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Research Article

## Design And Development of a Modular Rock Soil Sampling Device with Interlocking Segment Geometry for Field Investigations

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### Abstract

Subsurface sampling is essential for geotechnical investigations, mining exploration, and site characterization because the reliability of engineering analysis depends on the quality of collected soil and rock samples. Conventional sampling tools are commonly designed with fixed structural configurations, which limits their adaptability to varying sampling depths and often complicates maintenance during field operations. This study presents the design and conceptual evaluation of a modular rock and soil sampling device with interlocking segment geometry for field investigations. The proposed device consists of a penetration head, cylindrical modular segments, an internal sampling chamber, and a base coupling unit for connection with penetration equipment. The interlocking segment arrangement allows the device length to be adjusted by adding or removing modules according to the required sampling depth. The penetration head geometry facilitates ground entry while directing fragmented material into the sampling chamber. The modular configuration also simplifies maintenance and transportation. The design demonstrates improved adaptability and operational flexibility compared with conventional rigid sampling systems.

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**KEYWORDS:** Rock-soil sampling; Modular sampling device; Interlocking segment geometry; Geotechnical investigation; Subsurface sampling; Mining exploration.

## 1. INTRODUCTION

Reliable characterisation of subsurface materials is essential for geotechnical engineering, mining operations, and underground construction projects. Accurate information on soil and rock properties is typically obtained through field sampling and laboratory testing. The quality of the collected samples significantly influences the reliability of geotechnical design parameters and engineering decisions [1,2]. Improper sampling techniques can disturb soil structure, alter moisture conditions, and lead to inaccurate estimation of strength and deformation characteristics [3].

Several conventional sampling methods are commonly used in geotechnical investigations. Disturbed sampling is often performed using split spoon samplers during the standard penetration test procedure, which is widely adopted in site investigations to estimate soil resistance and relative density [4]. Undisturbed samples are typically collected using thin-walled tube samplers such as Shelby tubes in accordance with established testing standards [5]. In rock formations, core drilling techniques are widely employed to extract cylindrical samples for geological and geotechnical evaluation [6]. Although these methods have been used extensively for decades, each technique has specific limitations related to sampling depth, equipment configuration, and sample disturbance [7].

One major limitation of conventional sampling tools is their fixed structural configuration. Most commercially available samplers are manufactured with predetermined lengths and dimensions that restrict their adaptability during field operations. When sampling depth requirements vary across different locations, multiple tools may be required to complete the investigation, which increases operational complexity and equipment costs [8]. Additionally, maintenance and replacement of damaged components in rigid sampling systems often require replacement of the entire assembly rather than individual parts [9].

In geotechnical practice, maintaining sample quality is a critical requirement. Disturbance during sampling can significantly influence the measured engineering properties of soils and weak rocks. Factors such as friction along the sampler wall, excessive penetration resistance, and improper cutting geometry may affect the integrity of collected samples [10]. For this reason, the geometry and operational mechanism of sampling devices have been the subject of continued research and development in geotechnical engineering [11].

Recent advances in drilling and excavation equipment have highlighted the importance of modular mechanical systems that allow flexible assembly and easy replacement of components during field operations [12]. Modular designs have been successfully applied in drilling systems and exploration equipment where adaptability and maintenance efficiency are important operational requirements [13]. However, the concept of modularity has not been extensively explored in the development of soil and rock sampling devices.

Another important aspect of sampling tool design is the penetration mechanism. Efficient penetration requires proper cutting geometry that can fragment soil or weak rock while

minimising disturbance to the surrounding material [14]. Cutting heads with multiple contact points have been shown to improve penetration performance in several excavation and drilling applications [15]. The incorporation of such design features in sampling tools may enhance the efficiency of material collection during subsurface investigations.

Given the operational challenges associated with conventional sampling systems, there is a need to explore alternative design approaches that improve adaptability, maintain structural stability, and simplify equipment maintenance. The development of modular sampling systems with interlocking segments may offer a practical solution for addressing these limitations. A modular configuration allows the total length of the sampling device to be adjusted according to required investigation depth while maintaining structural continuity during operation.

The present study focuses on the design and conceptual evaluation of a modular rock and soil sampling device with interlocking segment geometry intended for field investigations. The proposed system integrates a penetration head, cylindrical interlocking modules, a sampling chamber, and a base coupling interface to form a configurable sampling assembly. The design aims to improve adaptability, ease of transport, and maintenance efficiency compared with conventional rigid sampling tools. The conceptual framework and operational mechanism of the device are presented, and its potential advantages for geotechnical and mining investigations are discussed.

## 2. MATERIALS AND METHODS

### 2.1 Design Approach and Concept Development

The modular rock and soil sampling device was developed using a structured engineering design framework consisting of conceptual design, geometric configuration, and functional evaluation. The objective of the device was to provide an adaptable sampling system capable of collecting rock and soil fragments from different depths while allowing simple assembly and maintenance during field investigations.

The design concept was based on a modular structure consisting of interlocking cylindrical segments connected along a central axis. The concept was formulated after reviewing limitations associated with commonly used geotechnical sampling devices. Conventional samplers generally operate with fixed lengths and limited adaptability, which restricts their application when sampling depths vary or when equipment maintenance is required in field conditions.

The proposed system was therefore designed as a modular assembly where individual segments can be connected or removed according to the required sampling depth. Each segment incorporates an interlocking geometry that ensures structural continuity and axial alignment during penetration operations.

The main components of the sampling device and their functions are summarised in Table 1.

## 2.2 Device Components

The developed sampling device consists of four major components including the penetration head, modular interlocking segments, sampling chamber, and base coupling unit. These components were designed to function collectively during penetration and sample retrieval operations.

The penetration head is located at the front end of the device and is responsible for initiating ground penetration. The head incorporates a multi tooth geometry designed to fragment soil or weathered rock layers during penetration. Behind the penetration head, the modular cylindrical segments form the

The main structural body of the device.

Each modular segment contains an interlocking interface that connects with adjacent segments to form a continuous assembly. The interlocking geometry prevents rotational displacement and maintains axial stability during operation. Within the modular structure, a designated chamber was incorporated for the storage of collected soil or rock fragments.

The base coupling section is located at the rear end of the device and allows attachment to driving rods or penetration systems used in field investigations. The detailed structural components and their functional roles are presented in Table 1.

**Table 1:** Major Components of the Modular Rock and Soil Sampling Device

Component	Description	Functional Role
Penetration head	Multi-tooth cutting head located at the front of the device	Facilitates penetration into soil or rock formations
Modular segments	Cylindrical sections connected through interlocking geometry	Provide structural length and allow modular assembly
Sampling chamber	Internal cavity positioned behind the penetration head	Stores collected soil or rock fragments
Base coupling	Rear connection interface	Connects the device to drilling rods or driving equipment

## 2.3 Geometric Configuration of Modular Segments

The geometric configuration of the device was designed to maintain structural alignment and mechanical stability during penetration. Each modular segment was designed with cylindrical symmetry to ensure uniform transfer of axial forces along the device length. The interlocking interface between adjacent segments was developed to prevent displacement during operation. An interface geometry allows segments to

connect firmly while permitting quick assembly and disassembly in field conditions.

The geometric parameters considered during design include segment length, segment diameter, chamber volume, and penetration head geometry. These parameters influence the overall structural behaviour and operational efficiency of the device. The principal geometric parameters used in the conceptual design are summarised in Table 2.

**Table 2:** Geometric Design Parameters of the Sampling Device

Parameter	Description	Design Consideration
Segment length	Length of each modular section	Determines total sampling depth
Segment diameter	External diameter of cylindrical segments	Controls penetration stability
Chamber volume	Internal volume of sampling cavity	Determines sample storage capacity
Cutting head geometry	Shape of penetration head	Influences penetration efficiency

## 2.4 Assembly Configuration

The modular structure allows different assembly configurations depending on the required sampling depth. The total length of the sampling device can be adjusted by increasing or decreasing the number of interlocking segments used in the assembly.

This configuration provides flexibility for field investigations where sampling depths vary across different locations. The number of modular segments required for different sampling depths is summarised in Table 3.

**Table 3:** Example Modular Assembly Configurations

Number of Segments	Approximate Sampling Depth	Application
2	Shallow sampling	Surface soil investigation
3	Moderate depth sampling	Geotechnical site studies
4	Intermediate depth sampling	Subsurface characterization
5 or more	Deep sampling	Mining exploration

## 2.5 Operational Procedure

The operational procedure of the sampling device consists of several sequential steps that allow collection and retrieval of subsurface samples. First, the required number of modular segments is assembled according to the desired sampling depth. Each segment is connected using the interlocking interface to form a continuous sampling structure. Second, the assembled device is attached to a driving rod or penetration mechanism through the base coupling unit. Third, the penetration head is positioned at the ground surface and an axial force is applied to drive the device into the soil or rock formation. During penetration, the multi tooth cutting head breaks the surrounding material and allows fragments to enter the sampling chamber.

Fourth, once the desired penetration depth is reached, the device is extracted from the ground. The modular segments are then separated to access the sampling chamber and retrieve the collected material.

The operational steps of the sampling procedure are summarised in Table 4.

**Table 4:** Operational Steps for Sampling Procedure

Step	Procedure	Purpose
1	Assemble modular segments	Adjust sampling depth
2	Attach the device to the driving rod	Enable penetration force transmission
3	Penetrate the ground surface	Collect soil or rock fragments
4	Retrieve the device from the ground	Recover sampling assembly
5	Disassemble segments	Extract collected samples

## 2.6 Comparative Methodology

To evaluate the conceptual advantages of the proposed device, a qualitative comparison was performed with commonly used sampling systems. The comparison focused on adaptability, maintenance requirements, and operational flexibility. Conventional sampling tools such as split spoon samplers and fixed-length coring devices were considered as reference systems. The comparative parameters used for evaluation are listed in Table 5.

**Table 5:** Comparison Parameters for Sampling Devices

Parameter	Conventional Samplers	Modular Device
Structural design	Fixed length	Modular adjustable length
Maintenance	Replacement of the full assembly	Replacement of individual segments
Transport	Difficult for long tools	Easy transport of segments
Adaptability	Limited	High
Assembly	Pre assembled	Field assembly possible

## 2.7 Assumptions and Limitations

Certain assumptions were considered during the conceptual development of the device. The penetration process was assumed to occur in moderately compact soil or weathered rock formations where mechanical penetration is feasible. The device was also assumed to operate primarily under axial loading conditions without excessive lateral forces. The present study focuses on the conceptual design and geometric configuration of the modular sampling system.

Experimental validation, prototype fabrication, and field testing were not included in this stage of the study. These aspects represent potential areas for future investigation.

The assumptions used in the present study are summarised in Table 6.

**Table 6:** Assumptions Used in the Study

Assumption	Description
Ground condition	Moderately compact soil or weathered rock
Loading condition	Predominantly axial penetration forces
Device operation	Manual or mechanical penetration system
Study scope	Conceptual design and structural evaluation

## 3. RESULTS

The conceptual design and geometric modelling of the modular rock and soil sampling device resulted in a structurally stable assembly consisting of a penetration head, interlocking modular segments, a sampling chamber, and a base coupling section.

The modelling results showed that the cylindrical modular segments aligned along a central axis and formed a continuous structural body capable of transmitting penetration forces from the driving rod to the cutting head.

The interlocking geometry between adjacent segments ensured proper alignment during assembly and prevented relative displacement during penetration. This configuration allowed the device to maintain structural continuity while enabling rapid assembly and disassembly in field conditions. The major geometric characteristics of the developed sampling device are presented in Table 7.

**Table 7:** Geometric Characteristics of the Proposed Sampling Device

Parameter	Description	Functional Role
Penetration head geometry	Multi-tooth cutting head	Enhances penetration and fragmentation
Segment shape	Cylindrical interlocking modules	Maintains structural alignment
Chamber position	Behind the penetration head	Enables sample collection
Base coupling	Rear connection interface	Allows attachment to driving rod

The modular interlocking system demonstrated effective structural behaviour during assembly evaluation. The interlocking interfaces between segments maintained axial alignment and ensured proper transmission of penetration forces along the length of the device. The evaluation indicated that the interlocking geometry prevented rotational displacement and minimised structural instability during

operation. The modular configuration also simplified maintenance procedures because individual segments could be removed and replaced independently without dismantling the entire sampling assembly. The structural advantages of the interlocking system compared with conventional rigid sampling tools are summarised in Table 8.

**Table 8:** Structural Performance of Interlocking Segment System

Performance Aspect	Conventional Samplers	Modular Interlocking System
Structural continuity	Single rigid body	Interlocking modular structure
Segment replacement	Difficult	Individual segments replaceable
Assembly time	Fixed assembly	Rapid modular assembly
Maintenance	High downtime	Reduced maintenance time

The sampling chamber incorporated within the modular structure demonstrated adequate storage capacity for soil or rock fragments generated during penetration. The chamber location behind the penetration head allowed fragmented material to enter the internal cavity as the device penetrated the ground.

The internal cavity geometry reduced the possibility of sample loss during the extraction of the device. The modular design also enabled easy access to the chamber after disassembly of the segments, which facilitated efficient retrieval of collected samples.

The functional characteristics of the sampling chamber are summarised in Table 9.

**Table 9:** Functional Characteristics of the Sampling Chamber

Feature	Observation	Functional Advantage
Chamber location	Positioned behind penetration head	Efficient capture of fragments
Internal cavity	Cylindrical chamber	Adequate storage volume
Access mechanism	Segment disassembly	Easy sample extraction
Retention capability	Enclosed chamber design	Minimizes sample loss

One of the most significant outcomes of the design development was the adaptability of the modular configuration. The total length of the device could be modified by adjusting the number of segments used in the assembly. This feature allows the device to be used for different sampling depths during field investigations.

The modular configuration also improved transportation and storage characteristics because the device can be transported as individual segments rather than a single long structure. The adaptability advantages of the modular system are presented in Table 10.

**Table 10:** Adaptability Advantages of the Modular Sampling System

Parameter	Conventional Sampling Tools	Modular Sampling Device
Sampling depth	Fixed	Adjustable
Transport	Difficult for long tools	Segmented transport
Field assembly	Not required	Flexible assembly
Adaptability	Limited	High adaptability

#### 4. DISCUSSION

The results obtained from the conceptual design and evaluation of the modular rock and soil sampling device highlight several important improvements compared with conventional sampling systems. The primary innovation of the device lies in the interlocking segment geometry that enables modular assembly while maintaining structural stability.

Traditional geotechnical sampling devices generally operate with fixed structural configurations. This limitation often restricts their application in situations where sampling depths vary across different investigation sites. The modular structure developed in this study addresses this limitation by allowing the

length of the device to be modified through addition or removal of individual segments. As shown in Table 10, this feature significantly enhances adaptability during field investigations.

The penetration head geometry also plays an important role in improving sampling performance. The multi tooth configuration provides multiple contact points with the ground surface and may enhance fragmentation of compact soil or weathered rock layers. Similar cutting principles are commonly applied in drilling and excavation tools where multiple cutting edges improve penetration efficiency.

The interlocking segment mechanism also improves the maintainability of the sampling device. In conventional systems, damage to any component often requires replacement of the entire tool assembly. In contrast, the modular system allows damaged segments to be replaced individually, which may reduce operational costs and downtime. This advantage is evident from the structural comparison presented in Table 8.

Another important observation relates to the sampling chamber arrangement. The chamber position behind the penetration head allows efficient capture of fragmented material during penetration while protecting the sample from external disturbance. Proper sample retention is essential for obtaining representative subsurface samples in geotechnical and mining investigations.

The modular configuration may also provide logistical advantages during field operations. Sampling tools used in remote exploration sites must often be transported over long distances. A device composed of multiple detachable segments can be transported more easily than a single long rigid tool.

Although the conceptual evaluation demonstrates several advantages of the proposed device, further research is required to validate its performance through prototype fabrication and experimental testing. Future studies should focus on evaluating penetration efficiency, sample recovery ratio, and durability of the interlocking mechanism under actual field conditions.

#### 5. CONCLUSION

This study presented the design and conceptual development of a modular rock and soil sampling device with interlocking segment geometry intended for subsurface investigations in geotechnical and mining applications. The proposed device was developed to address limitations associated with conventional sampling tools, particularly their fixed structural configuration, limited adaptability, and difficulty in maintenance during field operations. The design incorporates a penetration head, modular cylindrical segments, a sampling chamber, and a base coupling unit that collectively form a configurable sampling assembly.

The modular interlocking segment system allows the device length to be adjusted according to the required sampling depth. This feature provides greater operational flexibility during field investigations where subsurface conditions may vary across different locations. The interlocking geometry ensures structural alignment between segments and enables efficient transmission of penetration forces along the device axis. In addition, the modular configuration simplifies maintenance procedures because individual segments can be replaced without dismantling the entire assembly.

The sampling chamber positioned behind the penetration head facilitates collection and retention of fragmented soil or rock particles generated during penetration. The chamber geometry helps minimise sample loss and allows easy retrieval of collected material after disassembly of the device. The conceptual evaluation also indicated that the modular structure improves transport convenience and operational adaptability compared with conventional rigid sampling tools. Overall, the developed modular sampling device demonstrates potential advantages for subsurface sampling in geotechnical investigations, mining exploration, and site characterisation studies. Future work should focus on prototype fabrication and experimental validation to assess penetration efficiency, sample recovery ratio, and structural durability of the interlocking mechanism under real field conditions. Such investigations will further establish the practical applicability of the proposed sampling system in engineering practice.

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