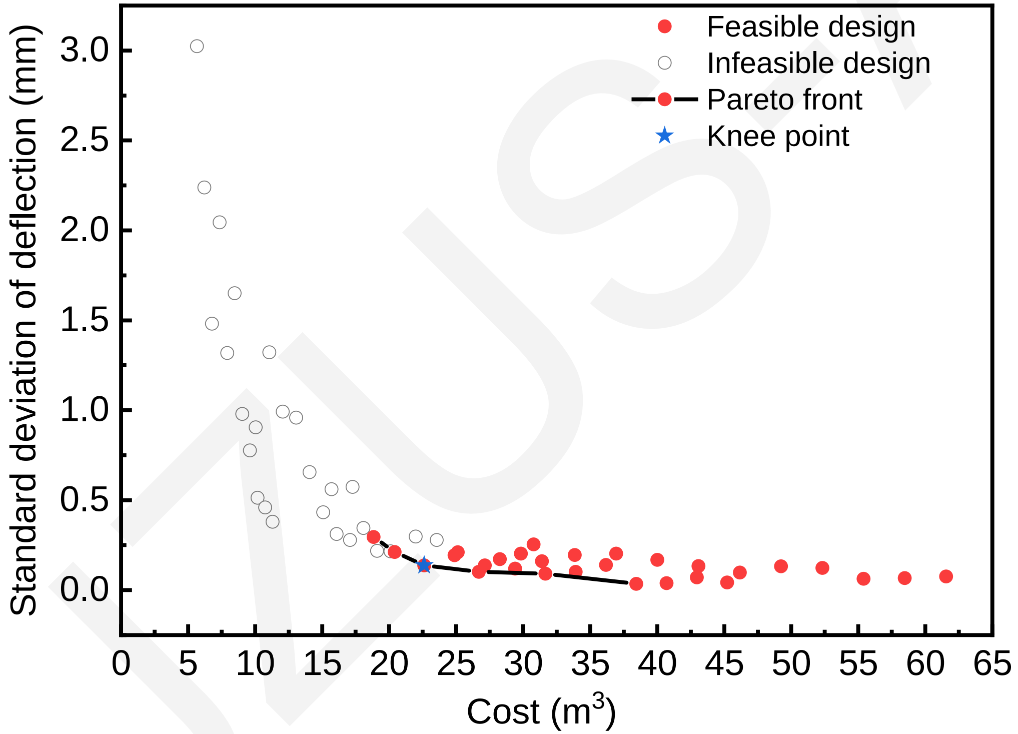

Fig. 8 Design robustness and cost of all 55 designs within the design space.

The contributions of this research

3. Influences of the necking defects and soil parameters on the optimal design are investigated.

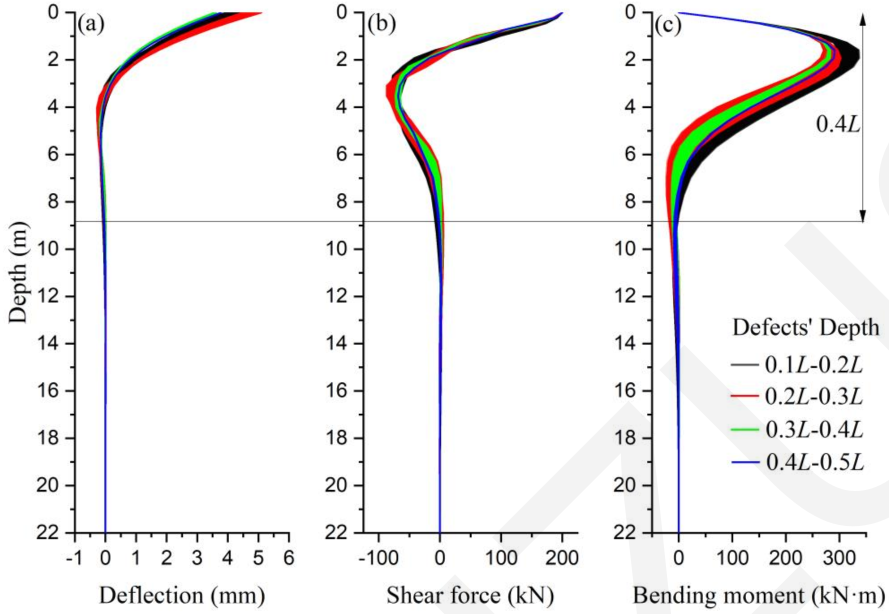

Fig. 10 Deflections, shear forces, and bending moments with necking defects located at different depths (L=22 m, D=1.0 m, and each color is composed of 300 lines).

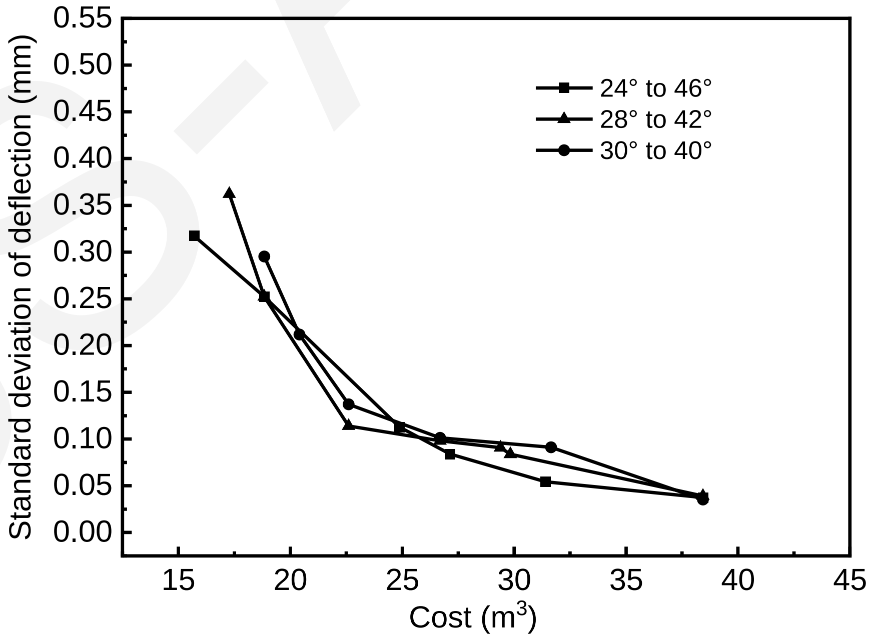

Fig. 12 Pareto fronts corresponding to variations in the friction angle of sand.

Main conclusions

- By leveraging the concept of RGD, the framework was aimed at mitigating the effects of necking defects. The efficacy of the method was substantiated through validation with experimental data.
- when the necking defect is situated deeper within the pile structure, the overall robustness of the design is enhanced. When the position of the necking defect is deeper than $0.4L$, the influence of the necking defect on the design robustness is minimal due to the distribution characteristics of bending moments along the pile.
- Large variations in the friction angle of sand were found to significantly influence the standard deviation of deflection for piles with infeasible design parameters. These variations have little in-fluence on the optimal designs since they employ larger design parameters, which are selected based on safety requirements, and are thus insensitive to such variations.

Limitations of this research

The interaction between the soil and pile would be more complicated in such conditions, so a series of nonlinear springs (p-y curve) may not accurately capture the nonlinear behavior of the soil and the pile in the 3D space. Therefore, a high efficiency method with accurate reliability-based design in complex environments would need to be developed in future research.