

# **Monotonic uplift behavior of anchored pier foundations in soil overlying rock**

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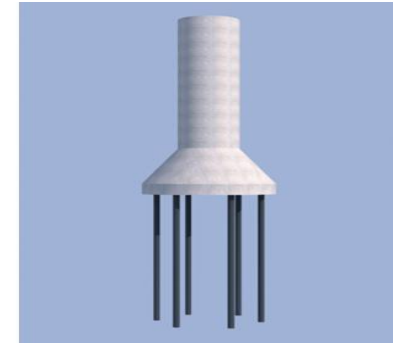
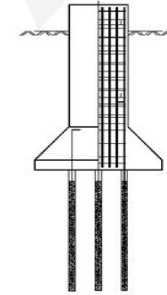
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# Introduction – Anchored pier

**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

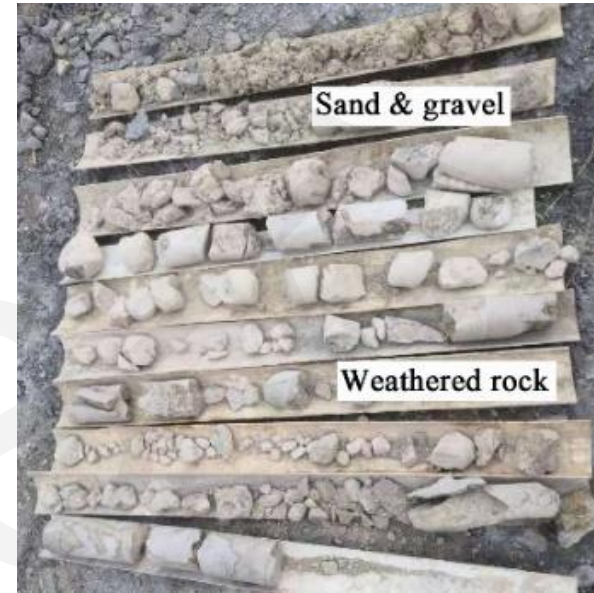
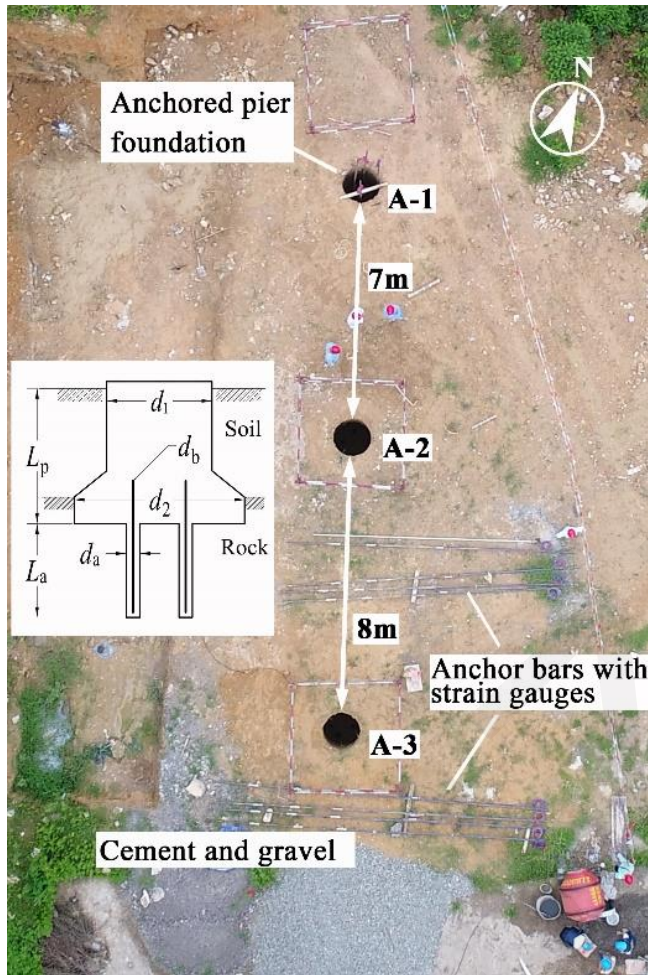


Fig. 2. Sampling of soil and rock

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

Fig. 1. The top view of the test site

# Field tests – Construction process



(a)



(b)



(c)



(d)



(e)



(f)



(g)



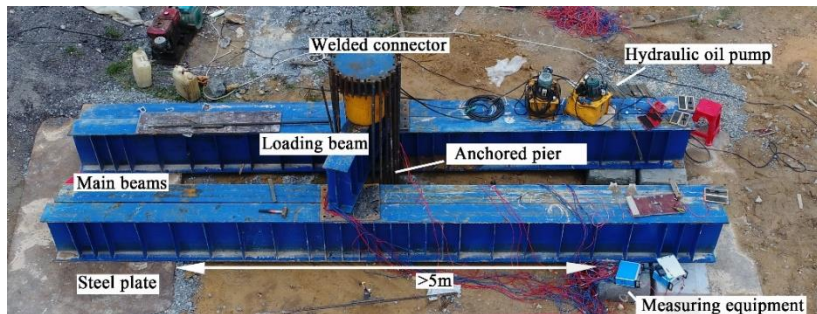
(h)

**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..**

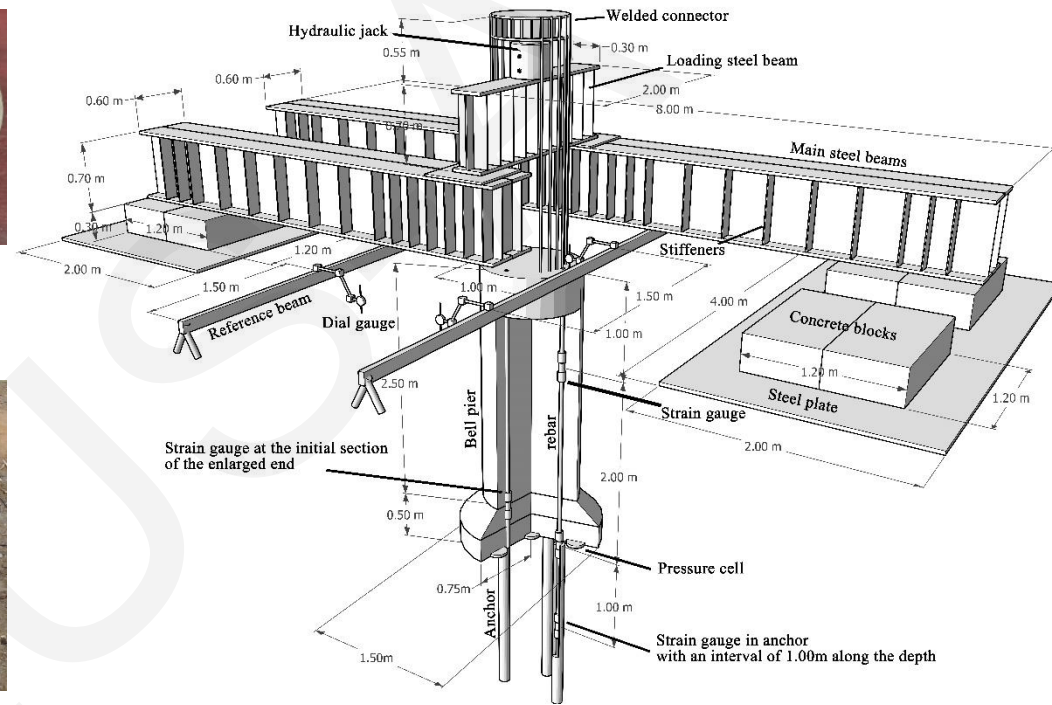
# Field tests – Loading system



(a)



(b)



(c)

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

# Field tests – Results

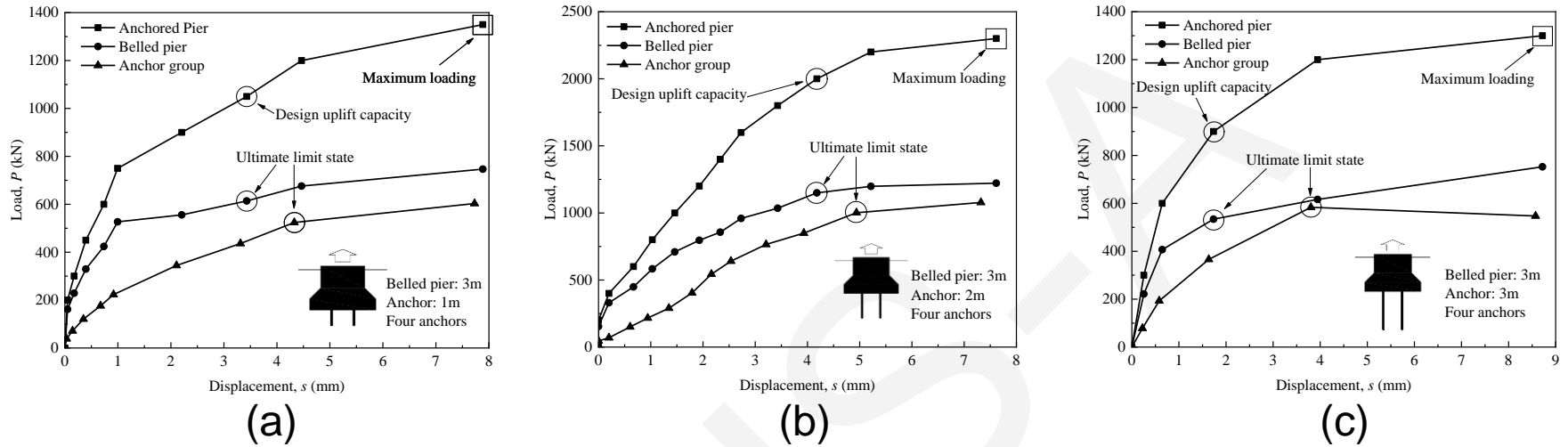


Fig. 5. Load–displacement curves: (a) A-1; (b) A-2; and (c) A-3

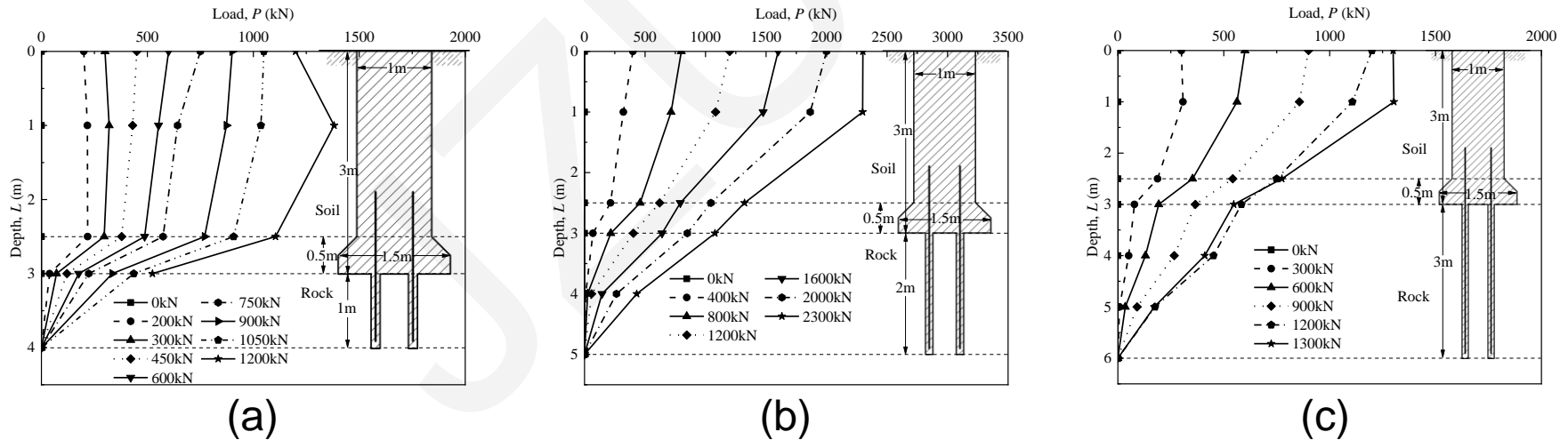
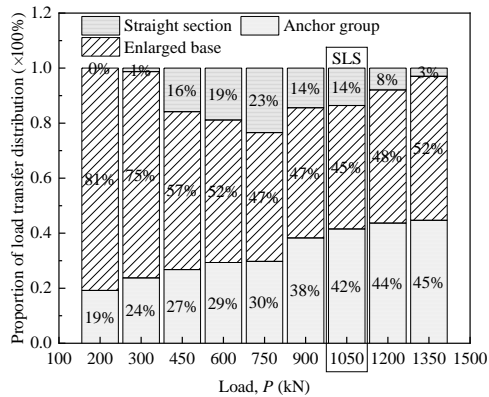
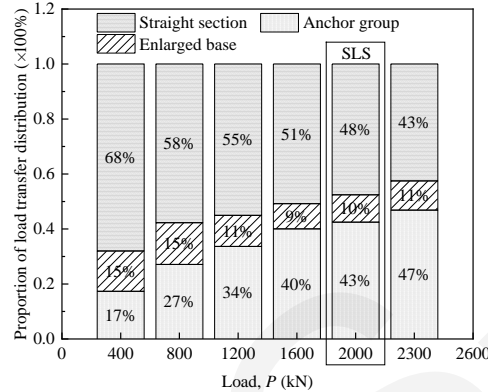


Fig. 6. Axial force distribution: (a) A-1; (b) A-2; and (c) A-3

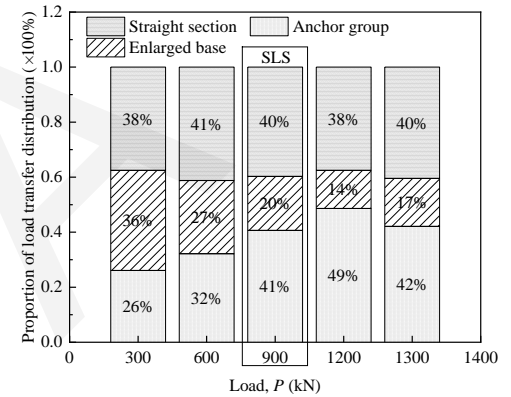
# Field tests – Results



(a)



(b)

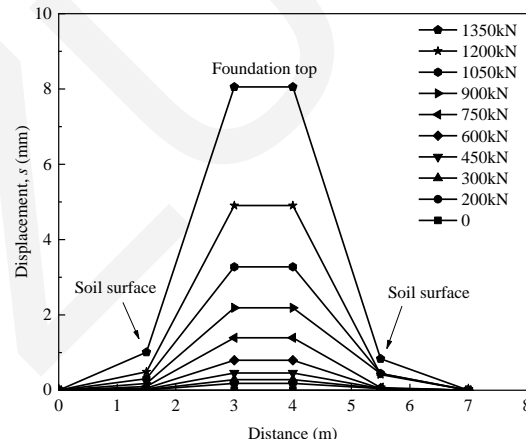


(c)

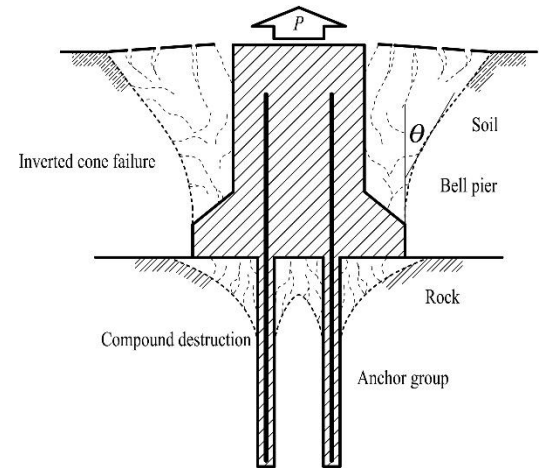
**Fig. 7. Load distribution: (a) A-1; (b) A-2; and (c) A-3**



(a)



(b)



(c)

**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.

$$P = \frac{s}{a + b \cdot s}, \quad a = \frac{1}{K}, \quad b = \frac{R_f}{P_u}$$

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.

$$k_1 = \frac{P_p}{P_{pu}} = \frac{\frac{s}{a_1 + b_1 s}}{P_{pu}} = \frac{a_2 P_a}{a_1 P_{pu} + (a_2 b_1 - a_1 b_2) P_a P_{pu}} = \frac{K_p P_a P_{au}}{R_{f1} K_p P_a P_{au} + (P_{au} - R_{f2} P_a) K_a P_{pu}},$$

$$k_2 = \frac{P_a}{P_{au}} = \frac{\frac{s}{a_2 + b_2 s}}{P_{au}} = \frac{a_1 P_p}{a_2 P_{au} + (a_1 b_2 - a_2 b_1) P_p P_{au}} = \frac{K_a P_p P_{pu}}{R_{f2} K_a P_p P_{pu} + (P_{pu} - R_{f1} P_p) K_p P_{au}}$$

# 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.