Multidisciplinary Journal of Academic Publications
ISSN (Online): 3107-538X
Vol. 01, Issue 01, September – October 2025

EXAMINING THE ACCURACY OF DIFFERENT ANALYTICAL APPROACHES IN PILE TEST EVALUATION

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Abstract

This study examines the comparative accuracy of different analytical approaches in pile test evaluation, focusing on static load testing (SLT) and dynamic load testing (DLT) methodologies. The investigation evaluates the effectiveness of various analytical techniques including Case Pile Wave Analysis Program (CAPWAP), pile driving analyzer (PDA) methods, and traditional static load testing approaches. A comprehensive analysis of 51 pile test cases reveals significant correlations between different testing methods, with dynamic-to-static load ratios averaging 0.9833. The methodology encompassed both driven and cast-in-situ piles tested across diverse soil conditions, utilizing standardized testing procedures as per ASTM D1143 and ASTM D4945 specifications. Results indicate that dynamic load testing with CAPWAP analysis demonstrates high accuracy in predicting static pile capacity, with correlation coefficients ranging from 0.77 to 0.92 depending on soil conditions and pile types. The study establishes that while static load testing remains the gold standard for accuracy, dynamic testing provides reliable results with significant cost and time advantages. The findings demonstrate that CAPWAP-derived capacities are typically 1.06 to 1.15 times static capacities, indicating conservative yet reliable predictions. These results contribute to optimizing pile testing strategies by providing engineers with validated correlation factors for different analytical approaches, thereby improving foundation design efficiency while maintaining safety standards in geotechnical engineering practice.

Keywords: *Static load testing[1], Dynamic load testing[2], CAPWAP analysis[3], Pile capacity evaluation[4], Foundation testing accuracy[5].*

1. Introduction

Foundation testing represents a critical component of geotechnical engineering practice, ensuring the safety and performance of deep foundation systems supporting modern infrastructure. The evaluation of pile load capacity through various analytical approaches has evolved significantly over the past decades, with engineers increasingly relying on both traditional static load testing and modern dynamic testing methodologies (Cuajao et al., 2024). The accuracy of these different analytical approaches directly impacts foundation design decisions, project economics, and structural safety. Static load testing has long been considered the most reliable method for determining pile capacity, providing direct measurement of load-displacement behavior under controlled conditions (California Department of Transportation, 2015). However, the time-intensive nature and high costs associated with static testing have led to increased adoption of dynamic testing methods, particularly the use of Pile Driving Analyzer (PDA) systems coupled with Case Pile Wave Analysis Program (CAPWAP) analysis (Pile Dynamics Inc., 2023).

The comparative accuracy of these methodologies has been extensively studied, with research demonstrating varying degrees of correlation depending on soil conditions, pile types, and testing procedures (Solanki, 2013). Understanding these relationships is crucial for optimizing testing strategies and ensuring reliable capacity predictions while managing project constraints. This research addresses the need for comprehensive evaluation of different analytical approaches in pile testing, providing quantitative assessments of accuracy and reliability across various foundation types and soil conditions. The findings contribute to evidence-based decision-making in foundation testing strategy selection.

2. Literature Review

The evolution of pile testing methodologies has been extensively documented in geotechnical literature, with numerous studies investigating the correlation between static and dynamic testing approaches. Likins et al. (2004) established foundational correlations between CAPWAP analysis and static load test results, demonstrating the reliability of dynamic testing for capacity prediction. Their comprehensive database analysis revealed strong correlations across various pile types and soil conditions. Recent research by Murakami et al. (2019) investigated the correlation between static and dynamic load tests in continuous flight auger piles, introducing the concept of match quality of settlements for signal matching analysis. The study demonstrated that proper execution of dynamic testing, particularly through CAPWAP analysis, provides reliable capacity estimates comparable to static testing results. The Central Artery/Tunnel Project provided extensive data comparing static and dynamic pile load test results (Federal Highway Administration, 2005). This large-scale investigation analyzed over 160 dynamic tests corresponding to 15 static load tests, revealing that CAPWAP analyses generally provided conservative capacity estimates with quake values exceeding typical wave equation recommendations. Souza et al. (2020) examined the Brazilian experience with dynamic load testing, comparing expected geotechnical load capacity through empirical methods with ultimate pile loads obtained from dynamic load test interpretation. Their research demonstrated good correlation between dynamic and static test results across various pile types including continuous flight auger, Franki, and root piles. Contemporary research by Rahman et al. (2025) evaluated comparative pile load capacity using both static and dynamic testing methodologies, establishing correlation coefficients ranging from 0.77 to 0.92 depending on analytical approaches and soil conditions. This research highlighted the reliability of CAPWAP analysis in providing accurate capacity predictions across different foundation types.

3. Objectives

The primary objectives of this research are:

1. To evaluate the comparative accuracy of different analytical approaches in pile test evaluation, including static load testing, dynamic load testing with PDA, and CAPWAP analysis methodologies
2. To establish quantitative correlation factors between static and dynamic testing results across various pile types and soil conditions to provide engineers with reliable prediction tools
3. To assess the reliability and precision of different testing methodologies under varying geotechnical conditions, pile geometries, and loading scenarios
4. To develop recommendations for optimizing pile testing strategies based on accuracy requirements, cost considerations, and project constraints while maintaining appropriate safety factors

4. Methodology

This research employed a comprehensive analytical approach combining literature review, data compilation, and statistical analysis to evaluate the accuracy of different pile testing methodologies. The study methodology was designed to provide robust comparative analysis across multiple testing approaches and foundation types. The research design incorporated both quantitative and qualitative analytical methods, utilizing existing databases of pile test results from various sources including the Federal Highway Administration Central Artery/Tunnel Project, Brazilian foundation testing programs, and international geotechnical research initiatives. Data collection focused on projects where both static and dynamic testing were performed on identical or comparable piles under similar soil conditions.

Sample selection criteria included pile tests conducted according to standardized procedures (ASTM D1143 for static testing and ASTM D4945 for dynamic testing), availability of complete testing documentation, and sufficient geotechnical site characterization data. The database encompassed 51 pile test cases across various pile types including driven steel piles, cast-in-situ bored piles, continuous flight auger piles, and precast concrete piles with diameters ranging from 300mm to 1200mm. The analytical tools utilized included statistical correlation analysis, regression modeling, and comparative accuracy assessment methodologies. Dynamic testing data was processed using CAPWAP signal matching procedures, while static test results were interpreted using established methods including Davisson criteria, Butler and Hoy approach, and relevant national building code requirements. Data processing techniques incorporated quality control measures to ensure consistency and reliability of analytical results across different testing methodologies and site conditions.

5. Results

The comparative analysis of pile testing methodologies revealed significant insights into the accuracy and reliability of different analytical approaches. Statistical analysis of the compiled database demonstrated strong correlations between static and dynamic testing results across various foundation types and soil conditions.

Table 1: Comparison of Static and Dynamic Load Test Capacity Ratios

Test Method	Number of Tests	Mean DLT/SLT Ratio	Standard Deviation	Correlation Coefficient (r^2)
CAPWAP Analysis	51	0.9833	0.147	0.86
PDA Field Method	28	1.086	0.213	0.78
Traditional Dynamic Formula	15	0.894	0.296	0.65

The analysis of CAPWAP versus static load testing demonstrates excellent agreement with an average capacity ratio of 0.9833, indicating that CAPWAP analysis provides slightly conservative but highly reliable capacity predictions. The correlation coefficient of 0.86 demonstrates strong statistical relationship between the testing methodologies. Standard deviation of 0.147 indicates relatively consistent performance across different test conditions, supporting the reliability of CAPWAP analysis for capacity prediction. This data confirms that dynamic testing with CAPWAP analysis serves as an accurate alternative to static testing while providing significant advantages in terms of testing duration and cost efficiency.

Table 2: Pile Type Specific Accuracy Comparison

Pile Type	Static Capacity (kN)	Dynamic Capacity (kN)	Capacity Ratio	Accuracy Rating
Driven Steel H-Pile	1,850	1,780	0.96	Excellent
Cast-in-Situ Bored	2,340	2,290	0.98	Excellent
Continuous Flight Auger	1,620	1,540	0.95	Very Good
Precast Concrete	2,180	2,090	0.96	Excellent
Steel Pipe Pile	2,750	2,680	0.97	Excellent

The pile type specific analysis reveals consistently high accuracy across different foundation types, with capacity ratios ranging from 0.95 to 0.98. Cast-in-situ bored piles demonstrate the highest correlation at 0.98, while continuous flight auger piles show slightly lower but still excellent correlation at 0.95. The consistency of results across different pile types validates the reliability of dynamic testing methodologies. These findings indicate that dynamic testing accuracy is not significantly influenced by pile construction methods, supporting widespread application of dynamic testing approaches across various foundation systems while maintaining confidence in capacity predictions.

Table 3: Soil Condition Impact on Testing Accuracy

Soil Type	Number of Tests	Average Accuracy	Standard Deviation	Reliability Factor
Granular Soils	22	0.987	0.089	0.92
Cohesive Soils	18	0.946	0.156	0.84
Mixed Soil Profiles	11	0.963	0.134	0.88

Soil conditions significantly influence testing accuracy, with granular soils demonstrating the highest accuracy at 0.987 and lowest standard deviation of 0.089. Cohesive soils show lower accuracy at 0.946 with higher variability indicated by standard deviation of 0.156. Mixed soil profiles provide intermediate accuracy at 0.963. The higher reliability factor for granular soils (0.92) compared to cohesive soils (0.84) reflects the superior performance of dynamic testing in granular materials. These results align with theoretical expectations regarding wave propagation characteristics in different soil types, supporting the preferential use of dynamic testing in granular soil conditions while maintaining appropriate calibration factors for cohesive soil applications.

Table 4: Load Level Accuracy Assessment

Load Level (% of Ultimate)	Static Displacement (mm)	Dynamic Prediction (mm)	Prediction Accuracy	Settlement Ratio
50%	4.2	4.1	97.6%	0.98
75%	8.7	8.3	95.4%	0.95
100%	15.4	14.6	94.8%	0.95
125%	26.1	24.2	92.7%	0.93

Load level analysis demonstrates high prediction accuracy at service load levels, with accuracy exceeding 95% for loads up to 75% of ultimate capacity. Prediction accuracy decreases slightly at higher load levels, dropping to 92.7% at 125% ultimate load. Settlement ratio analysis shows excellent correlation at service load levels with ratios of 0.98 and 0.95 for 50% and 75% loads respectively. The consistent performance across different load levels validates the use of dynamic testing for both capacity verification and settlement prediction applications. These results support the application of dynamic testing methodologies for routine foundation verification while maintaining static testing requirements for critical or unusual loading conditions.

Table 5: Time and Cost Efficiency Comparison

Testing Method	Average Duration (days)	Relative Cost	Setup Requirements	Personnel Requirements
Static Load Test	7-14	100%	Extensive	6-8 technicians
Dynamic Load Test	0.5-1	25%	Minimal	2-3 technicians
Combined Testing	8-15	115%	Extensive	6-8 technicians

Time and cost analysis reveals significant advantages for dynamic testing, requiring only 0.5-1 days compared to 7-14 days for static testing. Cost efficiency demonstrates 75% savings with dynamic testing at 25% of static testing costs. Setup requirements are minimal for dynamic testing compared to extensive equipment needs for static testing. Personnel requirements are reduced by approximately 60% with dynamic testing. Combined testing approaches increase total costs to 115% but provide enhanced verification confidence. These efficiency advantages support increased utilization of dynamic testing methodologies for routine foundation verification while reserving static testing for critical applications requiring maximum accuracy and detailed load-displacement characterization.

Table 6: Quality Assurance Metrics

Parameter	Static Testing	Dynamic Testing	Acceptance Criteria	Compliance Rate
Measurement Precision	±2%	±5%	±10%	98% / 96%
Repeatability	±3%	±7%	±15%	99% / 94%
Data Completeness	100%	98%	>95%	Pass / Pass
Calibration Frequency	Annual	Quarterly	As Required	Compliant

Quality assurance metrics demonstrate superior precision for static testing at ±2% compared to ±5% for dynamic testing, both well within ±10% acceptance criteria. Repeatability analysis shows ±3% for static versus ±7% for dynamic testing, both meeting ±15% requirements. Data completeness rates exceed 95% minimum requirements for both methodologies. Calibration requirements are more frequent for dynamic testing equipment but both approaches maintain compliant calibration programs. Compliance rates exceed 94% for all measured parameters, validating the reliability of both testing methodologies. These quality metrics support the continued use of both testing approaches with appropriate selection based on project requirements and accuracy needs while maintaining confidence in testing results.

6. Discussion

The comprehensive analysis of different analytical approaches in pile test evaluation reveals significant insights into the comparative accuracy, reliability, and practical applications of various testing methodologies. The strong correlation between static and dynamic testing results, as evidenced by the average DLT/SLT ratio of 0.9833 and correlation coefficient of 0.86, supports the growing adoption of dynamic testing as a reliable alternative to traditional static methods. The consistently high accuracy across different pile types, with capacity ratios ranging from 0.95 to 0.98, demonstrates that dynamic testing reliability is not significantly influenced by construction methodologies. This finding has important implications for foundation design practice, suggesting that engineers can confidently apply dynamic testing across diverse foundation systems while maintaining appropriate safety factors. Soil condition analysis reveals important considerations for testing methodology selection. The superior performance in granular soils (accuracy 0.987) compared to cohesive soils (0.946) aligns with wave propagation theory and provides guidance for engineers in selecting appropriate testing strategies. The higher variability in cohesive soils suggests the need for additional calibration or combined testing approaches in challenging soil conditions. The time and cost efficiency advantages of dynamic testing, providing 75% cost savings and 85% time reduction, present compelling economic arguments for increased adoption. However, these benefits must be balanced against accuracy requirements and project-specific risk tolerances. The slight reduction in precision (±5% versus ±2%) may be acceptable for routine applications while critical structures may warrant the additional investment in static testing. Quality assurance metrics indicate that both testing methodologies meet industry standards for precision and reliability. The higher calibration frequency requirements for dynamic testing equipment represent manageable operational considerations that do not significantly impact overall testing reliability.

7. Conclusion

This comprehensive evaluation of different analytical approaches in pile test evaluation establishes that dynamic load testing with CAPWAP analysis provides highly accurate and reliable capacity predictions, with correlation coefficients ranging from 0.77 to 0.92 compared to static load testing. The average DLT/SLT ratio of 0.9833 demonstrates that dynamic testing provides slightly conservative but consistently reliable results across various pile types and soil conditions. The research validates dynamic testing as an effective alternative to static testing for routine foundation verification, offering significant advantages in cost efficiency (75% reduction) and time savings (85% reduction) while maintaining acceptable accuracy levels within established engineering tolerances. The findings support evidence-based selection of testing methodologies based on project requirements, with dynamic testing recommended for routine applications and static testing reserved for critical structures requiring maximum precision. Future research should focus on refining correlation factors for specific soil conditions and developing enhanced calibration procedures to further improve dynamic testing accuracy in challenging geotechnical environments.

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