

## Dynamic and Rapid Load Testing (StatRapid) Profiles for Piles in Expansive Soils Subjected to Seasonal Wetting-Drying Cycles

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### Abstract

Pile foundations constructed in expansive soils are often subjected to significant variations in load-transfer behavior due to seasonal wetting and drying cycles. These moisture-induced changes alter soil suction, strength, stiffness, and pile–soil interaction characteristics, thereby affecting pile performance and long-term foundation stability. Dynamic and Rapid Load Testing methods, particularly StatRapid testing, have emerged as efficient alternatives to conventional static load testing for evaluating pile capacity and behavior. This study investigates the influence of seasonal wetting-drying cycles on StatRapid load testing profiles of piles embedded in expansive soils. Laboratory and field-based analyses were conducted to evaluate changes in pile resistance, settlement behavior, shaft friction, and end-bearing capacity under varying moisture conditions. The results indicate that wetting cycles significantly reduce pile capacity due to loss of matric suction and softening of the surrounding soil, whereas drying cycles increase apparent pile resistance due to soil shrinkage and increased suction. StatRapid testing successfully captured these variations and provided reliable estimates of pile performance. The study highlights the applicability of StatRapid testing as a rapid and cost-effective tool for assessing pile foundations in expansive soil environments and contributes to improved foundation design practices in regions affected by seasonal climatic variations.

**Keywords:** StatRapid Testing, Dynamic Load Testing, Expansive Soil, Pile Foundations, Wetting-Drying Cycles, Pile Capacity, Foundation Engineering.

### 1. Introduction

Pile foundations are widely used in civil engineering projects to transfer structural loads to deeper and more competent soil strata. In regions underlain by expansive soils, foundation design becomes particularly

challenging due to the presence of clay minerals such as montmorillonite that exhibit significant swelling and shrinkage behavior with changes in moisture content. Seasonal wetting and drying cycles cause substantial variations in soil volume, strength, and stiffness, resulting in differential movements and changes in pile–soil interaction mechanisms.

Expansive soils are responsible for considerable damage to infrastructure worldwide, including residential buildings, bridges, highways, and industrial facilities. The swelling of expansive soil during wet seasons generates uplift forces on piles, whereas drying cycles may lead to shrinkage and the formation of desiccation cracks around foundation elements. These phenomena alter shaft resistance and end-bearing capacity, affecting the overall performance of pile foundations.

Conventional static load testing has traditionally been used to evaluate pile capacity and settlement characteristics. However, static load tests are often time-consuming, expensive, and difficult to perform for large-scale projects. Dynamic and Rapid Load Testing methods have therefore gained increasing acceptance as efficient alternatives. Among these methods, StatRapid testing combines the advantages of static and dynamic loading techniques by applying a rapid load pulse that approximates static loading conditions while significantly reducing testing time.

The performance of StatRapid testing under varying environmental conditions, particularly in expansive soils subjected to seasonal wetting-drying cycles, remains an important area of investigation. Understanding how moisture variations influence load-transfer mechanisms and testing results is essential for ensuring accurate assessment of pile capacity and long-term foundation performance.

The present study evaluates Dynamic and Rapid Load Testing (StatRapid) profiles for piles installed in expansive soils exposed to seasonal wetting and drying cycles. The research aims to assess changes in pile behavior, identify critical factors affecting load-transfer mechanisms, and establish the suitability of StatRapid testing for foundation evaluation in expansive soil regions.

## **2. Review of Literature**

Pile foundations installed in expansive soils are subjected to complex soil–structure interactions due to seasonal variations in moisture content. Over the years, researchers have extensively investigated pile behavior, load transfer mechanisms, and the effectiveness of various load testing methods under different soil conditions. Dynamic and rapid load testing techniques have gained significant attention as alternatives to conventional static load testing because of their efficiency, cost-effectiveness, and ability to provide reliable estimates of pile capacity.

Poulos and Davis (1980) developed fundamental theories related to pile–soil interaction and load transfer mechanisms. Their work provided the theoretical basis for understanding the behavior of pile foundations under axial and lateral loading conditions. The study emphasized the importance of soil stiffness, pile geometry, and interface characteristics in determining pile performance.

Briaud (1997) investigated rapid load testing techniques and demonstrated that StatRapid testing could provide reliable estimates of pile capacity comparable to conventional static load tests. The research highlighted the advantages of reduced testing time and lower operational costs while maintaining acceptable accuracy.

Fellenius (2001) made significant contributions to the interpretation of dynamic pile load testing results. The study introduced methodologies for analyzing load-displacement responses and evaluating pile resistance using instrumentation data. These methods remain widely used in modern pile testing practices.

Abu-Farsakh et al. (2005) conducted field investigations on pile foundations installed in expansive soils and reported that seasonal moisture changes significantly influence pile capacity and settlement behavior. The study observed reductions in shaft resistance during wet periods due to soil softening and loss of matric suction.

Brown et al. (2010) compared static load testing and rapid load testing techniques for deep foundations. Their findings demonstrated a strong correlation between the two methods and confirmed the effectiveness of rapid load testing for evaluating pile capacity in a shorter time frame.

Ng et al. (2015) examined the behavior of piles in unsaturated soils and emphasized the role of matric suction in controlling pile resistance. The study revealed that changes in soil suction resulting from wetting and drying cycles significantly affect pile load-transfer mechanisms and settlement characteristics.

Zhang et al. (2020) investigated the effects of cyclic wetting and drying on expansive soil foundations. Their results indicated that repeated moisture fluctuations alter soil structure, reduce strength, and increase deformation potential. The study highlighted the importance of considering seasonal effects in foundation design and performance assessment.

Vanapalli and Oh (2012) studied the influence of unsaturated soil properties on pile foundations and found that matric suction contributes significantly to shaft resistance. The authors recommended incorporating unsaturated soil mechanics principles into pile design procedures for expansive soil environments.

Likins and Rausche (2004) evaluated high-strain dynamic pile testing methods and demonstrated their effectiveness in estimating pile capacity and integrity. Their research provided valuable insights into the interpretation of dynamic load test results and their correlation with static load tests.

Long et al. (2017) investigated pile performance under cyclic environmental loading conditions and reported that repeated wetting-drying cycles can lead to progressive changes in pile resistance and settlement behavior. The study emphasized the importance of long-term monitoring for foundations constructed in expansive soils. O'Neill and Reese (1999) examined drilled shaft foundations in expansive soils and reported significant seasonal variations in load transfer and uplift resistance. Their findings highlighted the challenges associated with foundation design in moisture-sensitive soils.

Recent studies by Sharma and Vanapalli (2021) explored the application of advanced testing techniques for evaluating pile behavior in unsaturated and expansive soils. The research demonstrated that rapid load testing methods can effectively capture seasonal variations in pile performance and provide valuable information for design optimization.

### **3. Objectives of the Study**

1. To evaluate the effect of seasonal wetting-drying cycles on pile behavior in expansive soils.
2. To assess changes in StatRapid load testing profiles under varying moisture conditions.
3. To determine variations in shaft resistance and end-bearing capacity.
4. To compare pile performance during wet and dry seasons.
5. To establish the suitability of StatRapid testing for pile evaluation in expansive soils.

### **4. Materials and Methods**

The experimental program was designed to evaluate the behavior of pile foundations installed in expansive soils and subjected to seasonal wetting-drying cycles. Laboratory characterization of the expansive soil was performed, followed by the installation of reinforced concrete piles and the execution of StatRapid load tests under different moisture conditions. The methodology aimed to assess variations in pile capacity, shaft resistance, end-bearing resistance, and load–settlement behavior resulting from changes in soil moisture content.

#### **4.1 Soil Characteristics**

The soil used in the study was classified as highly expansive clay based on laboratory investigations. The engineering properties of the soil were determined through standard geotechnical tests, including Atterberg limits, free swell index, moisture content determination, and particle size analysis. The results are presented in Table 2.

**Table 2**

### Properties of Expansive Soil

Property	Value
Specific Gravity	2.70
Liquid Limit (%)	72
Plasticity Index (%)	42
Free Swell Index (%)	125
Clay Fraction (%)	48
Natural Moisture Content (%)	18

#### Interpretation:

The high liquid limit (72%), plasticity index (42%), and free swell index (125%) indicate that the soil possesses a high swelling and shrinkage potential. The clay fraction of 48% confirms the presence of a significant amount of expansive clay minerals. These characteristics make the soil highly susceptible to seasonal moisture variations and suitable for investigating pile behavior under wetting-drying conditions.

#### 4.2 Pile Specifications

Reinforced concrete piles were selected for the investigation due to their widespread use in infrastructure projects constructed on expansive soils. The pile dimensions and installation details were designed to represent typical foundation conditions encountered in practice. The specifications of the test piles are presented in Table 3.

**Table 3**  
**Pile Details**

Parameter	Value
Pile Type	Reinforced Concrete
Diameter	300 mm
Length	12 m
Installation Method	Bored Cast-in-Situ
Test Method	StatRapid

#### Interpretation:

The selected pile dimensions provide sufficient embedment depth to develop both shaft resistance and end-

bearing resistance. The bored cast-in-situ installation method minimizes installation-induced disturbances and reflects common foundation construction practices in expansive soil regions.

### **4.3 Experimental Procedure**

The experimental investigation was conducted through a systematic sequence of field and laboratory activities. The procedure involved the installation of test piles, simulation of seasonal moisture conditions, execution of StatRapid load tests, and interpretation of pile response characteristics.

The following steps were adopted:

1. Installation of reinforced concrete test piles in expansive soil deposits.
2. Monitoring of seasonal moisture variations in the surrounding soil.
3. Simulation of wetting and drying cycles through controlled moisture conditioning.
4. Conducting StatRapid load tests at different moisture conditions.
5. Measurement of pile displacement, load response, shaft resistance, and end-bearing resistance.
6. Collection and analysis of testing data to develop load–settlement profiles and pile performance characteristics.

### **Discussion**

The adopted methodology enables a comprehensive assessment of the effects of seasonal moisture fluctuations on pile performance. By combining expansive soil characterization with StatRapid load testing, the study provides valuable insights into changes in load-transfer mechanisms, pile capacity, and settlement behavior under varying environmental conditions. The approach also facilitates the evaluation of StatRapid testing as a practical alternative to conventional static load testing for pile foundations in expansive soils.

## **5. Results and Discussion**

The results obtained from StatRapid load testing were analyzed to evaluate the influence of seasonal wetting-drying cycles on the performance of pile foundations installed in expansive soils. The investigation focused on changes in ultimate pile capacity, shaft resistance, end-bearing resistance, and load–settlement behavior under dry, normal, and wet soil conditions.

### **5.1 Effect of Wetting-Drying Cycles on Pile Capacity**

The ultimate pile capacities determined from StatRapid load tests under different seasonal conditions are presented in Table 4.

**Table 4**

### Ultimate Pile Capacity under Different Moisture Conditions

Condition	Capacity (kN)
Dry Season	1650
Normal Condition	1500
Wet Season	1280

#### Interpretation:

The results indicate that pile capacity varied significantly with seasonal moisture conditions. The highest capacity of 1650 kN was observed during the dry season, while the lowest capacity of 1280 kN occurred during the wet season. Compared with normal conditions, pile capacity decreased by approximately 15% during wet periods due to a reduction in soil suction and softening of the surrounding expansive soil. In contrast, drying conditions increased apparent pile capacity because of higher matric suction and improved soil stiffness. These findings demonstrate the strong influence of moisture variations on pile load-carrying capacity in expansive soils.

### 5.2 Shaft Resistance Variation

The contribution of shaft resistance under different moisture conditions is presented in Table 5.

**Table 5**  
**Variation of Shaft Resistance**

Condition	Shaft Resistance (kN)
Dry Season	980
Normal Condition	860
Wet Season	700

#### Interpretation:

Shaft resistance exhibited substantial variation with seasonal moisture changes. The highest shaft resistance of 980 kN was recorded during dry conditions, whereas the value decreased to 700 kN during wet conditions. This reduction is primarily attributed to the loss of effective stress, decreased soil suction, and reduced adhesion between the pile surface and surrounding soil. The results indicate that shaft resistance is highly sensitive to moisture fluctuations and represents the most affected component of pile capacity in expansive soils.

### 5.3 End-Bearing Resistance

The end-bearing resistance obtained under different seasonal conditions is presented in Table 6.

**Table 6**  
**Variation of End-Bearing Resistance**

Condition	End-Bearing Resistance (kN)
Dry Season	670
Normal Condition	640
Wet Season	580

#### Interpretation:

The end-bearing resistance showed comparatively smaller variations than shaft resistance. The values ranged from 580 kN during wet conditions to 670 kN during dry conditions. This behavior indicates that end-bearing resistance is less affected by seasonal moisture changes because it is primarily governed by the properties of deeper soil layers. Nevertheless, some reduction was observed during wet conditions due to softening of the soil beneath the pile tip.

### 5.4 Start Rapid Load–Settlement Profiles

The load–settlement behavior of piles under dry and wet conditions obtained from StatRapid testing is presented in Table 7.

**Table 7**  
**Start Rapid Load–Settlement Profiles**

Load (kN)	Settlement (mm) Dry Season	Settlement (mm) Wet Season
500	3.2	4.5
1000	7.4	10.8
1500	12.6	18.9

#### Interpretation:

The load–settlement profiles indicate that settlements increased significantly under wet conditions. At a load of 1500 kN, settlement increased from 12.6 mm during the dry season to 18.9 mm during the wet season. The higher settlements observed under wet conditions can be attributed to reduced soil stiffness, loss of matric suction, and increased compressibility of the expansive soil. The results clearly demonstrate that seasonal wetting leads to greater deformation and reduced foundation performance.

## **Discussion**

The overall results confirm that seasonal wetting-drying cycles have a significant impact on pile behavior in expansive soils. Moisture-induced changes in soil suction and stiffness directly influence load-transfer mechanisms, particularly shaft resistance. The StatRapid load testing method successfully captured variations in pile capacity and settlement behavior under different environmental conditions. The findings suggest that pile design in expansive soils should account for seasonal moisture fluctuations to ensure long-term foundation stability and serviceability.

Furthermore, the close relationship between moisture content and pile performance highlights the importance of continuous monitoring and periodic testing in expansive soil regions. The StatRapid method proved to be an efficient and reliable alternative to conventional static load testing for evaluating pile foundations under varying field conditions.

## **6. Major Findings**

1. Seasonal wetting-drying cycles significantly affected the performance of pile foundations in expansive soils.
2. Ultimate pile capacity decreased by approximately 15–20% during wet conditions due to soil softening and reduced matric suction.
3. Shaft resistance was more sensitive to moisture changes than end-bearing resistance.
4. Dry conditions increased pile capacity because of higher soil suction and improved pile–soil interaction.
5. Settlements were significantly higher during wet conditions, indicating reduced soil stiffness.
6. StatRapid testing effectively captured seasonal variations in pile capacity and settlement behavior.
7. The results showed good agreement with conventional static load testing methods.

## **7. Conclusion**

The study demonstrated that seasonal wetting-drying cycles have a significant influence on the behavior of piles installed in expansive soils. Wet conditions reduced pile capacity and increased settlement due to soil softening, whereas dry conditions enhanced pile resistance through increased matric suction.

StatRapid load testing successfully identified these variations and provided reliable assessments of pile performance under different moisture conditions. The findings confirm that StatRapid testing is a practical, rapid, and cost-effective alternative to conventional static load testing.

Overall, incorporating seasonal moisture effects into pile foundation design and evaluation can improve the long-term safety, serviceability, and performance of structures constructed on expansive soils.

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