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Monotonic uplift behavior of anchored pier foundations in soil overlying rock

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Introduction – Anchored pier

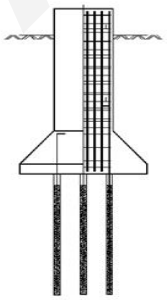
Hills and mountains

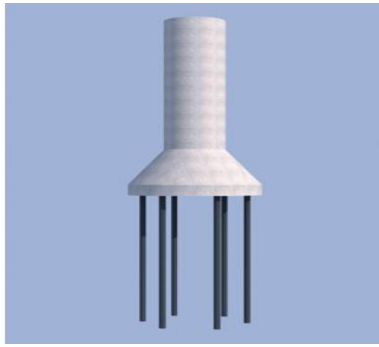


Rock anchors



Anchored pier





1. Piers are used in areas with deep soils and rock anchors are used in areas with exposed rock or rock with thin overburden.

2. The southern part of Zhejiang Province, China, is dominated by hills and mountains, and the rocks in these areas are generally covered with a thickness of soil.

3. An anchored pier foundation exhibits high stiffness and pullout resistance due to the pier being embedded in the in-situ soil and the rock anchors.

Field tests – Test site

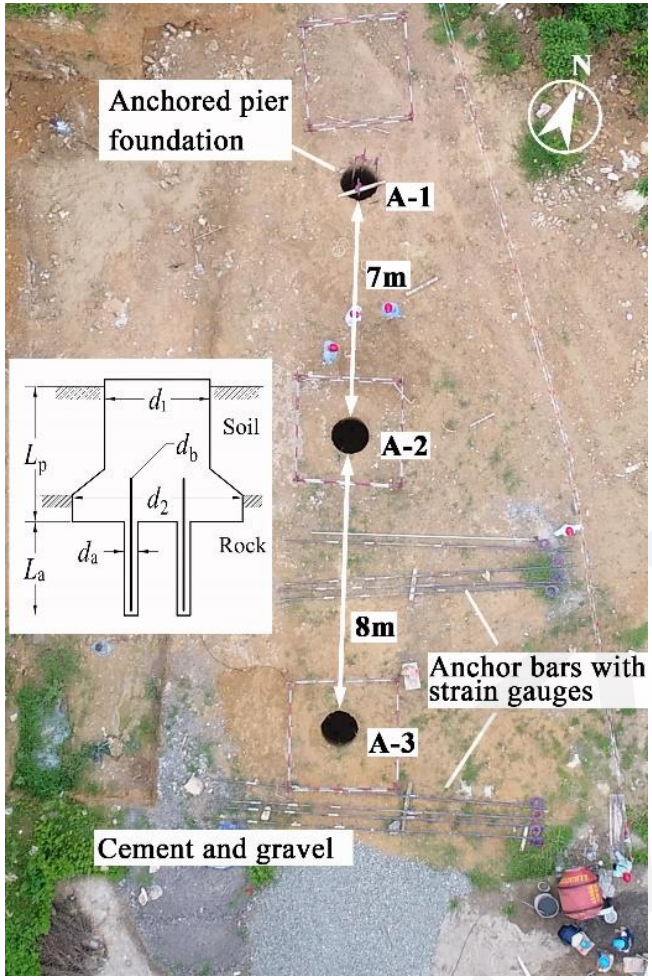


Fig. 1. The top view of the test site



Fig. 2. Sampling of soil and rock

Table 1. Dimension of test foundations

Foundation	L_p(m)	L_a(m)	d_1(m)	d_2(m)	d_a(mm)	d_b(mm)	Number of anchors
A-1	3	1	1	1.5	120	40	4
A-2	3	2	1	1.5	120	40	4
A-3	3	3	1	1.5	120	40	4

Field tests – Construction process



(a)



(b)



(c)



(d)



(e)



(f)



(g)



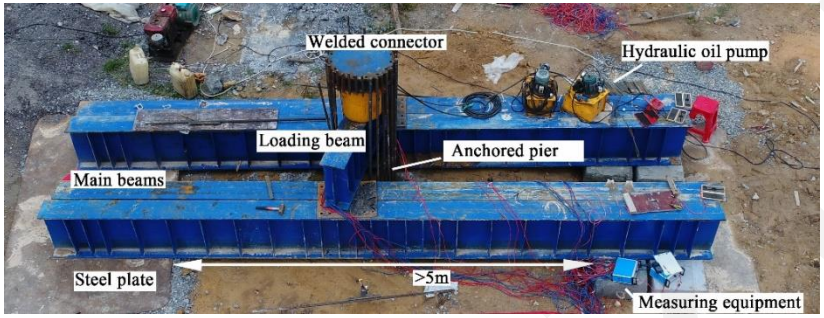
(h)

Fig. 3. Overview of construction, including: (a) geological survey and site selection; (b) excavating the belled pier; (c) drilling of boreholes; (d) preparation of reinforcement and sensors; (e) positioning and installation of steel bars and sensors; (f) foundation pouring; (g) fabrication of test components; and (h) construction of the test system..

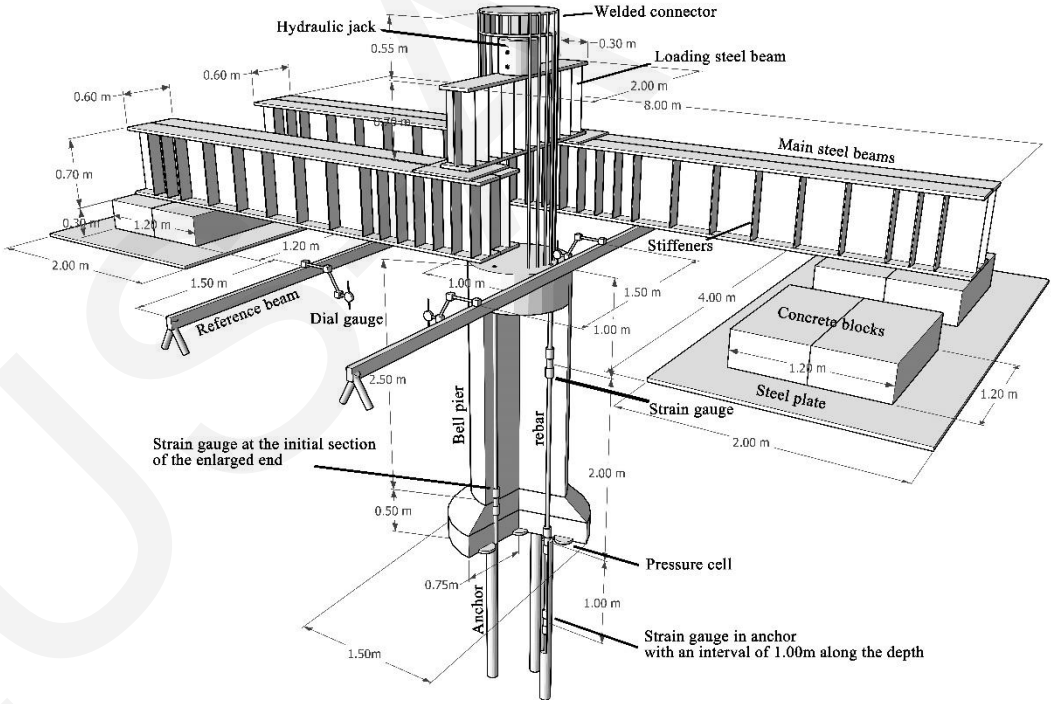
Field tests – Loading system



(a)



(b)



(c)

Fig. 4. Field tests: (a) in-situ core samples; (b) site photo; and (c) loading system

Field tests – Results

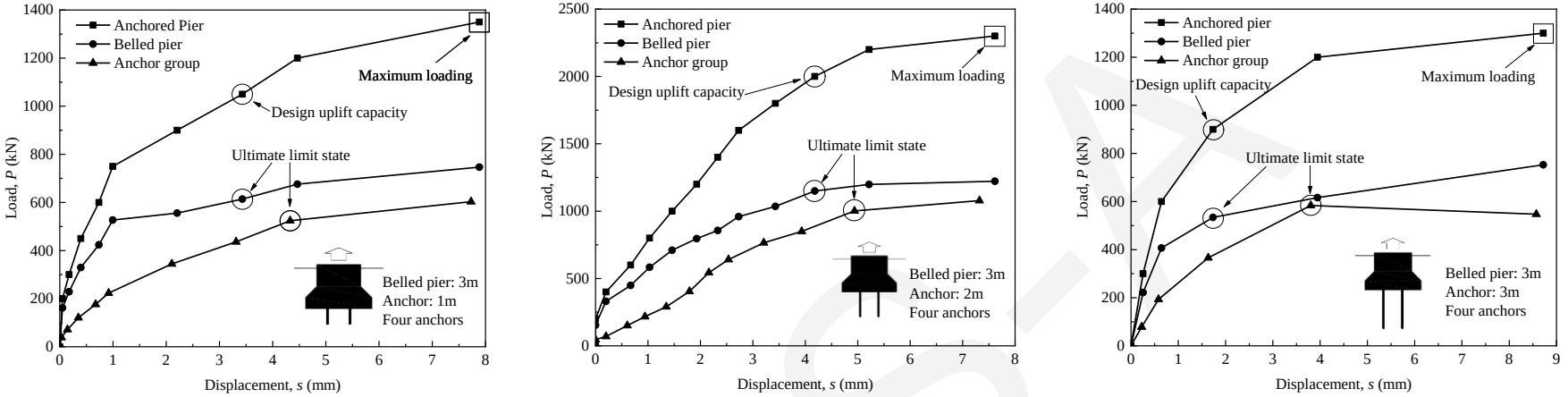


Fig. 5. Load–displacement curves: (a) A-1; (b) A-2; and (c) A-3

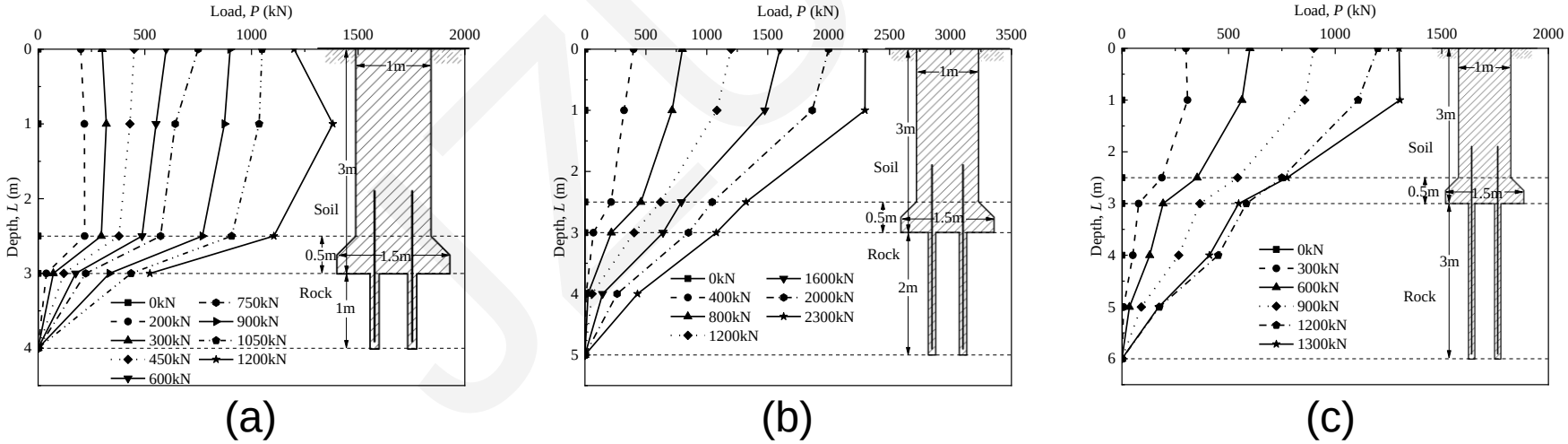


Fig. 6. Axial force distribution: (a) A-1; (b) A-2; and (c) A-3

Field tests – Results

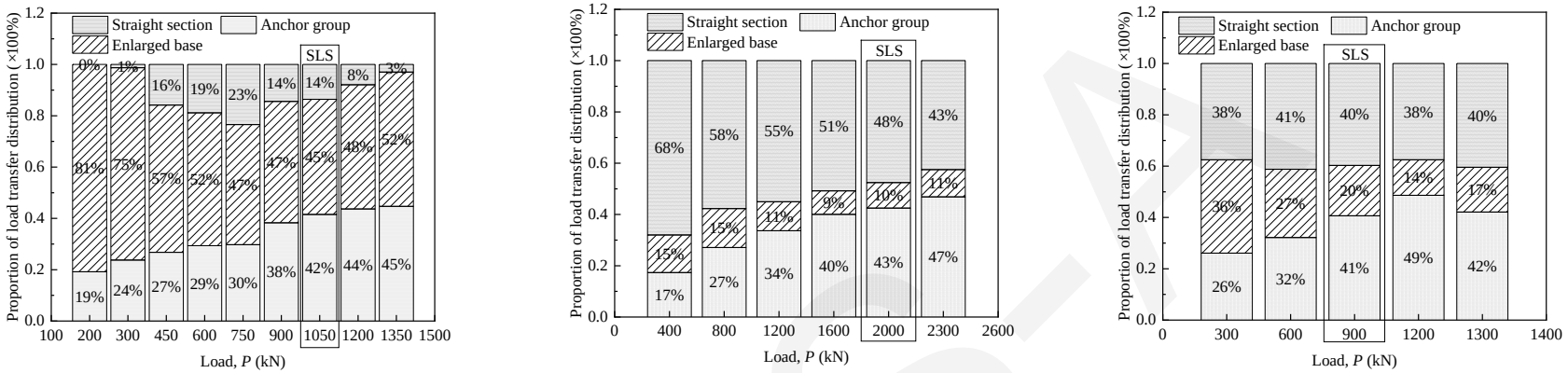


Fig. 7. Load distribution: (a) A-1; (b) A-2; and (c) A-3

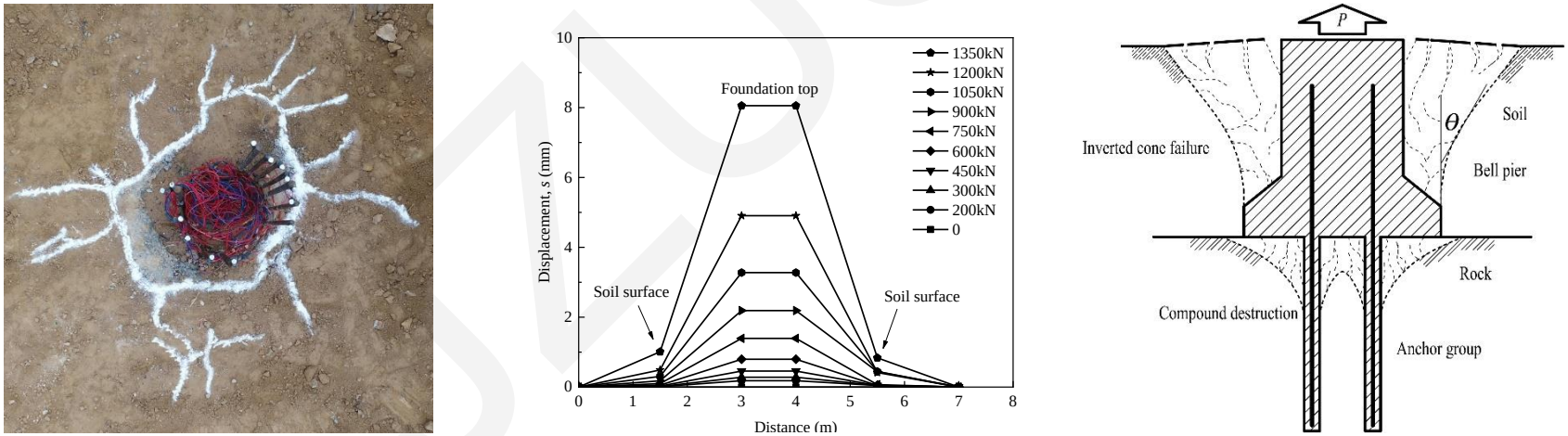


Fig. 8. Failure mode: (a) surface crack map; (b) foundation and ground displacement under various loads; and (c) schematic of the failure mode

Calculation of the uplift capacity

- **A normalized hyperbolic model proposed by Chin (1970) can be used to fit the *P*-*s* curves.**

$$P=\frac{s}{a+b\cdot s},\quad a=\frac{1}{K},\quad b=\frac{R_{\mathrm{f}}}{P_{\mathrm{u}}}$$

Chin FK, Proc. 2nd Southeast Asian Conference on Soil Engineering, (1970).

- **The expressions for the uplift mobilization coefficients k_1 and k_2 are as follows.**

$$k_1=\frac{P_{\mathrm{p}}}{P_{\mathrm{pu}}}=\frac{\dfrac{s}{a_1+b_1 s}}{P_{\mathrm{pu}}}=\frac{a_2P_{\mathrm{a}}}{a_1P_{\mathrm{pu}}+(a_2b_1-a_1b_2)P_{\mathrm{a}}P_{\mathrm{pu}}}=\frac{K_{\mathrm{p}}P_{\mathrm{a}}P_{\mathrm{au}}}{R_{\mathrm{f1}}K_{\mathrm{p}}P_{\mathrm{a}}P_{\mathrm{au}}+(P_{\mathrm{au}}-R_{\mathrm{f2}}P_{\mathrm{a}})K_{\mathrm{a}}P_{\mathrm{pu}}},$$

$$k_2=\frac{P_{\mathrm{a}}}{P_{\mathrm{au}}}=\frac{\dfrac{s}{a_2+b_2 s}}{P_{\mathrm{au}}}=\frac{a_1P_{\mathrm{p}}}{a_2P_{\mathrm{au}}+(a_1b_2-a_2b_1)P_{\mathrm{p}}P_{\mathrm{au}}}=\frac{K_{\mathrm{a}}P_{\mathrm{p}}P_{\mathrm{pu}}}{R_{\mathrm{f2}}K_{\mathrm{a}}P_{\mathrm{p}}P_{\mathrm{pu}}+(P_{\mathrm{pu}}-R_{\mathrm{f1}}P_{\mathrm{p}})K_{\mathrm{p}}P_{\mathrm{au}}}$$

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Conclusions

- (1) The uplift capacity of anchored pier is mainly provided by two parts: the belled pier and the anchor group.
- (2) The first part that reached the ultimate uplift capacity (UUC) is the control factor for the serviceability limit state (SLS) of the anchored pier.
- (3) A combination of the failure mechanisms of the belled pier and the anchor group characterizes the failure mode of the anchored pier.
- (4) The anchored pier foundation is an independent foundation that can be flexibly adjusted according to geological conditions.