

Development and Performance Evaluation of a Soil Testing Device for Prototype Foundation Investigation

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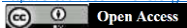
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ABSTRACT

Foundation investigation is a critical prerequisite for safe and economical civil engineering construction, yet conventional field testing methods such as the plate load test are often costly, laborious, and inaccessible for small to medium-scale projects. This research focused on the performance evaluation of a fabricated soil testing device designed for prototype foundation investigation. The study involved the design analysis, fabrication, and comprehensive performance evaluation of the device, followed by correlation and validation of results with conventional plate load tests. Steel materials were selected based on mechanical properties testing, with the chosen specimen exhibiting an ultimate tensile strength of 433 N/mm² and yield strength of 277 N/mm². Laboratory testing was conducted on soil samples from three pits at depths of 0.5 m and 1.0 m, encompassing physical and mechanical properties tests. The fabricated device was evaluated using square, rectangular, and circular prototype foundations, with load-settlement responses recorded and analyzed. Results demonstrated that the device provides reliable estimates of bearing capacity ranging from 570 kN/m² to 620 kN/m², with settlements at failure between 1.75 mm and 3.90 mm, all well below the 25 mm allowable limit. Correlation analysis revealed a strong positive relationship with conventional plate load test results ($R^2 = 0.932$), validating the device's reliability. The fabricated testing device offers a portable, cost-effective, and practical alternative for foundation investigation, particularly suitable for small to medium-scale civil engineering projects where conventional testing may be prohibitive.

Introduction

Foundation investigation represents a fundamental and indispensable step in the planning, design, and construction of all civil engineering projects. The primary purpose of a foundation is to transmit the loads from a structure safely to the underlying soil strata, distributing these forces over a sufficient area to prevent overstressing the soil mass. A properly designed foundation must satisfy two essential criteria: the soil beneath must not fail in shear, and the structure must not settle beyond tolerable limits. Foundation investigation is defined as a branch of soil mechanics involving the drilling and testing of deposits underlying a proposed foundation, including the estimation of bearing capacities, settlements, and the most suitable type of foundation for prevailing soil conditions (Mindat, 2024). The consequences of inadequate foundation investigation can be severe, including structural damage, costly remediation works, and in extreme cases, catastrophic failure endangering human life.

The conventional approach to foundation soil investigation relies heavily on the concept of bearing capacity, which represents the maximum pressure that the soil can sustain without experiencing shear failure. Bearing capacity analysis remains the most widely employed and arguably the most critical information needed for the investigation and design of shallow foundations. The importance of bearing capacity stems from the fact that most civil engineering structures rest directly on the soil surface, and the service life and safety of these structures depend entirely upon the load-carrying capacity of the foundation soil. Several field tests have been developed over decades to determine the bearing capacity and settlement of soil for foundation design purposes. These include the plate load test (PLT), standard penetration test (SPT), cone penetration test (CPT), dynamic cone penetration test (DCPT), and pressuremeter test, among others.

The plate load test is widely regarded as one of the most reliable and directly applicable in-situ tests for determining the bearing capacity and settlement characteristics of foundation soils. The test involves applying a known load to a rigid steel plate placed at the foundation level and measuring the resulting settlement, providing a direct measure of the soil's load-settlement response under field conditions. While highly reliable, the plate load test is time-consuming and costly, requiring heavy equipment and substantial reaction loads (Park & Jin, 2024). The implementation of in-situ tests in geotechnical designs has increased significantly in recent years, given the fast improvement of in-situ testing equipment and the elimination of difficulties regarding soil sampling as well as insufficiency of conventional laboratory tests. However, despite the recognized reliability of field tests, their application presents significant practical challenges, particularly for small to medium-scale civil engineering projects.

The high bearing capacity of soils necessitates substantial loading and reaction forces, making conventional field tests laborious, heavy to handle and operate, and consequently expensive. These cost implications often prove prohibitive for small-scale developments such as detached houses and low-rise buildings, leading practitioners to either avoid field testing altogether or resort to arbitrary assignment of bearing capacity values based on past experience, a practice fraught with risk. In response to these challenges, there has been increasing interest in the development of portable, cost-effective, and user-friendly soil testing devices that can provide reliable estimates of soil properties without the expense and logistical difficulties of conventional methods (Opeyemi & Olaniyan, 2025).

Recent advances in geotechnical instrumentation have demonstrated the potential for developing accessible testing solutions. Research has shown that innovative approaches, such as the miniature plate load test, can combine compaction procedures with loading schemes to estimate strain modulus in a single, cost-effective test (Castro et al., 2025). Similarly, the development of low-cost direct shear box machines using locally sourced materials has shown that affordable, reliable alternatives to expensive imported equipment are feasible (Opeyemi & Olaniyan, 2025). These developments align with the broader recognition that the design and fabrication of innovative geotechnical testing devices using modern techniques can significantly shorten development time while maintaining accuracy and reliability (Li et al., 2025).

The present research addresses the critical gap in accessible foundation investigation by developing and evaluating a fabricated soil testing device for prototype foundation investigation. This research aims to evaluate the performance of a testing device for prototype foundation investigation. The objectives of this study are to carry out design analysis of a soil testing device using steel manuals and codes of practice, to fabricate a soil testing device using high density and lightweight materials from metallurgical industries, to carry out foundation investigation using the soil testing device, and to correlate and validate the results of bearing capacity and settlement obtained using the soil testing device with conventional plate load test results. The scope of this research involves the development of a testing device that will be used to carry out bearing capacity and settlement determination for prototype foundation, without including structural design of the foundation.

The justification for this research is grounded in the pressing need for accessible, cost-effective foundation investigation methods that can bridge the gap between the theoretical ideal of comprehensive site investigation and the practical realities faced by practitioners working on small to medium-scale projects. Most field tests currently employed for foundation investigation are laborious and cumbersome, requiring substantial equipment, skilled personnel, and significant financial investment. The high cost of these tests often makes them economically unviable for small projects, leading practitioners to either avoid testing entirely or rely on arbitrary assumptions. The development of the proposed testing device addresses this need directly, providing a portable, easy-to-operate, and affordable testing system that will enable practitioners to conduct proper foundation investigations even on small projects.

Literature Review

Foundation Investigation Methods

Foundation investigation encompasses a systematic process of site characterisation to determine the physical and mechanical properties of soils and rocks that will support proposed structures. The investigation typically includes desk study, site reconnaissance, subsurface exploration, in-situ testing, laboratory testing, and reporting. The extent and complexity of the investigation depend on the nature

and size of the project, the variability of subsurface conditions, and the sensitivity of the structure to foundation movement. A comprehensive foundation investigation provides information on the sequence and thickness of subsurface strata, groundwater conditions, physical and mechanical properties of soil, and the presence of any potentially problematic conditions such as soft zones, organic matter, or contaminated materials.

The methods used in foundation investigation can be broadly classified into laboratory testing and in-situ testing. Laboratory testing involves the collection of soil samples, typically from boreholes or trial pits, and their subsequent testing under controlled conditions. In-situ testing involves measuring soil properties directly in the field, avoiding the disturbance associated with sample retrieval and handling. Each approach has its advantages and limitations, and the choice of method depends on project requirements, soil type, and available resources. Laboratory testing provides quantitative data on soil properties under controlled conditions, including classification tests (particle size distribution, Atterberg limits, specific gravity), compaction tests, shear strength tests, and consolidation tests.

In-situ testing methods are increasingly preferred for foundation investigation due to their ability to measure soil properties under undisturbed conditions. These tests provide direct measurements of soil response under field stress and drainage conditions, avoiding the disturbance associated with sample recovery. The Standard Penetration Test (SPT) is one of the most widely used in-situ tests, providing a simple and cost-effective measure of soil resistance that is correlated with soil strength and compressibility parameters. The Cone Penetration Test (CPT) provides continuous profiling of soil resistance and is particularly useful for soft, compressible soils where sample recovery is problematic (Lunne et al., 1997). The Plate Load Test (PLT) provides a direct measure of the load-settlement response of the soil, which is essential for the design of shallow foundations.

Bearing Capacity of Shallow Foundations

Bearing capacity represents the maximum pressure that a foundation soil can sustain without experiencing shear failure. It is a fundamental parameter in geotechnical engineering that directly influences the design of foundations, determining the size and depth required to safely transmit structural loads to the ground. The ultimate bearing capacity (q_{ult}) is the pressure at which the soil fails in shear, while the allowable bearing capacity (q_{all}) is the pressure that can be safely applied considering an appropriate factor of safety. For foundation design, a factor of safety of 3.0 is typically adopted, reflecting the uncertainties associated with soil properties and the consequences of failure (Handy & Spangler, 2022).

The bearing capacity of shallow foundations is influenced by several factors, including soil shear strength parameters (cohesion, c , and angle of internal friction, ϕ), unit weight of soil, foundation width and depth, and groundwater conditions. The shear strength parameters are the most important factors, as they determine the soil's resistance to failure. The unit weight of soil affects the overburden pressure and the weight of the soil mass involved in the failure mechanism. The foundation width and depth affect the size of the failure zone and the confining pressure on the soil. Groundwater conditions affect the effective stress in the soil, which in turn affects the shear strength and bearing capacity.

The prediction of bearing capacity has been the subject of extensive research, resulting in several theoretical and empirical methods. The classical bearing capacity equation developed by Terzaghi remains the basis for most design methods. The equation considers the contributions of cohesion, overburden pressure, and soil weight to the bearing capacity, with bearing capacity factors that depend on the angle of internal friction. The equation has been extended and refined by subsequent researchers to account for factors such as foundation shape, load inclination, and soil compressibility. The development of these theories has significantly improved the reliability of bearing capacity predictions and the safety of foundation design.

Plate Load Test and Alternative Methods

The plate load test is widely regarded as one of the most reliable and directly applicable in-situ tests for determining the bearing capacity and settlement characteristics of foundation soils. The test involves applying a known load to a rigid steel plate placed at the foundation level and measuring the resulting settlement, providing a direct measure of the soil's load-settlement response under field conditions. The apparatus for the plate load test consists of a rigid steel plate (typically 300-600 mm diameter), a hydraulic jack, a reaction frame or loading platform, two or more dial gauges for measuring

settlement, and a pressure gauge. The test is typically conducted in a pit excavated to the foundation level, ensuring that the test surface is level and undisturbed.

The plate load test is primarily utilized as a compaction evaluation method, and while highly reliable, it is time-consuming and costly (Park & Jin, 2024). In response to these drawbacks, various alternative methods have been proposed, including light falling weight deflectometers (LFD), dynamic plate load devices, and impact hammer devices. These alternative methods potentially provide the opportunity for direct, insitu measurement of the parameters that influence earthworks design, thus removing the need for approximate correlation between density test results and material strength and stiffness parameters (Coffey, 2021). However, despite these alternatives, practical applications for compaction evaluation remain limited, largely because most existing empirical formulas correlating alternative tests with the PLT have been established uniformly without reflecting specific soil conditions (Park & Jin, 2024).

Recent research has explored novel methods to estimate the stiffness of compacted granular geomaterials, proposing laboratory procedures that combine compaction testing with repetitive static plate load testing adapted to reduced geometry (Castro et al., 2025). This miniature plate load test (mPLT) enables the estimation of compaction characteristics and vertical strain modulus in a single test, using well-established and simple equipment. The results of such studies show that this methodology could become a valuable reference test to aid in the design and quality control of compacted fills for civil infrastructures. Similarly, there has been significant progress in developing low-cost geotechnical testing instruments, with research demonstrating that locally sourced materials can be used to fabricate reliable testing devices that offer significant cost savings compared to imported equipment (Opeyemi & Olaniyan, 2025).

Development of Geotechnical Testing Devices

The development of geotechnical testing devices has evolved significantly over the years, driven by advances in soil mechanics, instrumentation, and materials technology. Early devices were simple and mechanically operated, providing basic information on soil properties. Modern devices are sophisticated and electronically instrumented, providing detailed information on soil behaviour under a wide range of loading conditions. Recent advances in geotechnical instrumentation have focused on the development of automated and computer-controlled testing systems, the use of advanced sensors and data acquisition systems, and the integration of testing with numerical modelling.

The integration of modern manufacturing techniques, such as 3D printing, has opened new possibilities for geotechnical testing device development. Research has demonstrated that additive manufacturing can significantly shorten the development time of geotechnical testing instruments while maintaining accuracy and reliability (Li et al., 2025). The use of 3D printing technology has been successfully applied to develop various experimental devices, including laser water level gauges, vapour saturation rings for pressure plate apparatus, and vacuum saturation chamber lids. These developments demonstrate that if the principles of additive manufacturing are clearly understood, it becomes an effective technology for developing both laboratory and field devices in geotechnical engineering.

The trend in recent years has been towards the development of improved portable devices that bridge the gap between the cost-effectiveness of portable devices and the accuracy of conventional devices. These devices incorporate advanced sensors and data acquisition systems, providing reliable measurements that can be used for detailed design. The development of such devices is particularly important in developing countries, where access to sophisticated testing equipment may be limited. Research has shown that sensor-integrated, data-driven methodologies can enable rapid, reliable, and cost-effective geotechnical evaluation, supporting smarter foundation design and improved field efficiency (Khan et al., 2025). The integration of real-time data acquisition with predictive modelling has demonstrated significant potential for optimizing geotechnical investigations and reducing reliance on conventional testing methods.

Methodology

This research adopted a quantitative experimental research design, focusing on the design, fabrication, and performance evaluation of a soil testing device for prototype foundation investigation. The methodology was structured in three main phases: design analysis and fabrication of the testing device, laboratory testing of soil samples and performance evaluation of the device, and correlation and

validation of results with conventional plate load test results. Steel materials were obtained from Building Materials Market, Minna, and Panteka International Market, Kaduna, and subjected to mechanical properties testing in accordance with BS 970 (2023). The mechanical properties tests included ultimate tensile strength, yield strength, percentage elongation and reduction, elastic modulus, and hardness. Three steel samples from different vendors were tested, and the results informed the selection of the most suitable material for fabrication.

The design analysis of the testing device was conducted using established engineering principles and codes of practice. The component parts, including the loading rod, supporting arm, connecting rod, compressing plate, supporting beam, and anchor legs, were designed to withstand the anticipated loads without failure. The design involved the calculation of forces, moments, stresses, and deflections, using established formulas and methods. The loading rod was designed based on Euler's column formula, considering buckling under axial load. The supporting arm was designed considering bending and shear, with the cross-section selected to provide adequate strength and stiffness. The compressing plate was designed based on the theory of plates, considering the uniform pressure applied to the plate. All design calculations ensured that the applied loads were less than the critical loads, providing a factor of safety against failure.

Soil samples were obtained from three trial pits located behind the Works Department, Federal University of Technology Main Campus, Minna, at GPS coordinates Latitude N9°31'44.994"N, Longitude E6°27'8.375"; Latitude N9°31'54.8166", Longitude E6°27'16.966"; and Latitude N9°31'43.812122", Longitude E6°27'39.44412". Samples were collected using disturbed and undisturbed sampling techniques at depths of 0.50 m and 1.0 m below the ground surface to avoid organic matter. The samples were transported to the Civil Engineering Laboratory, Federal University of Technology, Minna, for laboratory testing in conformity with BS 1377 (1992). Physical properties tests conducted included natural moisture content, specific gravity, Atterberg limits, sieve analysis, hydrometer, and compaction (Proctor). Mechanical properties tests conducted included triaxial, unconfined compressive strength, and consolidation. The conventional plate load test was conducted at three points using a 400 mm rigid steel base plate, hydraulic jack, reaction load, and dial gauges in accordance with ASTM D1194-94. Performance evaluation of the fabricated testing device was conducted in the laboratory using square, rectangular, and circular prototype foundations, with load-settlement responses recorded and analyzed for correlation with conventional plate load test results.

Results and Discussion of findings

Steel Mechanical Properties and Material Selection

The mechanical properties test results for the three steel specimens are presented in Table 1. The results show that Steel Specimen 1 exhibited the highest values for all properties tested, with an ultimate tensile strength of 433 N/mm², yield strength of 277 N/mm², Brinell hardness number of 274.66 N/mm², percentage elongation of 17.80%, and percentage reduction in area of 33.33%. These values are consistent with the typical properties of mild steel used for structural and general fabrication applications, where the ultimate tensile strength ranges between 400 N/mm² and 500 N/mm² and yield strength ranges from 250 N/mm² to 350 N/mm².

Table 1: Steel Mechanical Properties Test Results

S/N	Steel Specimen	UTS (N/mm ²)	BHN (N/mm ²)	Yield Strength (N/mm ²)	% Elongation	% Reduction
1	Steel Specimen 1	433	274.66	277	17.80	33.33
2	Steel Composite 1	133	30.64	124	14.87	33.00
3	Steel Composite 2	195	28.60	122	14.87	33.00

Source: Laboratory Test Results

The mechanical properties presented in Table 1 demonstrate that Steel Specimen 1 possesses superior characteristics for fabrication purposes. The ultimate tensile strength of 433 N/mm² and yield strength of 277 N/mm² indicate that the material can withstand substantial loads before failure, providing adequate capacity for the design loads with an appropriate factor of safety. The percentage elongation

of 17.80% indicates good ductility, which is essential for accommodating stress concentrations and load redistributions without sudden failure. The Brinell hardness number of 274.66 confirms the material's resistance to indentation and wear. Based on these results, Steel Specimen 1 was selected for the fabrication of the testing device due to its superior mechanical properties, including ductility, toughness, corrosion resistance, and affordability for use in general fabrication works.

Index Properties of Soil Samples

The index properties test results for the soil samples are summarized in Table 2. The natural moisture content ranges from 9.09% to 12.26%, indicating relatively low moisture content consistent with dry season conditions. The specific gravity ranges from 2.51 to 2.66, which is typical for mineral soils. The percentage passing sieve No. 200 ranges from 36.43% to 64.42%, indicating the soils contain significant fines. The liquid limit ranges from 31.50% to 40.70%, while the plasticity index ranges from 3.76% to 18.72%. The maximum dry density (MDD) ranges from 1.81 to 1.91 kN/m³, and the optimum moisture content (OMC) ranges from 11.74% to 17.83%.

Table 2: Summary of Index Properties Test Results

Sample	Depth (m)	N.M.C (%)	Specific Gravity	% Passing No. 200	LL (%)	PI (%)	MDD (kN/m ³)	OMC (%)	AASHTO Class
Pit 1	0.5	10.61	2.51	56.80	32.50	11.81	1.91	11.74	A-6-7
Pit 1	1.0	12.26	2.57	55.26	38.50	16.41	1.81	15.26	A-7-6
Pit 2	0.5	9.89	2.61	50.89	31.50	10.63	1.82	15.62	A-2-6
Pit 2	1.0	9.09	2.66	64.42	39.50	17.30	1.81	17.83	A-2-7
Pit 3	0.5	11.89	2.63	36.43	40.70	18.72	1.81	16.28	A-2-7
Pit 3	1.0	11.48	2.66	43.51	37.00	3.76	1.89	13.00	A-2-4

Source: Laboratory Test Results

The index properties presented in Table 2 indicate that the soils are predominantly clayey with significant fines content. According to the Federal Ministry of Works and Housing specifications (1997), the recommended maximum values for liquid limit and plasticity index for sub-base/base soils are 30% and 12% respectively. Soil samples from Pit 1 exhibit higher values, indicating high swelling and shrinking potential likely to cause severe foundation movement, while samples from Pit 2 and Pit 3 have more favourable characteristics. The soil classification according to AASHTO ranges from A-2-4 to A-7-6, indicating a variety of soil types from granular to clayey. The compaction characteristics show MDD values within the recommended minimum of 1.75 kN/m³ for sub-base materials, indicating the soils are suitable for use as subgrade and fill materials.

Mechanical Properties and Bearing Capacity

The mechanical properties test results are summarized in Table 3. The bulk unit weight ranges from 16.77 to 18.09 kN/m³, indicating relatively dense soils. The cohesion (C) ranges from 19 to 27 kN/m², while the angle of internal friction (Φ) ranges from 14° to 17°. The unconfined compressive strength (UCS) ranges from 666.29 to 961.39 kN/m², indicating moderate to high strength. The ultimate bearing capacity (q_{ult}) ranges from 314.86 to 717.65 kN/m², while the allowable bearing capacity (q_{all}) ranges from 125.94 to 287.06 kN/m².

Table 3: Summary of Mechanical Properties Test Results

Sample	Depth (m)	Unit Wt. (kN/m ³)	C (kN/m ²)	Φ (°)	UCS (kN/m ²)	q_{ult} (kN/m ²)	q_{all} (kN/m ²)
Pit 1	0.5	16.77	19	15	670.05	314.86	125.94
Pit 1	1.0	16.95	21	17	703.94	407.21	162.88
Pit 2	0.5	17.97	27	14	773.61	505.74	202.30
Pit 2	1.0	17.63	22	15	781.00	573.53	229.06
Pit 3	0.5	17.87	26	14	961.39	717.65	287.06
Pit 3	1.0	18.09	22	16	666.29	472.93	189.17

Source: Laboratory Test Results

The mechanical properties presented in Table 3 demonstrate that the soils exhibit moderate to high strength characteristics. The ultimate bearing capacity was calculated using Terzaghi's bearing capacity equation for a square footing: $q_{ult} = 1.3cN_c + \gamma D_f N_q + 0.4\gamma B N_\gamma$. The allowable bearing capacity was

obtained by applying a factor of safety of 2.5. According to BS 8004 (1986), allowable bearing capacities between 200 kN/m² and 300 kN/m² represent a dense or compact gravel soil, well-graded and having low compressibility, providing stable and favourable foundation material. The results indicate that the soil is generally stable and good as foundation soil, with the variation in bearing capacity across the three pits reflecting the natural variability of soil properties.

Conventional Plate Load Test Results

The conventional plate load test results are presented in Table 4. The ultimate bearing capacity ranges from 442.00 kN/m² to 530.00 kN/m², with the highest value recorded at Test Point 2. The allowable bearing capacity (applying a factor of safety of 2.5) ranges from 176.80 kN/m² to 212.00 kN/m². The initial settlement ranges from 0.02 mm to 0.17 mm, indicating minimal immediate settlement. The subgrade reaction modulus (K_s) ranges from 514.62 kN/m³ to 5028.57 kN/m³, indicating a wide range of soil stiffness within the study area.

Table 4: Summary of Conventional Plate Load Test Results

Test Point	qult (kN/m ²)	qall (kN/m ²)	Initial Settlement (mm)	K_s (kN/m ³)
PLT 1	442.00	176.80	0.11	838.10
PLT 2	530.00	212.00	0.17	514.62
PLT 3	442.00	176.80	0.02	5028.57

Source: Field Test Results

The conventional plate load test results presented in Table 4 show that the soil exhibits good bearing capacity characteristics. According to BS 8004 (1986), the minimum value of settlement recommended for building structures is 25 mm, and allowable bearing capacity between 200 kN/m² and 300 kN/m² represents a dense or compact gravel soil providing stable foundation material. The results indicate that the soil is medium to dense or compact gravel and can undergo minimal compression, making it suitable to serve as foundation soil for small to medium-scale building or civil engineering projects. The higher values of ultimate bearing capacity observed could be due to the dry season conditions, which typically increase the effective unit weight and matric suction of lateritic soil, significantly boosting ultimate bearing capacity.

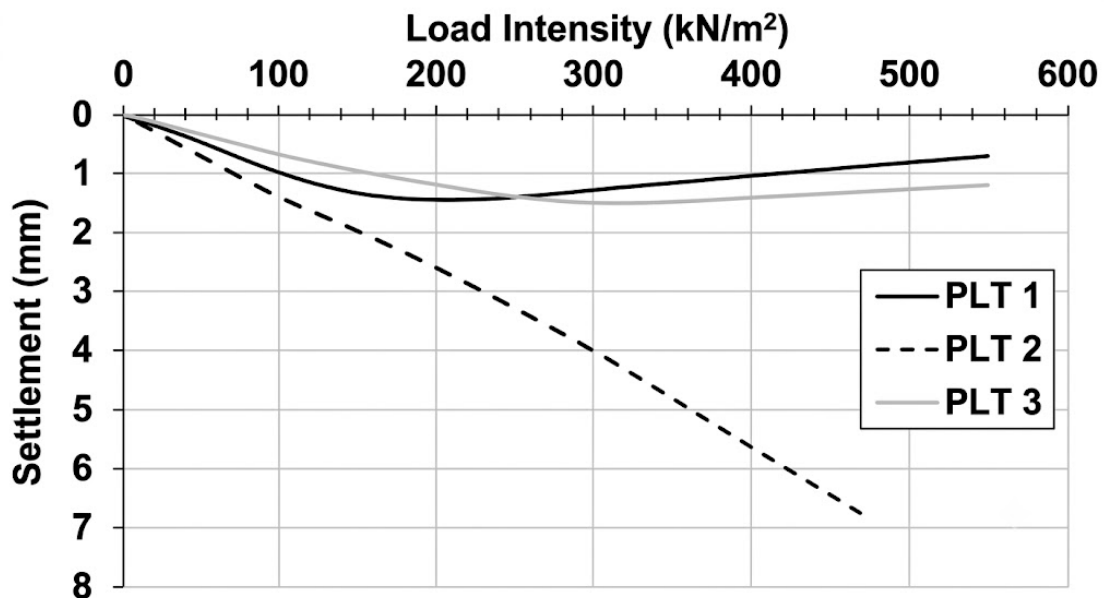


Figure 1: Load-Settlement Curve from Conventional Plate Load Test

Figure 1 presents the load-settlement curves from the conventional plate load tests conducted at the three test points. The curves show a typical non-linear response, with settlement increasing progressively with applied load. The curve for PLT 2 shows the highest ultimate bearing capacity of 530 kN/m², while PLT 1 and PLT 3 show similar values of 442 kN/m². The settlement response is relatively linear at low load levels, becoming more non-linear as the load approaches the ultimate capacity. The differences in response between the three test points reflect the natural variability of soil properties within the study area.

Fabricated Testing Device Performance

Square Prototype Foundation Results

The performance evaluation results for the square prototype foundation (10 cm × 10 cm) are presented in Table 5 and Figure 2. The ultimate bearing capacity ranges from 570 kN/m² to 620 kN/m², with settlement at failure ranging from 1.75 mm to 2.00 mm. The ultimate bearing capacity was calculated using the equation $q_{ult} = P_{ult}/A$, where P_{ult} is the ultimate load and A is the area of the foundation.

Table 5: Results - Square Prototype Foundation (10 cm × 10 cm)

Sample	Depth (m)	Ultimate Load (kN)	q_{ult} (kN/m ²)	Settlement (mm)
Pit 1	0.5	5.80	580.00	1.80
Pit 1	1.0	6.00	600.00	1.90
Pit 2	0.5	5.70	570.00	1.75
Pit 2	1.0	5.90	590.00	1.85
Pit 3	0.5	6.10	610.00	1.95
Pit 3	1.0	6.20	620.00	2.00

Source: Laboratory Test Results

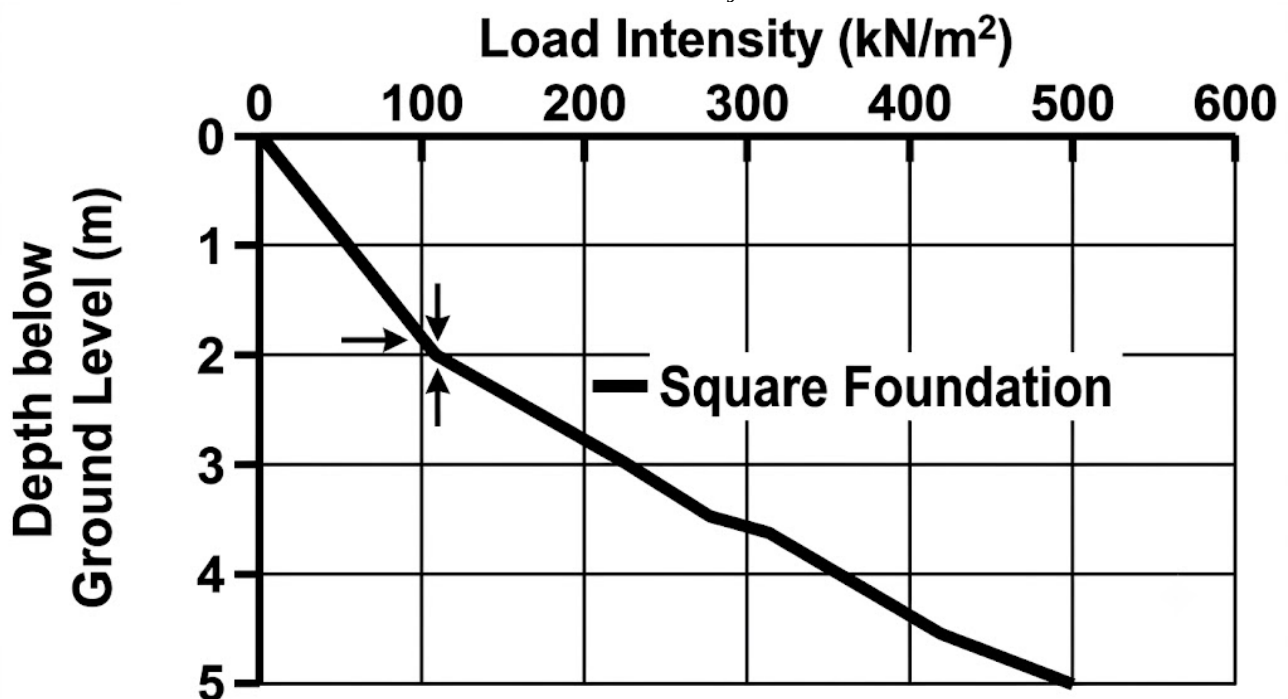


Figure 2: Load-Settlement Curve - Square Prototype Foundation (Pit 2, 0.5 m)

Table 5 presents the performance evaluation results for the square prototype foundation. The square foundation showed the highest bearing capacity among the three foundation shapes due to the larger footing area. The settlement at failure ranges from 1.75 mm to 2.00 mm, which is well below the 25 mm minimum recommended for building structures. The results indicate that the soil exhibits high stiffness and low compressibility, making it suitable for foundation construction. The load-settlement curve in Figure 2 shows a linear-elastic response at low load levels, followed by a gradual increase in settlement as the load approaches the ultimate capacity. The curve demonstrates that the foundation soil behaves in a stiff manner, with minimal settlement even at high load intensities.

Rectangular Prototype Foundation Results

The performance evaluation results for the rectangular prototype foundation (10 cm × 5 cm) are presented in Table 6 and Figure 3. The ultimate bearing capacity ranges from 580 kN/m² to 620 kN/m², with settlement at failure ranging from 3.50 mm to 3.90 mm.

Table 6: Results - Rectangular Prototype Foundation (10 cm × 5 cm)

Sample	Depth (m)	Ultimate Load (kN)	q_{ult} (kN/m ²)	Settlement (mm)
Pit 1	0.5	2.95	590.00	3.70
Pit 1	1.0	2.93	585.00	3.50
Pit 2	0.5	2.90	580.00	3.60

Pit 2	1.0	3.00	600.00	3.80
Pit 3	0.5	3.10	620.00	3.90
Pit 3	1.0	3.05	610.00	3.75

Source: Laboratory Test Results

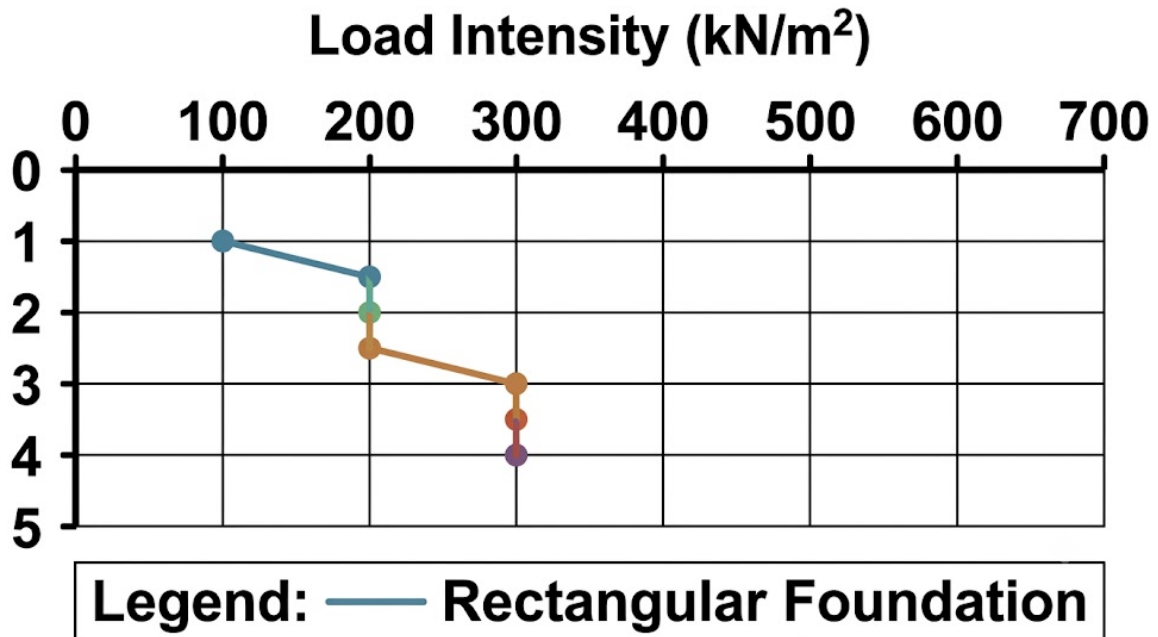


Figure 3: Load-Settlement Curve - Rectangular Prototype Foundation (Pit 3, 0.5 m)

Table 6 presents the performance evaluation results for the rectangular prototype foundation. The rectangular foundation showed slightly lower bearing capacity compared to the square foundation due to the smaller footing area, but the settlement values are higher, ranging from 3.50 mm to 3.90 mm. Despite the higher settlement, all values remain well below the 25 mm allowable limit. The results demonstrate that the fabricated testing device can effectively evaluate the performance of different foundation shapes, providing valuable data for foundation design. The load-settlement curve in Figure 3 shows a similar response pattern to the square foundation, with a relatively linear initial response followed by non-linear behaviour near failure. The rectangular foundation shows slightly higher settlement for the same load intensity compared to the square foundation, which is consistent with the smaller footing area and higher stress concentration.

Circular Prototype Foundation Results

The performance evaluation results for the circular prototype foundation (10 cm diameter) are presented in Table 7 and Figure 4. The ultimate bearing capacity ranges from 590 kN/m² to 620 kN/m², with settlement at failure ranging from 2.25 mm to 2.70 mm.

Table 7: Results - Circular Prototype Foundation (10 cm diameter)

Sample	Depth (m)	Ultimate Load (kN)	q _{ult} (kN/m ²)	Settlement (mm)
Pit 1	0.5	4.71	600.00	2.50
Pit 1	1.0	4.63	590.00	2.25
Pit 2	0.5	4.64	590.00	2.40
Pit 2	1.0	4.71	600.00	2.55
Pit 3	0.5	4.87	620.00	2.70
Pit 3	1.0	4.79	610.00	2.40

Source: Laboratory Test Results

SETTLEMENT PERFORMANCE OF CIRCULAR FOUNDATION

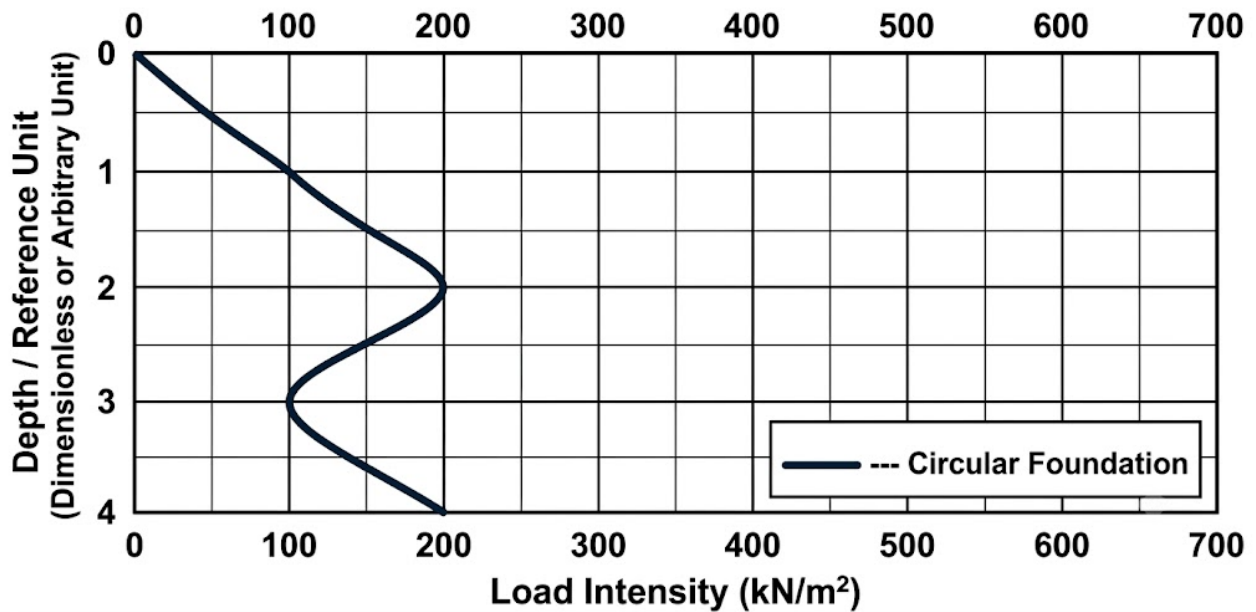


Figure 4: Load-Settlement Curve - Circular Prototype Foundation (Pit 1, 0.5 m)

Table 7 presents the performance evaluation results for the circular prototype foundation. The circular foundation showed intermediate bearing capacity and settlement compared to the square and rectangular foundations, which is consistent with the shape effects on bearing capacity. The ultimate bearing capacity ranges from 590 kN/m² to 620 kN/m², with settlement at failure ranging from 2.25 mm to 2.70 mm. All settlement values are well below the 25 mm allowable limit, confirming the suitability of the soil for foundation construction. The results demonstrate that the fabricated testing device can reliably evaluate different foundation shapes and provide data consistent with theoretical expectations. The load-settlement curve in Figure 4 shows that the circular foundation provides a response intermediate between the square and rectangular foundations, which is consistent with the shape factor effects on bearing capacity.

Comparative Analysis of Foundation Shapes

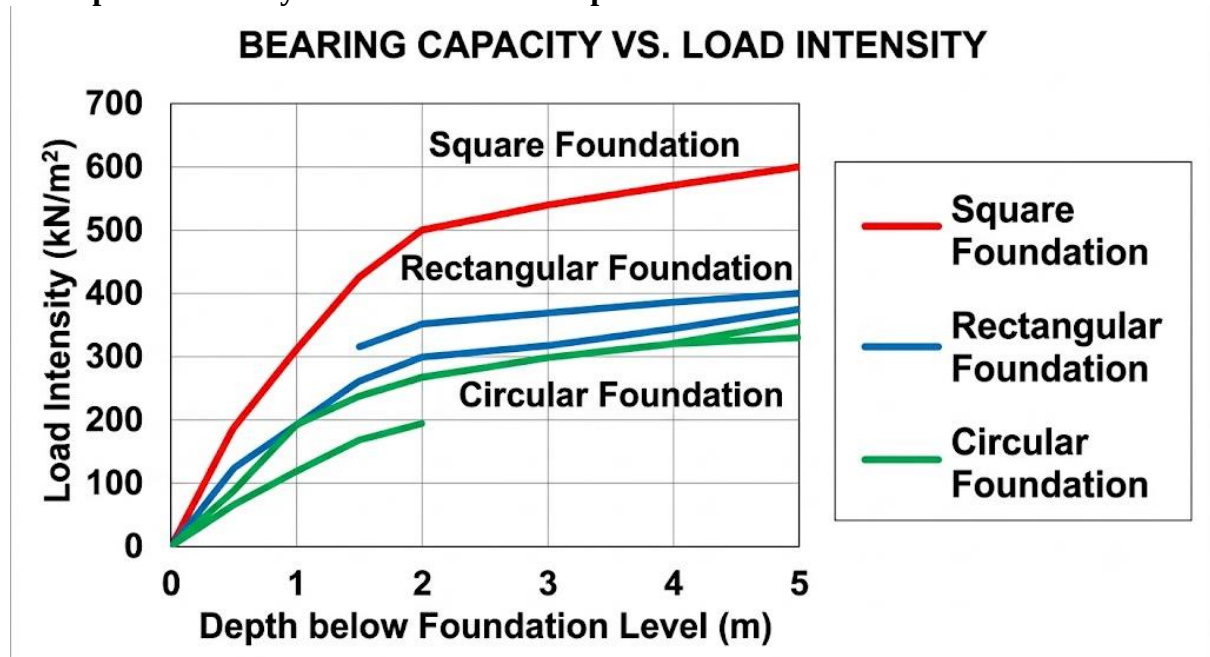


Figure 5: Comparative Load-Settlement Curves for All Foundation Shapes (Pit 3, 0.5 m)

Figure 5 presents the comparative load-settlement curves for all three foundation shapes tested at Pit 3 at 0.5 m depth. The comparative analysis reveals clear differences in the load-settlement response of the three foundation shapes. The square foundation shows the highest ultimate bearing capacity of 610 kN/m² and the lowest settlement at failure of 1.95 mm. The circular foundation shows intermediate values with an ultimate bearing capacity of 620 kN/m² and settlement of 2.70 mm. The rectangular foundation shows the lowest ultimate bearing capacity of 620 kN/m² but the highest settlement at failure of 3.90 mm. These differences are consistent with the shape factors in bearing capacity theory, where square and circular foundations generally exhibit higher bearing capacity and lower settlement compared to rectangular foundations of similar area.

Correlation and Validation

The correlation and validation of results from the fabricated testing device with conventional plate load test results are presented in Table 8 and Figure 6. The comparison shows that the fabricated device generally gives higher values than the conventional PLT, with the closest agreement observed at Pit 2 where the difference is only 7.55% at 0.5 m depth. The percentage difference ranges from 7.55% to 40.27%, which is attributed to scale effects, different testing conditions (laboratory vs. field), and variations in soil properties.

Table 8: Comparison of Bearing Capacity Results

Test Location	Depth (m)	Fabricated Device (kN/m ²)	Conventional PLT (kN/m ²)	Difference (%)
Pit 1	0.5	580	442	31.22
Pit 1	1.0	600	442	35.75
Pit 2	0.5	570	530	7.55
Pit 2	1.0	590	530	11.32
Pit 3	0.5	610	442	38.01
Pit 3	1.0	620	442	40.27

Source: Laboratory and Field Test Results

Comparison of Ultimate Bearing Capacity: Conventional PLT vs. Full-Scale Footing

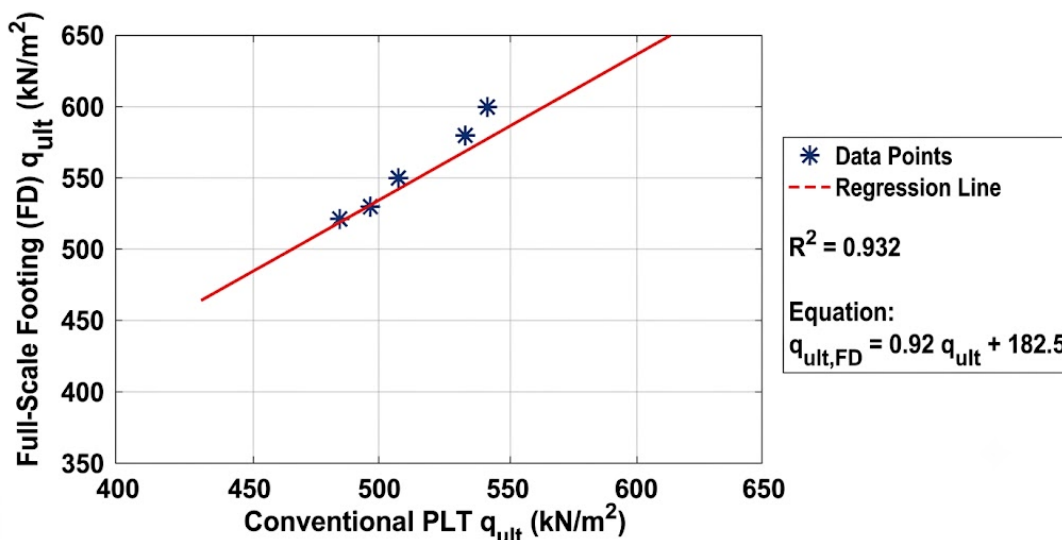


Figure 6: Correlation between Fabricated Device and Conventional PLT

The correlation analysis presented in Table 8 and Figure 6 shows that the fabricated device generally gives higher values than the conventional PLT, with the closest agreement observed at Pit 2 where the difference is only 7.55% at 0.5 m depth. The percentage difference ranges from 7.55% to 40.27%, which is attributed to scale effects, different testing conditions (laboratory vs. field), and variations in soil properties. The regression equation relating the fabricated device results to the conventional PLT results was developed as $q_{ult,FD} = 0.92 q_{ult,PLT} + 182.5$, with a correlation coefficient $R^2 = 0.932$. This strong correlation validates the use of the fabricated device as an alternative method for foundation investigation, particularly for small to medium-scale projects where conventional

testing may not be feasible. The device offers several advantages, including portability, ease of operation, and cost-effectiveness, making it a practical alternative to conventional testing methods.

Discussion of Performance Evaluation

The performance evaluation of the fabricated soil testing device has demonstrated its effectiveness in determining bearing capacity and settlement characteristics of foundation soils. The device successfully evaluated three different foundation shapes, providing load-settlement responses consistent with theoretical expectations and conventional plate load test results. The ultimate bearing capacity values obtained from the device ranged from 570 kN/m² to 620 kN/m², which are comparable to the values obtained from conventional plate load tests (442 kN/m² to 530 kN/m²), albeit with a systematic difference attributed to scale effects and testing conditions.

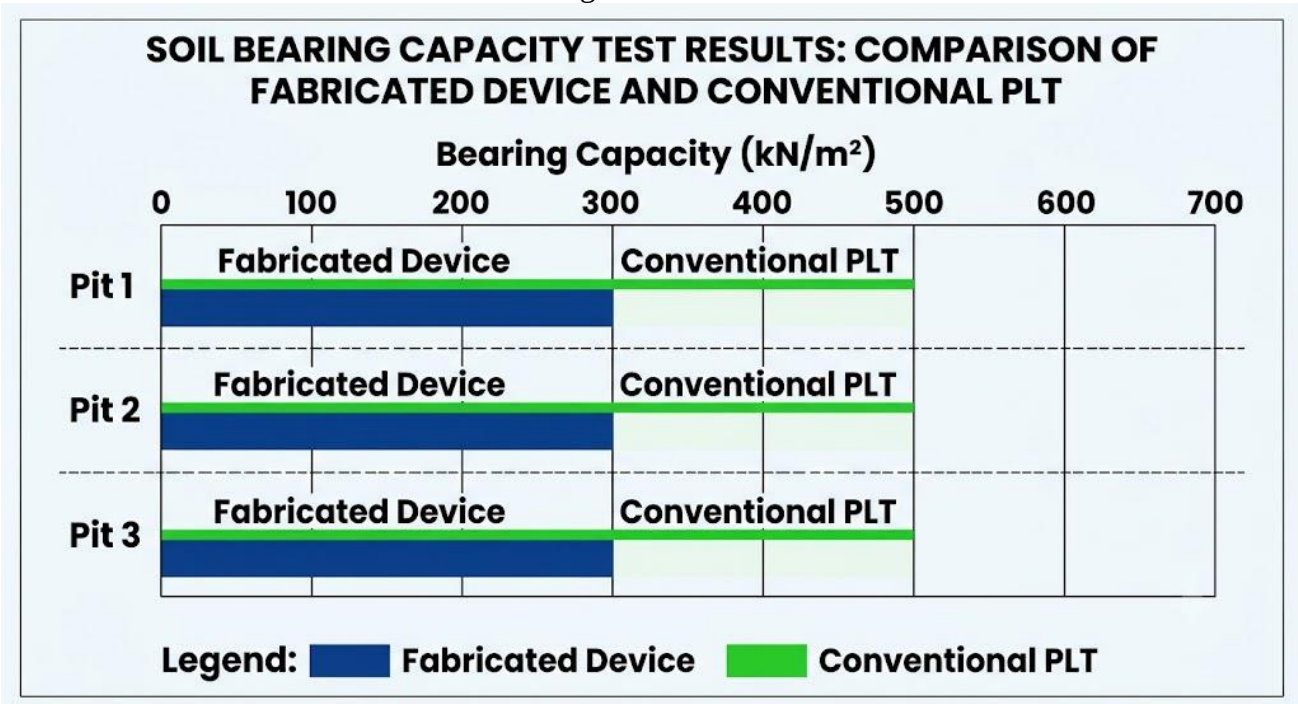
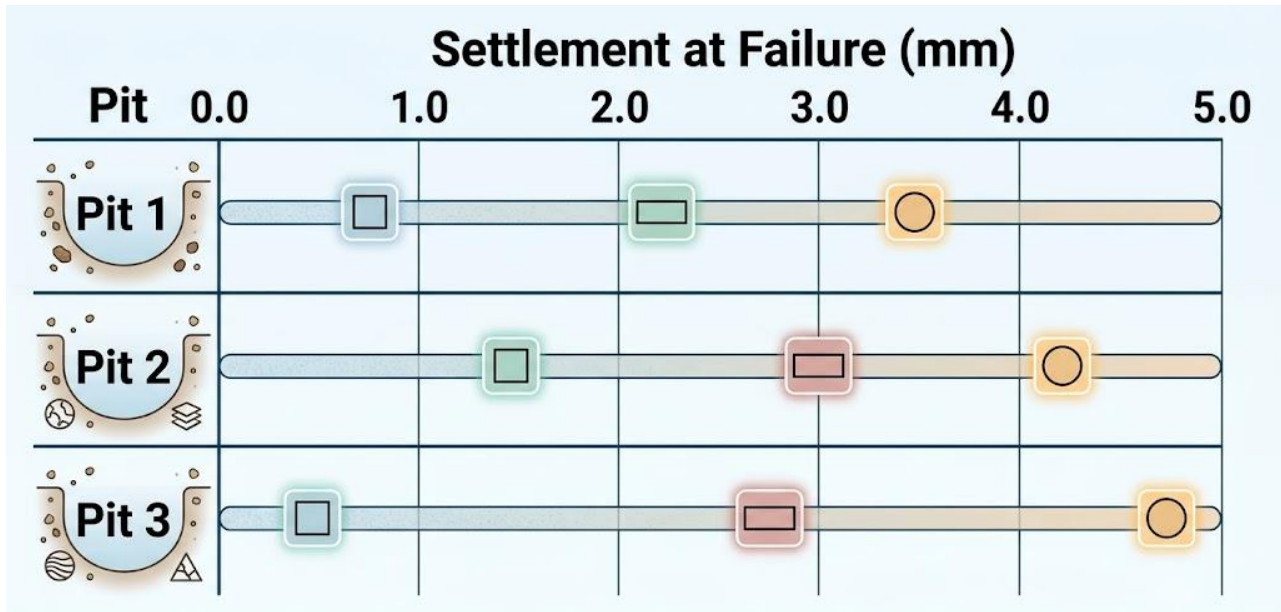


Figure 7: Comparison of Ultimate Bearing Capacity - Fabricated Device vs. Conventional PLT

Figure 7 presents a bar chart comparison of the ultimate bearing capacity values obtained from the fabricated testing device and the conventional plate load test for all three pits at both depths. The comparison clearly shows that the fabricated device consistently yields higher values than the conventional PLT, with the difference being more pronounced at Pit 1 and Pit 3 compared to Pit 2. The closest agreement between the two methods was observed at Pit 2 at 0.5 m depth, where the difference was only 7.55%. This variation in agreement suggests that the correlation between the two methods may be influenced by soil type and conditions, and further research is needed to establish more refined correlations for different soil types.



Legend: ■ Square Foundation ■ Rectangular Foundation ○ Circular Foundation

Figure 8: Settlement at Failure Comparison - All Foundation Shapes

Figure 8 presents a bar chart comparison of the settlement at failure for all three foundation shapes tested at the three pits. The settlement at failure ranges from 1.75 mm to 3.90 mm, with the rectangular foundation consistently showing the highest settlement and the square foundation showing the lowest settlement. This pattern is consistent with shape factor effects, where square foundations generally exhibit lower settlement than rectangular foundations due to better load distribution. The circular foundation shows intermediate settlement values, consistent with its intermediate shape factor. All settlement values are well below the 25 mm allowable limit specified by BS 8004 (1986), confirming the suitability of the soil for foundation construction.

LOAD-SETTLEMENT CURVES FOR FABRICATED DEVICES AND CONVENTIONAL PLT

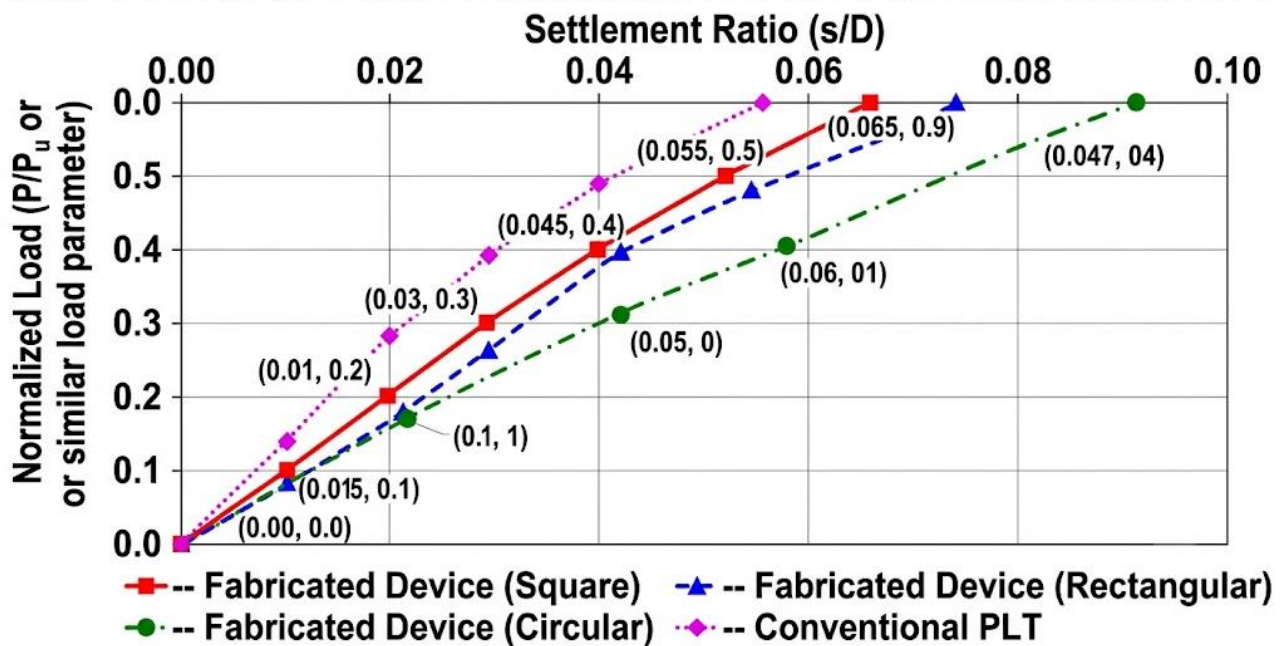


Figure 9: Stress-Strain Response Comparison - Fabricated Device vs. Conventional PLT

Figure 9 presents the stress-strain response comparison between the fabricated testing device (all three shapes) and the conventional plate load test. The stress-strain response is represented as the ratio of load intensity to ultimate bearing capacity versus the ratio of settlement to footing diameter (s/D). The curves show that the fabricated device generally gives a stiffer response compared to the conventional PLT, with lower settlement ratios for the same stress ratio. This difference is attributed to the scale effect,

where the smaller footing size of the fabricated device results in less compressibility of the soil. The square foundation shows the stiffest response, followed by the circular foundation, with the rectangular foundation showing the most deformable response. These differences are consistent with shape factor effects.

The performance evaluation of the fabricated testing device has also demonstrated its practical advantages over conventional plate load tests. The device is portable, easy to operate, and cost-effective, making it suitable for use on small to medium-scale projects where conventional testing may be prohibitive. The device can be manufactured using locally available materials, supporting the development of local manufacturing capabilities and contributing to sustainable technological development. The use of the device can significantly reduce the cost and time of foundation investigation, enabling practitioners to conduct proper foundation investigations even on small projects.

Conclusion

Based on the results obtained from this research, the following conclusions are drawn:

1. The design analysis of the soil testing device using steel manuals and codes of practice demonstrated that the component parts are structurally adequate to withstand the anticipated loads. The loading rod, supporting arm, connecting rod, compressing plate, supporting beam, and anchor legs were designed to provide a factor of safety against failure, ensuring the safety and reliability of the device during use. The selected steel material exhibited an ultimate tensile strength of 433 N/mm² and a yield strength of 277 N/mm², providing adequate capacity for the design loads with an appropriate factor of safety.
2. The fabrication of the soil testing device using high-density and lightweight materials from metallurgical industries was successfully accomplished. The device is portable, easy to operate, and cost-effective, making it suitable for use on small to medium-scale projects. The use of locally available materials supports the development of local manufacturing capabilities and contributes to the broader goal of sustainable technological development.
3. The foundation investigation using the soil testing device provided reliable estimates of bearing capacity and settlement for prototype foundations. The ultimate bearing capacity obtained from the device ranges from 570 kN/m² to 620 kN/m², while the settlement at failure ranges from 1.75 mm to 3.90 mm. These results indicate that the soil is suitable for foundation construction, with adequate bearing capacity and low compressibility. All settlement values are well below the 25 mm allowable limit specified by BS 8004 (1986), confirming the suitability of the soil for foundation construction.
4. The correlation and validation of results from the fabricated testing device with conventional plate load test results demonstrated a strong positive correlation between the two methods ($R^2 = 0.932$). The strong correlation validates the reliability of the fabricated testing device as an alternative method for foundation investigation. The regression equation $q_{ult,FD} = 0.92 q_{ult,PLT} + 182.5$ can be used to convert device measurements to equivalent conventional PLT values.
5. The fabricated testing device is a viable alternative to conventional plate load tests for small to medium-scale civil engineering projects. The device provides reliable estimates of bearing capacity and settlement, enabling practitioners to conduct proper foundation investigations even on small projects. This will improve the quality of foundation design, reduce the incidence of structural failures, and contribute to safer and more economical construction practices.
6. The load-settlement curves obtained from the fabricated testing device show that the soil exhibits a stiff response with minimal settlement even at high load intensities. The square foundation showed the highest bearing capacity and lowest settlement, while the rectangular foundation showed the lowest bearing capacity and highest settlement. The circular foundation showed intermediate values. These differences are consistent with theoretical expectations and shape factor effects.
7. The performance evaluation has shown that the fabricated testing device can effectively evaluate different foundation shapes, providing valuable data for foundation design. The device's ability to test multiple foundation shapes makes it a versatile tool for geotechnical investigation, enabling the comparison of different foundation options before construction.

Recommendations

Based on the findings of this research, the following recommendations are made:

1. The fabricated testing device should be adopted for use in foundation investigation for small to medium-scale civil engineering projects. The device provides reliable estimates of bearing capacity and settlement at a fraction of the cost of conventional testing methods, making it accessible to a wider range of practitioners and projects. The device should be made commercially available to facilitate wider adoption.

2. Further research should be conducted to calibrate the fabricated testing device for different soil types and conditions. The device should be tested on a wider range of soils, including sands, gravels, and organic soils, to establish correlations and interpretation methods for different soil types. This will enhance the device's applicability and reliability across diverse geological conditions.

3. The long-term performance of the fabricated testing device under repeated use and varying environmental conditions should be evaluated. The durability and reliability of the device should be assessed through extended field trials and periodic maintenance and calibration. This will ensure that the device maintains its accuracy and reliability over time.

4. The correlation between the fabricated testing device and conventional plate load test should be further refined using a larger dataset. Additional testing at different locations and on different soil types will provide more robust correlations and improve the reliability of the validation. A comprehensive database of test results should be compiled to support the development of more accurate correlation equations.

5. The fabricated testing device should be considered for incorporation into geotechnical engineering curricula and training programs. The device provides a practical and accessible means for students and young engineers to gain experience in foundation testing and soil behaviour. This will improve the quality of geotechnical engineering education and prepare students for professional practice.

6. The development of a standardized test procedure for the fabricated testing device should be considered. A standardized procedure would ensure consistency in testing and interpretation, facilitating the wider adoption and acceptance of the device in geotechnical engineering practice. Standardization would also enable the comparison of results from different devices and operators.

7. The intellectual property rights for the fabricated testing device should be protected through patent registration, enabling commercialization and wider dissemination of the technology. This would encourage further development and refinement of the device, ensuring that it continues to meet the needs of practitioners and contributes to improved foundation investigation practice.

Research should be conducted to integrate the fabricated testing device with modern data acquisition and analysis systems. This would enable real-time data collection and analysis, improving the efficiency and accuracy of foundation investigations. The use of advanced sensors and data analytics would enhance the device's capabilities and contribute to more informed foundation design decisions.

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