

## **Full-Scale Field Tests of Different Types of Piles: Project-based Study**

### Author

Zhou, Jialin, Wang, Songyan, Oh, Erwin

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# Chapter 1 Introduction

## 1.1 Background

With the soaring requirement for building space in metropolises, high-rise buildings are becoming increasingly popular. Pile foundations can resist more loading through end bearing and friction resistance than can shallow foundations; hence, the use of pile foundations is more common. As a structural element that transfers the loads from upper structures into the soil layers, piles can be generally categorized into precast piles and cast-in-situ piles. As a result of the numerous advantages—such as convenience of construction without considering the transfer of piles, cost and schedule of construction—cast-in-situ piles are the most accepted type of piles in construction projects.

For bored piles, the process of construction leads to soil deposits remaining at the base area after drilling the hole, which consequently leads to a decrease of the pile capacity and increase of settlement. Engineers currently use admixture, such as bentonite or polymeric slurry, to avoid the collapse of the soil during the drilling process. However, these admixtures create a layer between the concrete pile surface and soil layers. This new layer, created by the reaction among bentonite, soil and water, has a low friction coefficient, which results in decreased shaft resistance. To solve the above problems, the post grouting technique is the most acceptable method. This method involves pressurizing admixtures into soils through a device, such as a pipe installed inside the pile. The highly pressurized materials compact the loose soils, and the injected materials mix with the soils and reinforce the pile end or shaft.

For precast piles, piles are driven into the soil layers and the soils are forced to compact. Based on the amount of soil compacted, these precast piles can be categorized into small and large displacement piles. Normally, open-ended pipe piles are considered small displacement piles, and solid piles are identified as large displacement piles. A non-displacement pile generally refers to a bored pile (or cast-in-place pile) because the soil is removed during construction. There are many investigations in terms of the small and large displacement piles, but the research of the non-displacement precast piles is very limited.

When based on the selected type of materials, the pile foundation can be categorized into timber, steel, concrete or composite piles. Past studies investigated Fiber-reinforced polymer (FRP) composite piles with consideration of their damage or corrosive effect on steel, timber, fiber and concrete materials. Different to the previous research on FRP piles that are made of fiber and polymer, this book provides the investigation on concrete piles with inside FRP bar reinforcement and outside FRP laminar reinforcement.

Within this context, there are different types of piles used under different construction technology. To investigate these piles under different effects, such as post grouting or composite confinement, it is vital to determine the ultimate bearing capacity and settlement behavior of the pile foundation. Compared with experimental tests, field tests can provide the most accurate information about pile behavior. For compressively loaded piles, the test method can include Static Load Tests (SLTs), dynamic load tests, Osterberg Cell (O-cell) tests and static tests. However, for tests that apply lateral and uplift loading, SLTs are the only option. Interpretations based on the data obtained from field tests can provide the ultimate bearing capacity, but these tests are mostly Proof Tests (PTs), which aims to assure the designed pile foundation possessing adequate capacity within required settlement. Field tests for loading the pile to failure are quite limited.

This book focuses on field tests of different types of piles associated with various up-to-date technologies. Static and dynamic load tests are performed to determine the ultimate compressive bearing capacity and settlement behaviors of pile foundations. However, the SLT can only provide limited loads especially when testing the super-long and large diameter pile

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foundations. Thus, this book also introduces an improved SLT that can provide large compressive loads and the load transfer mechanism research is involved.

## 1.2 Objectives

The objectives of this book are to investigate bored piles with different grouting technology; small, large and no displacement precast piles; FRP composite piles, super-long and large diameter piles and piles applied with ultimate loading. A full-scale field tests are illustrated including static compressive, uplift and horizontal load tests, dynamic load tests, inclinometer tests as well as tests for determination of the stress in pile foundation.

For cast-in-situ concrete piles, this book aims to:

1. Determine the compressive and uplift ultimate bearing capacity of non-grouted, base grouted only, and base-and-shaft grouted piles.
2. Research the shaft resistance mechanism of grouted piles through conducting static and dynamic load tests.
3. Propose empirical formula for vertical settlement and uplift displacement prediction.
4. Investigate the pile behavior of pile foundations under different types of failure conditions, and compare with proof test.
5. Study the capacity as well as the load transfer mechanism of the super-long and large diameter pile foundations.

For precast concrete piles, this book aims to:

1. Determine the ultimate bearing capacity of small and large displacement piles (concrete pipe and rectangular piles).
2. Research the geotechnical mechanism of concrete pipe and rectangular piles.
3. Investigate the behavior of non-displacement piles through performing uplift and horizontal SLTs.
4. Propose empirical formula for horizontal displacement prediction.

For composite piles, this book aims to:

1. Determine the ultimate bearing capacity of precast pipe and rectangular piles confined by Carbon FRP (CFRP), and determine the capacity improvement compared with piles without FRP confinement effect.
2. Research the deflection behavior of concrete bored pile with inside Glass FRP (GFRP) reinforcement as a replacement for traditional steel bar reinforcement.

For the super-long and large-diameter concrete piles, this book aims to:

1. Research the load transfer mechanism, shaft resistance development and shear stress distribution of the super-long and large diameter pile foundations.
2. Introduce an improved static load tests which can apply large amount of compressive load.

For piles applied with ultimate loads, this book aims to:

1. Determine the concrete pile behavior under failure caused by inadequate concrete strength.
2. Investigate the failure of concrete piles because of the application of eccentric loading, via performing field tests.
3. Study the plunging failure of a pile foundation.

## 1.3 Book Organization

After the background and objectives have been illustrated in Chapter 1, the related academic general principles and practices is provided in Chapter 2. Chapter 2 first reviews the

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methods to determine the soil parameters and subsurface exploration, and then reviews the categorization of piles. This is followed by discussion of the analytical methods used to design the pile capacity, and review of field tests to indicate which test methods should be selected to obtain the real pile capacity onsite.

Based on the research methodology presented in Chapter 2, Chapter 3 focuses on studying concrete bored piles with consideration of the construction process, and provides one case study. The post grouting technique effect is researched through comparing base-and-shaft grouted, base grouted and non-grouted piles. The ultimate compressive and uplift bearing capacities of these piles are determined through interpretations of the result obtained from SLTs. Further, the shaft resistances of these piles are analyzed and compared with the results obtained from dynamic load tests.

Chapter 4 investigates small, large and non-displacement concrete precast piles through two case studies. For the small and large displacement piles, this chapter focuses on determining compressive behaviors by considering various pile lengths and concrete strengths. For the non-displacement precast piles, this chapter focuses on determining the piles' uplift and horizontal ultimate bearing capacity. This chapter also analyses the uplift load transfer mechanisms of these non-displacement precast piles.

Different to the investigations of bored piles (Chapter 3) and precast piles (Chapter 4), Chapter 5 focuses on the composite piles with use of FRP materials. Chapter 5 presents two case studies. The first case study researches the ultimate bearing capacity of concrete piles with CFRP laminar confinement, and the second case study examines the deflection behavior of passive bored piles in which steel reinforcement is replaced by GFRP bars during the construction process.

Chapter 6 illustrates the improved compressive static load test which is used for testing the super-long and large diameter piles. Detailed pile design as well as installation of the steel rebar meter (also known as strain gauge or sister rebar) are demonstrated based on a case study. The load transfer mechanism, shaft resistance development and shear stress distribution are discussed via comparing the results from three super-long and large diameter piles.

As a result of SLTs mostly being used as PTs, which requires extrapolation of the results, previous research on SLTs until failure is limited, and data demonstrating plunging failure is rare. Thus, in Chapter 7, SLTs under different failure conditions are performed, with consideration of the aspects of rigidity of concrete, soils and eccentric loading.

Chapter 8 provides the capacity and settlement discussion of the different types of concrete pile foundations obtained from performed field tests. Also, the methods to obtain the empirical formula that are used for prediction of vertical and lateral displacement of soil-pile system are proposed. Finally, Chapter 9 presents the study findings, conclusions and recommendations based on all the case studies undertaken in Chapters 3 to 7. It also discusses potential avenues for further research.