ASSESSMENT OF THE CAUSES AND IMPACT OF INADEQUATE GEOTECHNICAL INVESTIGATION ON CONSTRUCTION PROJECTS' PERFORMANCE IN NIGERIA

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MTech/SEMT/2018/9154

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OCTOBER, 2021

ABSTRACT

The issue of inadequate geotechnical investigation usually leads to over or under design of structural elements which eventually contributes immensely to project cost overrun and poor performance**.** This research aims to assess the impact of inadequate geotechnical investigation on construction projects' performance which was achieved through the research objectives. The objectives were to examine the difference in awareness level among clients, contractors, and consultants about geotechnical investigation practices in construction projects; to identify the causes of inadequate geotechnical investigation in construction projects; to assess the impact of inadequate geotechnical investigation on construction project performance; and to identify strategies to mitigate the impact of inadequate geotechnical investigation on construction projects**.** The study adopted quantitative research methods using a structured questionnaire to ascertain the perceptions of respondents on some geotechnical investigation related issues. The survey was conducted with a sample size of 384 with 239 responses (62.2% response rate). The Sampling technique employed was random sampling of professionals in the bracket group of client organizations, contracting firms, and consulting firms. Professionals of interest included Civil Engineer, Geotechnical Engineer, Engineering Geologist, Project Manager, Builder, Architect, Quantity Surveyor, Surveying and Geo-informatics. Data analysis was carried out using a combination of descriptive analysis, rank order, and inferential statistics using Microsoft excel, Statistical Package for the Social Sciences (SPSS), and Statgraphics XVII**.** The study findings showed that there exists a heterogeneous practice of geotechnical investigation for construction projects among the contracting firms, consulting firms, and client organizations in Nigeria. Findings also showed that the major causes of inadequate geotechnical investigation in building and road projects are sampling technique, equipment, financial constraint, lack of geotechnical expertise, supervision, results presentation, and client awareness. The impact of inadequate geotechnical investigation on cost, schedule, and performance of construction projects amount to overruns and poor performance. The regression model of this study is given as "$Y = -.250 + .089X_1 - .038X_2 + .387X_5 + .582X_6$" for building projects; while in road projects "$Y = 1.533 - .055X_2 + .106X_3 + .486X_5 + .139X_6$". Additionally, the study rejected the three research hypotheses (null) accepted the alternate hypotheses that "there exists a significant relationship between geotechnical investigation related defects and project cost overrun", "there exists a significant relationship between geotechnical investigation related defects and project schedule overrun", "there exists a significant relationship between geotechnical investigation related defects and project performance". The study recommends adequate sample management, strict adherence to results from geotechnical investigations, and assigning skilled personnel to conduct geotechnical investigation.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AAV	Aggregate Abrasion Value
AIV	Aggregate Impact Value
ANFIS-SI	Adaptive Network Fuzzy Inference System – Site Investigation Model
ASTM	American Society for Testing and Materials
BS	British Standard
CPT	Cone penetration test
GI	Geotechnical investigation
II	Inadequate investigation
MDD	Maximum dry density
OMC	Optimum moisture content
USCS	Unified soil classification system
WAS	West Africa Standard
SPT	Standard penetration test

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The success of the majority of civil engineering projects largely depend on the adequacy of geotechnical investigation of surface and subsurface soil condition. Geotechnical engineering and its application has been a major concern for centuries. Excellent progress has however been made in terms of research findings over the years. Geotechnical investigation is a continuous practice which spans throughout the project development process. Inadequate or insufficient geotechnical investigations leads to inappropriate designs, environmental damage to the site, delays in construction schedules, costly construction modifications, and other related issues (Temple and Stukhart, 1987; Zumrawi, 2014; Žlender and Jelušič, 2016; Neupane, 2016).

Site investigation may be described as process of data collection, appraisal, and assessment in a timely manner, and to an adequate degree that is appropriate to each design phase and development (Watts and Davis, n.d.). Subsurface investigation as a crucial part of geotechnical investigation is needed to gather information such as geological, hydrological, geotechnical, and groundwater condition which have very crucial impact on the planning, design, construction, and operation of some construction projects (Sadaghiani, 2018). Studies over the past decades have however shown that huge financial and technical risks exist in the ground. Albatal *et al.* (2014) stated that inadequate geotechnical investigation is a major source of project delay, claims, disputes, and projects' cost overrun. Again, other studies such as Goldsworthy *et al*. (2004); Carlsson (2005) suggested that the quality and quantity of information acquired from geotechnical investigation largely determines the failure rate or durability of structural elements. This position was reinforced by Roy and Bhalla (2017) that the geotechnical properties of soil aggregates affect the stability of civil engineering structures. The utilization of the knowledge about these properties ensures appropriate design and construction of civil engineering projects, hence reducing or preventing adverse impact on the environmental, structural failure or post-construction problems (Nwankwoala and Amadi, 2013; Avwenagha *et al.*, 2014)

Additionally, Ezenwaka *et al*. (2014), opined that construction soil materials must go through engineering geological and geotechnical investigations in order to determine the safe bearing capacity as well as recommendation for foundation type. These foundation types may experience failure due to concealed geological features which can lead to subsurface subsidence (Fajana *et al.*, 2016). Hence, it is imperative prior to building construction to conduct investigation on the physical properties of subsoil to determine the suitability for design and construction choice (Fajana *et al*., 2016). Similarly, in the construction of road, aggregates are essential components making up the subgrade, sub base and base courses for flexible pavement. Ifabiyi and Kekere (2013) identified that numerous lives and valuable properties worth millions of naira are lost annually to road crashes, and the financial burden of road rehabilitation is enormous on the government. Furthermore, the study attributed factors responsible for pavement failure in Nigeria to geological, road usage, geomorphological, bad construction and wrong approach to maintenance. Thus, selecting the right soil is essential in overcoming the frequent pavement failure in Nigeria (Egesi and Tse, 2012). Road pavement failure could be in form of bulges, potholes, cracks, and depression, making the road unsafe to road users. Zumrawi (2014) noted that inadequate geotechnical investigations can arise from low client awareness, insufficient finance, insufficient time and lack of geotechnical expertise. In Ethiopia, Tsegaselassie and Tadesse (2015), concluded that lack of geotechnical analysis leads to cost imprecision and delays in road projects.

Time constraints according to Kelly *et al*. (2020) limits the scope of geotechnical investigation. Others could be drilling technique, testing methods, sampling techniques (Kelly et al., 2020). Jaksa *et al*. (2003) identified the major consequences of inadequate or inappropriate geotechnical investigation to include the under-design of foundation, leading to some degree of structural distress, over-design of foundation, and unforeseen conditions requiring substantial changes to the structural elements. Charles (2005) noted that even though total foundation failures may be rare, inadequate foundation performance cannot be ruled out. This may render a building unfit for its design purpose, even where structural collapse is not visible yet. The Federal Ministry of Environment as the apex recognition/ accreditation body for Environmental laboratories in Nigeria oversees the registration, regulation, monitoring/supervision, and sanction of existing and new laboratories. There are quite a number of accredited laboratories undertaking site investigation or geotechnical testing and analysis across the federation. The Council for the Regulation of Engineering in Nigeria (COREN) is the professional body responsible for the monitoring and regulating site/geotechnical investigation practices in the country. COREN ensures strict adherence to specified codes and recommends appropriate sanction and penalty to violators.

Project completion time according to Kadiri and Shittu (2015) is a major yardstick for measuring project success. There exists a large body of literature exploring the impact and contributory factors to project time/schedule overrun. For instance, Ameh and Osegbo (2011) in their study established a positive relationship between productivity and time overrun on construction sites in Nigeria and the study identified 18 causes of time overrun and 14 factors leading to low productivity.

Over all, cost overrun, time overrun, and other detrimental factors leads generally to poor project delivery in form of delays, claims and variations. Ameh and Osegbo (2011) supported that inadequate projects fund, preliminary planning, equipment and delay in delivery of construction materials to site, were identified as the major causes of project delay in Nigeria. Similarly in Malaysia and Pakistan according to Majid (2006) and Haseeb *et al.* (2011), the major causes of delays in the construction industry identified include time factor, incorrect cost estimation, insufficient equipment, unforeseen site conditions, amongst others. In China, Chan and Kumaraswamy (1997) also identified site mismanagement, poor decision making strategies, unforeseen ground conditions, and client-initiated changes.

1.2 Statement of the Research Problem

Generally, construction project cost overrun can be attributed to numerous factors. An insight from the existing literature is that variations in designs, planning (Doloi, 2013), economic factors (Diugwu *et al*., 2017; Siemiatycki, 2016), lack of experience and expertise, geotechnical investigations in one way or another contribute to project cost overrun. While construction project cost overrun is attributable to several factors, it has been shown that the level of adequacy of geotechnical investigation is a major factor (Hoek and Palmieri, 1998; Zumrawi 2014; Nazir 2014; Amadi and Higham 2017; Amadi and Higham, 2018). Jaksa *et al.* (2003) had earlier opined that the majority of financial and technical risk often lies below the ground. Although there are suggestions that geotechnical investigations which seek to assess the geological and geophysical properties of the surface and subsurface soil, is an essential but overlooked aspect of the design and planning of construction projects Charles (2005). According to Albatal *et al.* (2014), inadequate geotechnical investigation usually leads to over or under design of structural element which eventually contributes immensely to project cost overrun. Zlender and Jelušic (2016) stated that carrying out sufficient geotechnical investigation substantially reduces risks due to site geotechnical properties. According to Hytiris *et al*. (2014), about 80% of structural failures and damages are related to unforeseen and unfavourable ground conditions which is largely due to inadequate site investigation. However, geotechnical investigation is described as a failure when subsurface condition needed for accurate design and effective management of projects are nor correctly reveal. Watts and Davis (n.d) highlighted that inadequate or inappropriate geotechnical investigation may lead to inappropriate design or foundation type, and the economic cost can be enormous

1.3 Significance of the Study

Geotechnical investigation seeks to assess the geological and geophysical properties of surface and subsurface soil which are crucial for the design of structures and adequate planning for construction procedures. In addition, geotechnical investigation seeks to identify, analyze, and characterize the subsurface conditions in details to allow for economic and safe delivery of projects. Some existing works suggest that for buildings that are likely to impose very heavy loads on the surface or subsurface soil, it may be desirable to spend more on subsurface exploration for detailed investigation rather than to overdesign the building and make it costlier (Arora, 2008). This however arises from knowledge of materials distribution in the ground, their properties, and behaviour under different constraints during the construction phase and throughout the lifetime of the structure. Additionally, geotechnical investigations may greatly improve the quality of construction project delivery as it focuses on the performance of soil aggregates (Oyedele *et al*., 2009). Temple and Stukhart (1987) argue that a relationship exists between lower construction costs and good geotechnical investigations. An inadequate geotechnical investigation is a major contributor to costly, overdesigned foundation, project delays, disputes, and claims. To this end, thorough geotechnical investigation is regarded as a success factor for construction project delivery. More so, losses incurred from cases of building collapse would be unnecessary if geotechnical investigation is done before and during project execution.

The significance of geotechnical investigation cannot be overemphasized as findings would curb project failure drastically. As such, risks are minimized, and the potential for a safe and economic design is maximized. Higher likelihood of project completion within time and cost is also realizable (Watts and Davis, n.d.). It is also imperative that project team member, including young and inexperienced practitioners be accustomed with minimum geotechnical investigation requirements for basic knowledge applicable to any kind of project.

1.4 Aim of Study

This study aims to assess the impact of inadequate geotechnical investigation on construction projects' performance

1.5 Objectives of the Study

The objectives of the study are to:

i. examine the difference in awareness level among clients, contractors, and consultants about geotechnical investigation practices in construction projects
ii. identify the causes of inadequate geotechnical investigation on construction projects
iii. assess the impact of inadequate geotechnical investigation on construction project performance
iv. identify strategies to mitigate the impact of inadequate geotechnical investigation on construction projects

1.6 Research Questions

i. What is the difference in the awareness level among clients, contractors, and consultants about geotechnical investigation practices in construction projects?
ii. What are the causes of inadequate geotechnical investigation in construction projects?
iii. How does inadequate geotechnical investigation impact on construction project performance?
iv. What strategies are required to mitigate the impact of inadequate geotechnical investigation on construction projects?

1.7 Research Hypotheses

$H0_1$ there exist no significant relationship between geotechnical investigation related defects and project cost overrun

$H0_2$ there exist no significant relationship between geotechnical investigation related defects and project schedule overrun

$H0_3$ there is no significant relationship between geotechnical investigation related defects and project performance

1.8 Scope of the Study

The scope of this research is to investigate the causes and impact of inadequate geotechnical investigation on construction projects' performance in Nigeria – limited to building and road pavement projects. The study was limited to the four research objectives and three research hypotheses earlier stated. The study was however conducted in the context of the Nigerian construction section with focus group on client organizations, contracting and consulting firms limited to the following professionals; Civil Engineer, Geotechnical Engineer, Engineering Geologist, Project Manager, Builder, Architect, Quantity Surveyor, Surveying and Geo-informatics.

1.9 Study Area

The North-central geopolitical zone of Nigeria was selected for as the study area of this research. The zone comprises of seven (7) states as shown in Figure 1.1, which includes; FCT, Kwara, Kogi, Nassarawa, Niger, Benue, and Plateau states. However, due to the heightened security challenges in some parts of the zone, the states actually considered for survey were Niger, Kwara, FCT, and Kogi states. The author excluded Nasarawa, Benue, and Plateau, states.

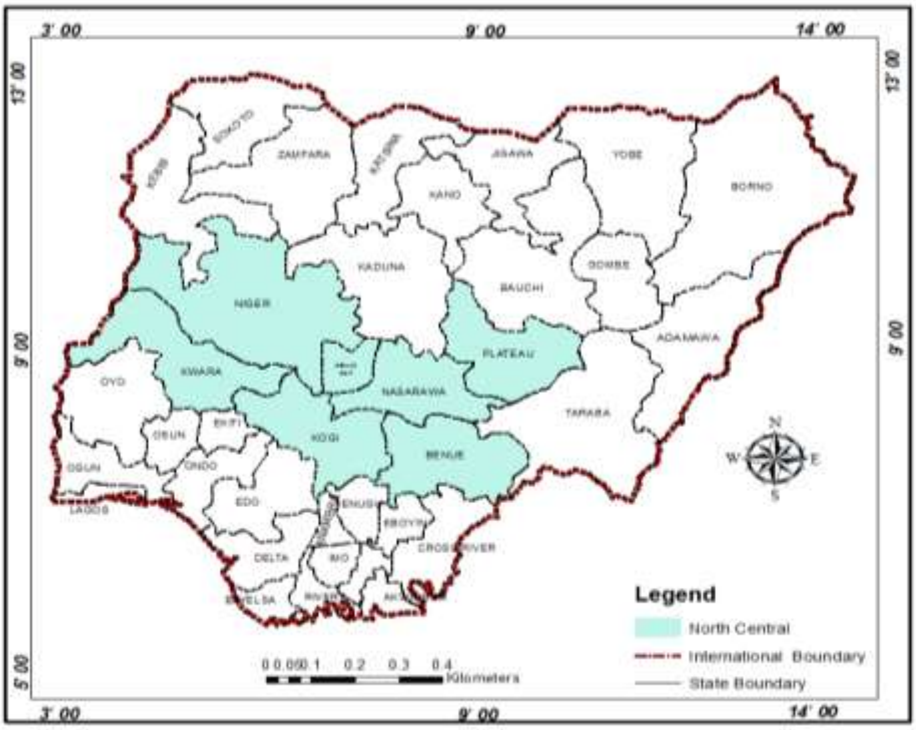


Figure 1.1: Map of Nigeria Showing Study Area

Source: Federal Ministry of Land and Housing, (2019)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Nigerian Construction Industry in Brief

The socio-economic development of any nation is largely dependent on the size of its construction industry. According to Mansur and Tahar (2017), the construction industry is considered amongst the world's largest industries, with an estimated 13% of world output. The construction industry globally improves standard of living through the provision of basic structural amenities such as hospitals, schools, roads, and other facilities Saidu and Shakantu (2017). Mansur and Tahar (2017) supports that the construction industry is the provider of infrastructures essential for human provisions and economic development. However, the construction industry has been reported to be one of the most complex, time and material driven industry which is constantly challenged with low productivity, low quality, delay, cost overrun, etc. (Singh, 2009; Akinradewo and Aigbavboa, 2019; Chulkov *et al*., 2019). According to Tunji-Olayeni *et al*. (2016) the Nigerian construction industry is one of the most vibrant and largest in Africa comprising of over 78% indigenous firms (predominately small and medium – sized) and 22% foreign firms.

2.2 Geotechnical Investigation

2.2.1 Geotechnical investigation, an overview

The stability and durability of civil engineering structures (for instance, buildings, highways, dams, bridges, etc.) are dependent on the stability of soil used for foundation or as construction materials (Laskar and Pal, 2012). Earlier studies on geotechnical investigation according to Nwankwoala and Amadi (2013); Avwenagha *et al*. (2014);

and Nazir (2014) have shown that engineers, project managers, and other built environment practitioners use information acquired from geotechnical investigation to design and effectively manage these projects to meet project constraints (time, cost, quality). More so, the results from the geotechnical investigation are used to determine the strength of the soil, ground water levels, and to propose any geometry of the supporting structures (Nazir, 2014).

Geotechnical engineering is the study of the engineering behavior of the ground Charles (2005). This discipline adopts the principles of soil mechanics and engineering geology to investigate surface and underground conditions of soil aggregates to determine relevant engineering, physical/mechanical, and chemical properties using standardized laboratory procedures. Geotechnical investigation is conducted in order to reduce or prevent structural failures with their attendant disastrous consequences as its major aim. According to Adepelumi *et al*. (2009), it enhances the knowledge of the character of the soil aggregate which bears the load to be transferred by the proposed structure. According to Feld (2005), the geotechnical investigation usually comprises of site geological survey, topography survey, geophysical survey, in-situ testing, and laboratory testing. Table 2.1 contains details of some of the commonly conducted geotechnical tests such as specific gravity, natural moisture content, density test, compaction (standard or modified proctor test), Atterberg Limit, standard penetration test (SPT), cone penetration test (CPT), aggregate impact value (AIV), aggregate Abrasion Value (AAV), consolidation test.

Table 2.1: Standard geotechnical tests

Parameters		Laboratory Test
Index Properties	Particle size distribution	Grading analysis Atterberg Limits (PI, LL, SI) Moisture content
Permeability	Permeability	Falling head permeameter (fine grained soils) Constant head permeameter (coarse grained soils) Rowe cell (fine and coarse grained soils)
Physical characteristics	In-situ Density	Bulk Density Determination
	Specific Gravity	Specific Gravity test
	Moisture (water) Content	Moisture Content test
Strength Parameters	Undrained Shear strength	Undrained triaxial test
	Unconfined compressive strength	UCS Test (rocks)
	Drained shear strength	Shear box test
	Cohesion (*c*) and Friction angle (*Ø'*)	Drained triaxial test Undrained triaxial with pore water pressure
Deformation Parameters	Consolidation	Consolidometer test Rowe test
	Compaction	Standard or Modified Proctor test
	Collapse	Double Oedometer Collapsible potential test
	Heave	Double Oedometer Swell under load test

Source: Byrne *et al*. (2008)

The design of an effective geotechnical investigation must be given utmost importance, as this step would either make or mar entire investigation. Hence, Watts and Davis (n.d) designed a list of objectives or guidelines to be followed to ensure effective site investigation. Site investigations should be conducted and effectively coordinated to ensure;

- Clear understanding of design specifications.
- Understanding the significance of having an in-depth understanding of the site
- Necessary advice is obtained from qualified personnel with relevant practice experience.
- Physical investigations are carried out to gather relevant samples and data required for design and construction.
- Natural and manmade features are accurately documented
- In-situ soils are correctly characterised.

2.2.2 Phases of Geotechnical Investigation

Geotechnical investigation is a continuous process, lasting throughout the project development process. Figure 2.1 shows the interrelationship between the geotechnical investigation and the project cycle.

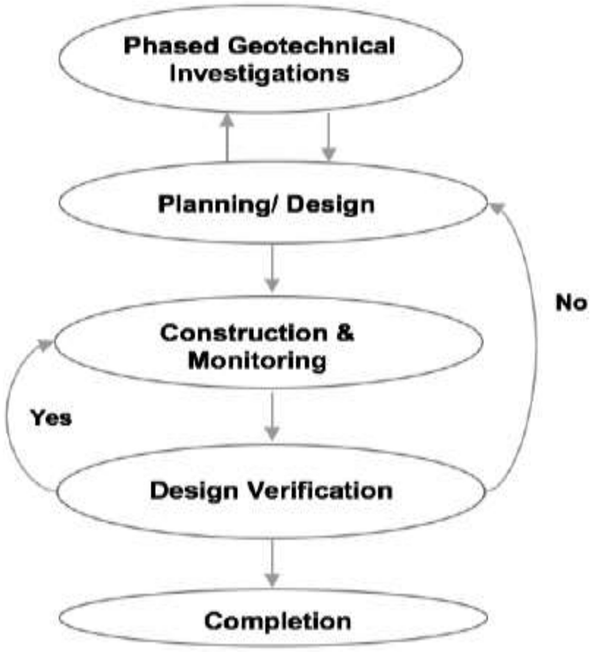


Figure 2.1: Phased geotechnical investigations with project development process (Adopted from Hung *et al*., 2009)

Geotechnical investigation is usually carried out in phases, many scholars highlight the phases involved as preliminary investigation or desk study, detailed investigation, and investigation during construction (Baecher and Christian, 2003; Zumrawi, 2014; Albatal *et al*., 2014; Myburgh, 2018). The initial phase involves carrying out a desk study or acquiring geological information about the region. Myburgh (2018) notes that the desk study involves review of existing records, detailed study. After the initial phase, a detailed investigation is carried out to obtain data through in-depth exploration, sampling, measurement, physical examination, laboratory tests, and analyses of both surface and subsurface soils. Although this phase may be regarded as the costliest, it is however, the most cost-effective phase of the investigation process by reducing the potential for unforeseen ground risks. The investigation during construction phase is mainly aimed at enhancing previous findings of preceding phases of the investigation (Myburgh, 2018). This investigation is carried out during earthwork or construction of foundation; therefore, it is imperative that geotechnical investigations be conducted and supervised by a qualified and experienced professionals in order to guard against the observation by (Charles, 2005).

2.2.3 Typical cost of geotechnical investigation

Geotechnical investigation requirements differ from by project type due to complexities and uniqueness of construction projects. Arsyad *et al*. (2013) suggested that it could range from 0.1% - 3% of the construction budget. While some geotechnical investigations may require simple laboratory experiment, others require the use of sophisticated equipment for analysis. The scope of a geotechnical site investigation is influenced by financial and time constraints placed on the investigation, as well as the knowledge of the geotechnical engineer (Jaska *et al*., 2003). Watts and Davis (n.d) stated that the approach, extent, and technique of site investigation for any particular location depends on site-specific circumstances, and the experience of those involved. Further factors that influence the cost of geotechnical investigation include accessibility to site, the distance between anticipated sample collection points, level of experience of the engineering geologist or geotechnical engineer, laboratory personnel, availability of equipment, and required laboratory and in-situ tests (Myburgh, 2018). In addition, Zlender and Jelušic (2016) identified structure type, project location, among others as factors influencing cost of investigation.

Thus, it is difficult to assign an actual cost for geotechnical investigation, even though Oyenuga (2008) suggested that geotechnical investigation cost in Nigeria is less than 1% of the total construction cost.

2.3 Project Performance

The Nigerian construction industry just like in most developing countries is constantly trying to improve its performance due to poor performance in terms of cost, delivery time, quality, and productivity (Tunji-Olayeni *et al.*, 2016). These problems are compounded by lack of resources and appropriate institutions to tackle them. Performance measurement indicators are employed to enhance project execution by taking a glimpse at the criteria to be estimated and assessed to get the outcomes.

Findings of Olowosile and Oke (2019) on the criteria for measuring project performance revealed that on habitability of construction projects, safety and incident risk, acoustic comfort and visual comfort are the most important factors to be considered. For attractiveness, Olowosile and Oke (2019) presented that, art in architectural design, and unique styled, are important factors to be considered. In addition, when considering the liveability, space efficiency, ventilation and public accessibility are the most significant factors to consider. According to findings of Tunji-Olayeni *et al*. (2016), the main performance measures adopted by construction SMEs in Nigeria are cost, time, quality, safety, profitability of the project, team work, labour productivity, and , customer satisfaction (Tunji-Olayeni *et al*. 2016).

2.3.1 Building defects

The issue of building collapse has been a reoccurring issue over the past few decades in Nigeria (Ayedun *et al*., 2012; Mansur and Tahar 2017). A failure is observed in a component when they can no longer be trusted to fulfill its primary purposes Ayininuola and Olalusi (2004). Building failure according to Okagbue *et al*. (2018) often results to collapse if not identified and addressed early. Lawal *et al*. (2017) also argued that buildings give initial symptoms of distresses in form of defects before they eventually fail. Defects in buildings thus constitute undesirable challenges and threats to users. Structural failures according to So *et al*. (2008) may occur at three phases of the building's lifespan: construction, operation, and rebuilding. Hence, failures for every stage may result in potentially dangerous unexpected accidents for construction workers or end users as the case may be. Defects as described by Olanitori (2011) emanate from design requirements errors, defective materials, improper installation of materials, and lack of strict compliance to the design. Lawal *et al*. (2017) identified active cracks (>1.5mm wide) on beams, columns, slabs and walls, improperly sloped roof gutters as building defects. The probable causes of these defects according to their study was workmanship error and defective materials.

Islam and Ahmed (2021) presented that building professionals frequently experience defects and failures in different structural components in its service period, which are essential to buildings' performance. Their study revealed that the most severe defects in buildings were footing/column settlement, tilting, crack in (column, beam, wall, and slab), efflorescence, and seepage in wall and slab. Furthermore, the study identified the common causes of these defects as no/improper sub-soil investigation, no/imperfect structural design, poor quality of materials used, poor workmanship, and excessive live load due to change in service types after construction.

Ayedun *et al*. (2012) in in their study identified poor workmanship by contractors, non-compliance with standards by contractors, incompetent contractors, and faulty construction method as the major causes of building collapse in Lagos State. Similarly, Okagbue *et al*. (2018) through a systematic literature review harmonized the causes of building failure and collapse in Nigeria. The findings revealed the most common causes were poor construction materials, geophysical or natural causes, and structural defects

2.3.2 Flexible pavement failures

The asphalt road (flexible pavement) is usually exposed to numerous distresses depending on the level of stress on the pavement Alaamri *et al*. (2017). Pavement deterioration process according to Zumrawi (2013) starts immediately after opening the road to traffic flow. Hence, Zulufqar and Rakesh, (2019) categorized defect`s in flexible pavement into cracks, rutting & shoving, and pot holes and patching. Shaikh and Wadekar (2021) also categorized flexible pavement failures into cracking, surface deformation, disintegration, and surface defects. These defects amount to issues for road users such as discomfort, increased travel time These defects often leads to loss of human life in failed-road-precipitated motor accidents, man-hours loss and high cost of goods and services (Fatoba *et al*., 2015; Alaamri *et al*., 2017). In addition, Zulufqar and Gupta (2019) posits that vehicle operating cost also increases as the condition of existing pavements starts deteriorating. Ezeagu (2018) in an earlier study identified poor design, poor workmanship, use of low quality and substandard materials account for most of the early failure of pavement in Nigeria. A recent study by Ezeagu *et al*. (2021) investigated the causes of failure in a selected failed case study road by subjecting the samples (asphalt and concrete) to physical and laboratory examination. The properties tested for the asphaltic sample revealed that most of them are outside the specification limits. In addition, the compressive strength (rigid pavement) test result also showed that the concrete elements are below the specification limits. These shortcomings among others must have contributed significantly to early road failure as reported by the authors (Ezeagu *et al*., 2021).

Fahkri *et al*. (n.d.) categorized the evaluation of pavement condition into two key indices; technical indices and structural indices. The study explained that technical indices focuses on the surface roughness and skid resistance, while the structural indices looks at the capacity of the pavement to bear imposed traffic loads. Zumrawi (2015) visually inspected existing pavement failures in a part of Khartoum, and investigated failure causes. Findings revealed majority of failed pavement sections suffered failed through cracks and rutting. The study further identified that fatigue due heavily trucks on pavement, poor drainage, inadequate design and improper pavement materials used are the major causes of pavement failure. Another study by Shaikh and Wadekar (2021) identified water stagnation issues, traffic congestion, climate condition, material quality, condition of the sub grade, and problems of compaction as factors causing pavement failure. In addition, the type of road failure in the study area according to Shaikh and Wadekar (2021) were cracks, depressions, and raveling.

Tijani and Olawale (2020) also investigated the causes of pavement failure along Ede – Akoda road, Osun State, Southwestern Nigeria. Physical inspections revealed that substantial section of the drain had collapsed or blocked. Additionally, identified pot holes were deep and common in most place. Similarly, Osadebe *et al*. (2013) also examined the extent and causes of road pavement failure along Enugu-Port Harcourt Expressway. Findings based on visual inspection of the pavement showed that infiltration of both surface and groundwater into the sub-grade soil, overloading, and poor drainage system could be major causes early of the road deterioration. In addition, cracks, potholes and structural base failure were frequent for the case study road.

2.4 Project delay and cost overrun in the context of building and road projects

Cost overrun is used interchangeably with "cost increase", it involves unanticipated costs acquired in excess of the initial cost (Shanmugapriya and Subramanian, 2013). Wideman (1992) defined cost overrun as the amount by which actual costs supersede the approved costs. Avots (1983) also described cost overrun as the difference between the original cost and the actual cost when the project is completed. Over the years, the menace of delay and cost overrun has been rigorously researched by scholars and industry professionals alike. A Monte Carlo simulation model of cost overrun developed by Geletaw (2019) using showed a 10% frequency of cost overrun occurrence, which indicates that the actual cost for majority of construction projects runs up to at least 10 % ahead of the initial budget cost.

Construction industries around the world have a poor reputation in terms of project completion within agreed time and on budget (Aljohani *et al*., 2017). These challenges of delay and cost overrun have been a frequent issue in the construction industry. In fact, nine out of ten projects experience cost overrun according to (Aljohani *et al*. 2017). Findings from literature thus showed that cost overrun leads to delay in construction projects (Amoa-abban and Allotey 2014). Alda and Assed (2018) in their study identified the most prevalent causes of cost overrun as scope change, and absence of sufficient design detail during budgeting. In addition, Shah (2016) identified the most influential causes of delay and cost overrun as planning deficiencies, contractor's improper planning, payment delays, and construction methods. Conversely, Mansfield *et al*. (1994); Anyanwu *et al.* (2017) identified that asides the usual causes identified, material shortages and changes in site conditions, unexpected subsoil condition are also major causes of cost overrun.

In building projects, Akinradewo and Aigbavboa (2019) concluded that poor financial control on site, previous experience of contractor, contract management, and wrong estimation method are the frequent factors causing cost overrun in building projects. Enshassi and Ayyash (2014) in their study categorized the causes of cost overrun in building projects as project team-related, client-related, contractor-related, political-related, economic-related or manpower-related. Similarly, Chulkov *et al*. (2019) grouped the underlining factors into project, contract, client, contractor consultant, workforce and external.

For road pavement projects, the high cost of funding involved in these type of projects necessitates government involvement in the financing, construction and maintenance (Ahmad *et al.*, 2018). Road projects are unique in terms of public acceptance, technical solutions, operational logistics, and investment scheme; as well as their characteristics depending on their location, response of the society to their services, and the interaction between parties involved (Sarkar and Kovid 2015). Cost overruns in road projects are large leading to huge waste of financial resources, time and even abandonment of projects (Ahmad *et al*., 2018)

The findings of the research conducted by Ahmad *et al*. (2018) revealed that, just like in building projects, road pavement projects are also open to cost overruns, with a very large magnitude. Lee (2008) identified that 95% of road projects have 50% cost overruns, while the causes of cost overruns was attributed to increase in capacity after the feasibility study or during project execution phase, varying compensation, and lane addition.

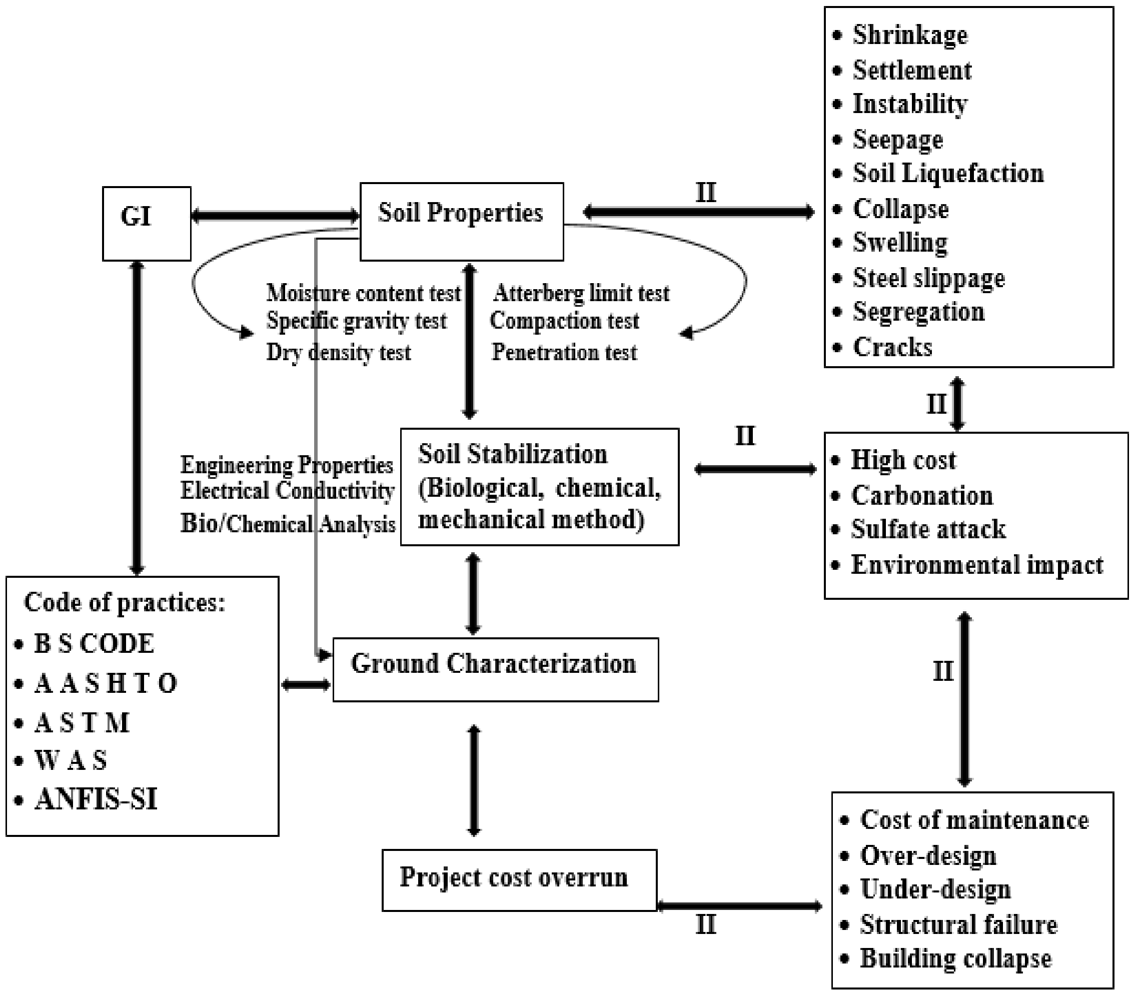
Therefore, the causes of delays and cost overruns in the construction sector have been attributed to numerous factors in the construction industry. These factors varied with the nature and scope of the project, as well as location and region of the project.

2.4.1 Relationship between geotechnical analysis and project cost overrun

Cost Overrun is defined as the amount by which the actual project cost surpasses the budgeted cost (Wideman 1992). The excessive cost overrun experienced generally in the construction industry is a major concern for stakeholders and focused on research studies. The study by Aljohani *et al*. (2017) states that cost overrun may result from both internal and external factors, while the prevalent factors contributing to cost overrun are, frequent design change, lack of contractor experience, poor cost estimate, poor tendering documentation, and poor material management. The magnitude of cost overrun tends to increase with the projects' size and complexity (Adam *et al*., 2017). The reasons for the reported cost overruns of construction projects include changes in the projects' scope, inflation, and other factors such as inadequate or inappropriate geotechnical investigation (Clayton 2001; Anyanwu *et al*., 2017). On a different note, Kelly *et al*. (2020) posits that regardless of the scope of geotechnical investigation, there will always be residual risk because not every ground element can be tested.

It has been shown that a link exists between geotechnical analysis and cost overrun in infrastructure projects (Amadi and Higham 2016; Hintze 1994; Stukhart (1987). In addition, case histories presented by Kelly *et al*. (2020) demonstrated that the quality and depth of site investigation has a direct impact on actual performance versus predicted performance and hence on cost and time performance of the project. Attributed risks within the ground amount to significant cost and time overruns on construction projects. Sadly, a comprehensive site investigation to address such risks are often ignored as an unnecessary cost (Hytiris *et al*., 2014). Contrarily, Moh (2004) and Nazir (2014) attributed geotechnical failures inadequacy of standard specifications concerning the scope and quality of site investigation.

The consequences of insufficient information from geotechnical conditions adversely affect both the financial and technical performance of construction projects, resulting in additional costs of construction, operation, or maintenance (Clayton, 2001) and, in worst cases, loss of lives and properties, building collapse, or complete demolition and reconstruction. Inadequate site investigation can lead to the overdesign, under design. This could have be avoided if proper site investigation was conducted. According to Hytiris *et al*. (2014), the analysis of cost performance for some selected building projects showed that 44% of cost increases are attributable to inadequate site investigation. This is similar to the outcome presented in Albatal *et al*. (2014), which shows that inadequate geotechnical and site investigation lead to cost overrun by about 64.2%. The contribution of inadequate geotechnical investigations to the additional cost of projects is shown in Figure 2.2:



GI Geotechnical Investigation**
II Inadequate Investigation**

Figure 2.2: Relationship between geotechnical investigation and cost overrun

Source: Adapted from Nazir, (2014).

2.5 Empirical Reviews

The empirical reviews presented in Table 2.2 shows the summary and evaluation of related literature which are relevant to this study. The Table identifies the objectives, methodology, and major findings.

Table 2.2: Empirical Reviews

S/NO	AUTHORS/TITLE	OBJECTIVES	METHODOLOGY	CONCLUSION
1	(Egesi and Tse, 2012). Engineering-Geological Evaluation of Rock Materials from Bansara, Bamenda Massif Southeastern Nigeria, as Aggregates for Pavement Construction	Investigation of the properties of basement rock to assess suitability of performance for pavement materials	The strength of the aggregates were evaluated by a series of composite tests including Aggregate Abrasion Value (AAV), Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Specific Gravity and Water Absorption as contained in BS 812, and AASHTO T96-92. Aggregate abrasion value was determined using the Los Angeles machine	The Biotite-Granite gave Aggregate Abrasion Value (AAV) of 22.0%, Aggregate Crushing Value (ACV) of 23.3%, Aggregate Impact Value (AIV) of 18.5% and water absorption of 0.54% while Granite-Gneiss has 27.0%, 26.1%, 22.8% and 0.73% and the Greenstone has 45.2%, 55.9%, 49.6% and 3.90% respectively
2	(Al Rousan, 2004). Characterization of Aggregate Shape Properties Using a Computer Automated System	To develop an improved version of the Aggregate Imaging System (AIMS) for measuring shape properties To evaluate the improved version of AIMS along with other available methods used to measure aggregate shape properties for repeatability, reproducibility, accuracy, cost, and operational characteristics To develop a comprehensive methodology for classification of aggregates based on the distribution of their shape characteristics measured using the improved version of AIMS	Development of improved version of Aggregate Imaging System (AIMS) to measure the shape characteristics of both fine and coarse aggregate. The comparison of AIMS against other tests was conducted based on statistical analysis of the accuracy, repeatability, reproducibility, cost, and operational characteristics	The study developed a new aggregate classification methodology based on the distribution of their shape characteristics
	(Sabhaya *et al*., 2018).	To provide information about sub-	Standard Laboratory test for Standard	The results of sub-surface investigations

S/NO	AUTHORS/TITLE	OBJECTIVES	METHODOLOGY	CONCLUSION
3	Geotechnical Characteristics of soils to identify sub-stratification of Vadodara City, Gujarat, Western India	surface stratification of soils, index and shear properties of the study area for planning of land use and engineering works	Penetration Test (SPT N value), Grain size analysis, Atterburg test,	suggested that the soil stratification of Vadodara city is composed of thick pile of unconsolidated flood plain deposits consisting of gravelly clays, poorly graded sand, silty sand, clayey sand, silty clay, clay etc. The SPT N-values reach >50 at depth of almost 15.0 m. However, at some places, SPT N-values are high in soil layers encountered at depths ranging from 20m to 25m.
4	(Ezenwaka *et al*., 2014). Geotechnical Investigation for Design and Construction of Civil Infrastructures in Parts of Port Harcourt City of Rivers State, Southern Nigeria.	To look at the clay member within the Benin Formation, as well as the sandy unit and determine their suitability with respect to load bearing	All the tests followed standard procedures of testing soils for civil engineering purposes	The geotechnical behavior of the materials within the study area showed that the cohesive materials failed some relevant material specifications for most civil infrastructures, having ultimate and safe bearing capacity averaging 410.48KN/m2 and 136.83KN/m3 respectively
5	(Albatal *et al*., 2014). Effect of inadequate site investigation on the cost and time of a construction project	This paper aims to focus on the impact of varying the scope of the site investigation process, on the financial risk of construction projects. Another goal is to compare the cost of extra site investigation with the repairing or reconstruction cost result from improper site investigation	Case study application on Al-Ertikaa Factory.	The results of the analyses conducted in this research, show that the inadequacy of the sit investigation represents major factor on the construction cost and duration Due the inadequate site investigation, the extra cost represents 65.7 times the required site investigation cost. While the delay time due to the inadequacy of site investigation represents 25% of the project total duration
6	(Hytiris *et al*., 2014). The importance of site investigation in	The aim of study was to investigate the high incidence of cost overruns and	Study methodology involved comparison between the spend/cost based on a virtual site	The study concluded that there exists a lack of clear guidance on spending on site

S/NO	AUTHORS/TITLE	OBJECTIVES	METHODOLOGY	CONCLUSION
	the construction industry: a lesson to be taught to every graduate civil and structural engineer	programme delays in construction and civil engineering as a result of unforeseen ground conditions.	designed by the author of this project and that of an actual project	investigation works as a proportion of the overall contract sum of a project.
7	(Wood and Ashton, 2007). An Investigation to Identify the Role of Pre-Construction Site Investigative Information Used By Small Medium Sized Enterprises (SME)	The paper discussed the issues surrounding risk, uncertainty and complexity in relation to pre-construction planning, specifically looking at the role of site Investigation at the planning stage.	Questionnaire survey	The main outcome from this study has therefore been to highlight the conflict between what contractors understand to be happening and what research is telling us, contractors feel that there is no problem with SI information whereas research has identified that inadequate site investigation is a significant problem that results in losses in time and expense
8	(Agbede *et al.*, 2015). Geotechnical Investigation into the Causes of Cracks in Building: A Case Study of Dr. Egbogha Building, University of Ibadan, Nigeria	The study examined the geotechnical properties of soil supporting Egbogha building that has been revealing deep cracks around its wall	Soil samples were collected around the building for laboratory study. The properties determined were natural moisture content, particle size, Atterberg limits, compaction, and consolidation.	According to the soil settlement estimated, the result indicated insignificant settlement at 1.5m depth. According to the classification of potential swell of the soil, the soil has medium potential for shrinkage or swelling. This could be attributed to high clay content in the soil. Hence, the soil has tendency for expansion
9	(Nazir, 2014). Managing Geotechnical Site Investigation Work – Getting Away from Old Practice	The paper aim to provide practicing engineers a good insight into the importance of site investigation and its process by looking into old habits and getting away from it.	Expository approach	The consequences of inadequate investigations are not only severe for the design and construction phases of a project but are even more serious when continued into full-life costing. Inadequate site investigations can arise from a lack of client awareness, inadequate finance, insufficient

S/NO	AUTHORS/TITLE	OBJECTIVES	METHODOLOGY	CONCLUSION
				time and a lack of geotechnical expertise
10	(Owamah *et al.*, 2018). Assessment of Some Geotechnical Properties of Nigerian Coastal Soil: A Case-Study of Port-Harcourt Beach Mud	To investigate the geotechnical properties of the underlying soils of the Port-Harcourt Beach Mud, Rivers State, Nigeria	Five boreholes namely BH1, BH2, BH3, BH4 and BH5 were drilled using hand auger at different depths of 300mm, 350mm, 400mm, 450mm and 500mm respectively. Basic geotechnical tests were then performed on the samples in the laboratory to determine their properties	Results obtained showed that the area is underlain predominantly by poorly graded sands based on the Unified Soil Classification System (USCS). The soil material had an average Moisture Content of 71%, Liquid Limit of 13%, Plastic Limit of 11%, Plasticity index (PI) of 2% and Hydraulic Conductivity (K) of 2.88 x 10-1 cm/s. The high values of K show that the aquifer system in the area is prolific. The soil material however met the requirements of the Nigerian General Specifications for use as subgrade in the construction of roads.
11	(Pospíšil and Rozsypal, 2017). Site investigation as tool for elimination of natural hazard Impact on construction project.	The article dealt with the process of site investigation focused on elimination of natural hazards impact on the structure. It is described the importance of gradual assessment especially of rock environment conditions in relation to specific traffic structure.	Expository approach	The study concluded that ground investigation results should be presented to the designer in an “understandable” form; either in 2D or 3D. The use of the design-build (DB) procurement process has become increasingly popular in recent years especially in the transportation industry.
12	(Oyelami and Rooy, 2016). Geotechnical characterisation of lateritic soils from south-western Nigeria as materials for cost-effective and energy-efficient building bricks	The paper looked critically at the geotechnical properties of lateritic soil which make it suitable as a material for brick manufacturing with a focus on the influence of geology on its structure, texture and mineralogy.	The samples were air-dried by atmospheric exposure for about three weeks prior to laboratory testing. Laboratory testing can be grouped into soil classification tests, geotechnical tests, mineralogical tests and brick durability testing. All tests were carried out	Lateritic soils from the study area were found to be suitable as materials for bricks (CEB) with good compressive and durability strength which qualifies them as sustainable and cost-effective materials for low-cost housing development.

S/NO	AUTHORS/TITLE	OBJECTIVES	METHODOLOGY	CONCLUSION
			according to the British Standard BS 1377 (1990) procedures with small modifications where necessary.	
13	(Surendra and Sanjeev 2017). Role of Geotechnical Properties of Soil on Civil Engineering Structures	In this paper, different geotechnical properties of soils such as specific gravity, density index, consistency limits, particle size analysis, compaction, consolidation, permeability and shear strength and their interactions and applications for the purpose of civil engineering structures have been discussed	Literature Review	Higher the specific gravity, higher will be the load carrying capacity of soils. Density index is used for the compaction of coarse grained soils. Consistency limits indicate the properties of fine grained soils. The interactions among different geotechnical properties of soils can help the researchers while designing the foundations for different types of civil engineering structures
14	(Umoren *et al*., 2016). Geotechnical Assessment of a Dam Site: A Case Study of Nkari Dam, South Eastern Nigeria	The geotechnical Investigations involved sample collections, in-situ tests and laboratory analysis to investigate the parameters such as Atterberg Limits, soil classification, moisture-density relationship, stability analysis, drainage, bearing capacity, consolidation settlement, permeability and ground water level.	Test pits and trenches were opened and undisturbed soil samples were collected for necessary laboratory tests and analyses. Field/In-situ tests included Dutch Cone Penetrometer (CPT) measurement, Standard Penetration Test (SPT) natural moisture content determination and borehole drilling for groundwater level observation and lithologic identification	The study concludes that the site is suitable for the dam construction, the overburden soils, though of very low density and highly compressible nature has very low permeability characteristics.
15	(Zumrawi, 2014). Effects of Inadequate Geotechnical Investigation on Civil Engineering Projects	To study the influence of reliable and factual geotechnical investigation data in design and construction of foundations for civil engineering structures	Case studies of two projects in Khartoum state was been chosen; a multi storey building in Khartoum and Alarda road in Omdurman town.	The study concluded that geotechnical investigation is an interdisciplinary subject and professionals with special training and experience in geotechnical engineering should be involved.

S/NO	AUTHORS/TITLE	OBJECTIVES	METHODOLOGY	CONCLUSION
16	(Neupane, 2016). Causes and Impacts of Geotechnical Problems on Bridge and Road Construction Projects	To determine the geotechnical-related causes of cost and schedule growth and claims as well as their impacts on the bridge and pavement projects' performance. To identify mitigation measures to avoid cost and schedule growth and claims in these projects.	A survey was conducted with 53 engineers from state Department of Transportations (DOTs) and 43 engineers from design consultant firms	Out of a total of nine methods of subsurface investigation, the results showed that the top three rated methods were: the Standard Penetration Test, the Cone Penetration Test, and the Geophysical Method for bridge projects. The results also showed that consultants and clients were more favorable to the Standard Penetration Test (SPT) for bridge projects. Again, out of a total of nine possible geotechnical-related causes of cost growth for bridge projects, the top three causes were: a lack of sufficient boring locations, misclassified or mischaracterized subgrade, and a level of groundwater table higher than expected.
17	(Amadi and Higham 2016). Geotechnical Characterization of cost overrun Drivers in Highway Projects: Predicted on the Heterogeneous Ground Conditions in the Niger Delta Region of Nigeria	The study explores geological settings as a trigger for cost overrun. Examined geotechnical practices among construction practitioners and compare with best practice guidance	Geotechnical characterizing the heterogeneous sub-soil configuration of the Niger Delta region. In addition, questionnaire survey to determine geotechnical practices	Cost overrun are not necessarily the outcome of calculated acts of deception, although this could be contributing to some of the variance not accounted for within the model. In addition, difficulties associated with the wetland geology, and the limitations of existing geotechnical practices used by highway agencies in the Niger Delta, account for most of the reported cost overrun in the region.
18	(Madhavarao *et al.*, 2018). A Critical Analysis of Material Management Techniques in	To compare the planned and actual material consumption and also to find out the problems facing in planning,	The application of ABC analysis and S-curve analysis for classification of materials	The S curve technique provides the difference in the planned cost and actual cost of the project. Due to some factors like

S/NO	AUTHORS/TITLE	OBJECTIVES	METHODOLOGY	CONCLUSION
	Construction Project.	purchasing, procurement and regarding the material management Find out the analysis of planned and actual cost of construction material.		weather conditions, natural calamities, improper procurement of materials and material fluctuation in market increases the construction cost and budget
19	(Žlender and Jelušič 2016). Predicting Geotechnical Investigation Using the Knowledge Based System	To evaluate the optimal number of investigation points and each field test and laboratory test for a proper description of a building site	The Adaptive Network Fuzzy Inference System (ANFIS-SI) model was used to characterize building site	The study concluded that the model ANFIS-SI, with integrated recommendations can be used as a systematic decision support tool for engineers to evaluate the number of investigation points, field tests, and laboratory tests for a proper description of a building site
20	(Aleksander *et al.*, 2017) Geotechnical parameters of soil, considering the effect of additional compaction of embankment	The paper investigated multi-layersoil embankments during construction analysis of a new geotechnical approach, used for construction of non-typical soil embankments	The tests were conducted in in-situ conditions.	Construction of multi-layer embankments from mineral native soil is a very complex geotechnical process consisting of many stages. It is influenced by many factors that depend on the type of built-in material and competent decisions of the direct contractor.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

The major aim of research is to provide answer to specific problems. Kothari (2004) defines research as a "scientific and systematic search for valid information on a specific subject area", as well as an art of scientific investigation. As an academic activity, Clifford Woody in Kothari (2004) notes that "research comprises of defining and redefining problems, formulating hypothesis or suggested solutions; collecting, organizing and evaluating data; making deductions and reaching conclusions; and carefully testing the conclusions".

Research methodology is however a method of systematically solving an identified research problem through the application of required research principles or techniques. It may be viewed as the science of studying how research is done scientifically (Kothari, 2004). It is imperative to have an in-depth knowledge of the basic principles of research methodology and techniques. This is to understand "how", "why", "when" to carry out or adopt certain research methodology or techniques. Techniques to accomplishing this systematic investigation according to (Burns, 2000) could either be through scientific empirical method or the naturalistic phenomenological approach. Thus, this chapter explains the fundamental principles of research method with a view to justify the choice of research technique.

This chapter discusses in details the traditional scientific and the qualitative method following approaches that were used in carrying out the research investigations. The researcher adopted the quantitative methods. The research method involved the use of a structured survey questionnaire to elicit views from a sample population comprising of key construction stakeholders on various geotechnical related issue in the construction industry.

3.1 The Traditional Scientific Method

This approach is commonly described as nomothetic approach applies quantitative research methods to establish general laws and principles (Diugwu, 2008). This quantitative method employs the use of experimental, inferential, and simulation methods of research. The inferential approach according to Kothari (2004) uses survey research where a population sample is studied through questions or observations to determine its features, which is then used to characterize the population. Whereas, experimental approach observes the effect of varying some variables on others. Lastly, the simulation method involves the construction of an artificial environment to acquire the relevant information to generate data without external interference. This also permits an independent observation of the dynamic feature of a system (or its sub-system) under controlled conditions.

Burns (2000) opines that data must produce strong confirmation in probability terms, of a theory or hypothesis in research setting. The steps involved in this type of approach according to Kothari, (2004) include:

1. assuming a hypothesis from the theory
2. operationalizing the hypothesis to investigate the relationship between two specific variables, and indicating how the variables are to be measured
3. testing the operationalized statement using statistical testing, experimental procedure.

4. examining the specific result of the enquiry which will either affirm the theory or show the need for improvement.
5. modification of the theory to accommodate the findings

The traditional scientific research method is high in precision and accuracy, which are achieved through design & sampling, and quantitative & reliable measurement respectively. In addition, the use of quantitative data according to Burns (2000) permits statistical analysis which provides answers having a solid background than those achieved using other methods. Thus, it is a general believe that only a systematic or quantitative method to generate and test ideas is satisfactory.

However, the scientific method is also one with weaknesses. One of them according to Diugwu (2008) is the fact that environmental impact on human beings affect the way they interpret and respond to certain occurrences. Similarly, individual differences among humans influence the manner and approach in which they respond to issues. As such, it is very difficult to predict the manner of response of a particular individual under different circumstances. Another weakness of the traditional scientific method according to Burns (2000) is the constraint limiting human judgment, notion of freedom, and choice due to the subjectivity involved, as well as interpretation of results. This method does not consider people's unique ability to interpret matters based on their individual differences.

In conclusion, since the scientific research method defeats the objectivity nature of science, scholars realized the need to adopt more than one method in researches.

3.2 Qualitative Approach

This approach is concerned with subjective assessment of attitudes, views and conduct (Kothari, 2004). Eisner, (1979) describes qualitative research as processes focused rather than implications, concerned more with organic wholeness than independent variables, and collective meanings over behavioral statistics. This outcome of this approach is dependent on the researcher's understandings and impressions of identified problems. Results generated are either in non-quantitative format or in the form not subjected to complex quantitative analysis. Techniques used for qualitative research approach involves focus group interviews, projective techniques and depth interviews.

3.2.1 Quantitative Approach

This approach involves the generation of data in quantitative format which can be subjected to rigorous quantitative analysis in a formal and rigid fashion. This approach can be sub-classified into inferential, experimental and simulation methods to research. The purpose of inferential method is to form a data base from which to infer characteristics or relationships of population. This usually means survey research where a sample of population is studied (questioned or observed) to determine its characteristics, and it is then inferred that the population has the same characteristics (Kothari, 2004). This study adopted this approach was selected as it requires careful experimental design and ability to replicate both the test and results. Additionally, data analysis is much easier with this approach with less error (Devault, 2020).

Research studies generally tries to explore, investigate events, to contribute to existing body of literature (Diugwu, 2008). This study has been designed with a view to investigating and understanding the issue of geotechnical investigation in the Nigerian construction industry context. This research also aimed at assessing the impact of inadequate geotechnical investigation on construction projects' performance. Hence, it seeks to answer "how" inadequate geotechnical investigation arises and "why" it has the potential to affect construction projects' performance.

3.3 Structure of the Questionnaire

A structured questionnaire was used as a survey instrument for primary data collection. According to Robson (2002), research survey is a medium of collecting standardized information from specific group of people (sample population). Surveys are also applicable for descriptive studies to explain and provide data for hypothesis testing.

Primary data in this research refers to data collected directly from people before being processed through analysis to reach conclusions concerning issues under investigation. These primary data formed the basis for the analysis of this research, aimed to have an understanding of the perception level of major stakeholder in the construction industry on geotechnical investigation related issues for construction projects. The survey questionnaire contained a mixture of open-ended questions (where the respondents were free to register their opinions), and multi-choice response (here, the respondent is restricted to pre-determined responses or variables).

Prior to the questionnaire structuring, the researcher conducted a preliminary in-depth review of literature related to geotechnical investigation, causes of inadequate geotechnical investigation, impact of inadequate geotechnical investigation on construction project performance (cost and schedule). This gave the researcher a clear understanding of the type of questions to ask to collect information and data using the survey questionnaire. After successfully designing the questionnaire, it was sent out to professionals to examine the clarity, and relevance of the questions asked. Lin and Mills (2001) affirms that pilot studies improves questionnaires for better understanding by examining their ability to obtain required information for the research, and identify potential errors.

A pilot test of the questionnaire used was carried out using:

- Academics (Federal University of Technology, Minna and University of Ilorin) with relevant experiences in geotechnical engineering, and construction management.
- Geotechnical engineers in supervising agencies (Federal Ministry of Works)
- Project managers in a major construction firm based in Abuja
- Geotechnical Engineer of a major construction firm based in Abuja

Questionnaire as an instrument for data collection is generally regarded as an efficient way of data collection from a sample population. It also gives the possibility of determining the validity, reliability, and statistical significance of responses using statistical techniques (Diugwu, 2008). In addition, they are easy to administer, and economical because the structured survey questions are only administered to sample population based on sampling technique adopted. However, the reliability of this approach is dependent on the honesty, mood, and willingness of the respondents to respond. This is why the respondent through interaction, got approval and willingness to participate in the survey from a larger proportion of the responds. Again, privacy, and anonymity of the respondent were ensured to encourage honest response without any fear of consequences.

The questionnaire used for data collection was divided into three (3) parts. The first section sought data on the biography and personal details (e.g. gender, academic qualification, profession, type of organization, and relevant years of experience) of the respondents. The second part asked questions relating to geotechnical investigation practices, causes of inadequate geotechnical investigation, the impact of geotechnical related issues on project cost, schedule, and performance in building construction while the third asked questions concerning geotechnical investigation practices, causes of inadequate geotechnical investigation, the impact of geotechnical related issues on project cost, schedule, and performance in road pavement construction. Majority of the variables used were identified from literature, and respondents were requested to rate variables on a five-point Likert scale of (Always, Very Often, Often, Sometimes, Never) and (Very High, High, Medium, Low, Very Low). In addition, the respondents were requested to rate strategies to mitigate the impact of inadequate geotechnical investigation on construction projects.

3.4 Data Sampling Technique

Sampling techniques are broadly categorized into two; probability sampling and non-probability sampling. Probability sampling, also known as random sampling according to (Kothari, 2004) is based on the theory of random selection. It is a method in which individual samples are selected from the whole group strictly by some mechanical process. Non-probability sampling, also known as deliberate sampling, purposive sampling and judgment sampling. Hence, the probability sampling design was adopted because the researcher can measure the degree of error, or the significance of the results

(Kothari, 2004) which makes it superior over the non-probability sampling. However, the sample population was divided into clusters, by geographical location. According to Levy and Lemeshow (1991) cluster units can be described based on geographic, temporal, or spatial features

According to Baker (2002), in situations where all the members of a sample population cannot be identified, a defined group can be sampled on the basis of suitability factors such as convenience and accessibility. Due to time and resource constraints of this research, it is not practicable to conduct a survey of the subject matter in Nigeria as a whole. Thus, the survey sample population was firstly restricted geographically to North central geopolitical zone of the country. This geopolitical zone comprises of the following states; Kogi, Kwara, Niger, Plateau, Benue, Nasarawa, and Federal Capital Territory (FCT). However, due to the heightened security challenges in some parts of Nasarawa, Benue, and Plateau, the researcher excluded these states. The second restriction of the sample population was to organized group of construction industry practitioners with at least five years professional practice experience (majorly Civil Engineer, Geotechnical Engineer, Engineering Geologist, Project Manager, Builder, Architect, Quantity Surveyor, Surveying and Geo-informatics) working with consulting or contracting firms (in public or private sector); as well as clients. In view of this, the researcher applied a mixed sampling design in this study.

3.5 Population and Sample Size Determination

Sample size determination is based on sampling theory. Kothari (2004) describes the theory as “a study of the relationship between a population and the samples selected from the population”. Kothari (2004) further discussion states that the sample must be of an optimal size, although the sample size should be large enough to give a significant confidence level, and chosen through a logical process.

The Cochran's sample size formula was adopted to determine the sample size of the study. This is because the population size of a national survey of this nature cannot be ascertain. Taking p as 0.5, e as 0.05, and a 95 % confidence level gives us Z values of 1.96, from the Z table.

Cochran (1977)

$$n_0 = \frac{Z^2pq}{e^2} \qquad \text{(Eqn. 3.1)}$$

Where e = precision level (i.e. the margin of error),

p = the proportion of the population which has the attribute in question,

q = 1 – p.

Thus

$$n_0 = \frac{1.96^2(0.5*0.5)}{0.05^2} \qquad \text{(Eqn. 3.2)}$$

$n_0 = 384$

Sampling technique employed was random sampling of professionals in the bracket group of client organizations, contracting firms, and consulting firms. Target professionals include Civil Engineer, Geotechnical Engineer, Engineering Geologist, Project Manager, Builder, Architect, Quantity Surveyor, Surveying and Geo-informatics.

3.6 Statistical Analysis

Statistical testing procedures broadly fall into two major categories; parametric and non-parametric. In parametric test, the test statistic is based on distribution. Non-parametric tests which is also known as distribution free data "is a statistical procedure whereby the data does not match a normal distribution" (Mardiapoulle *et al*., 2012). The type of test analysis to be conducted is dependent on whether the acquired data is normally distributed or not. Table 3.1 identifies some parametric and non-parametric tests can be carried out. Sample data acquired for this study is regarded as ordinal data which does not depend on arithmetic properties, hence was analyzed using non-parametric tests. It was further subjected to normality test using the Kolmogorov Smirnov Test to ascertain the normality. This test is similar to the Shapiro Wilks Test, the only difference is that the Kolmogorov Smirnov Test can be used for sample data greater than 50. This technique checks the similarity between cumulative distribution of the samples and that of the normal population. This technique tests whether the sample is taken from a normally distributed population. A significant less than 0.05 *p*-value shows that the sample data is nor normally distributed. The Author tested an hypothesis that;

H_0 Sample data are normally distributed

H_1 Sample data are not normally distributed

Table 3.1: Examples of Parametric and Non-parametric tests

S/No	Analysis Type	Parametric Procedure	Non-parametric Procedure
1	Compare means between two distinct/independent groups	Two-sample t-test	Wilcoxon rank-sum test
2	Compare two quantitative measurements taken from the same individual	Paired t-test	Wilcoxon signed-rank test
3	Compare means between three or more distinct/independent groups	Analysis of variance (ANOVA)	Kruskal-Wallis test
4	Compare of two independent samples.	Independent Sample t Test	Mann-Whitney test/UK-SZ
5	Comparison of three or more dependent samples.	Two way repeated measures of ANOVA	Friedman test

6	Estimate the degree of association between two quantitative variables	Pearson coefficient of correlation	Spearman's rank correlation

Source: Mardiapoulle *et al*. (2012); Hoskin (n.d)

Hence, based on the descriptions in Table 3.1, the Author adopted the use of Spearman's correlation technique to test for relationship, and the use of Kruskal-Wallis to test the difference between two or more independent variables. Data analysis was carried out using a combination of descriptive analysis, rank order, and inferential statistics using Microsoft excel, Statistical Package for the Social Sciences (SPSS), and Statgraphics XVII. Respondents' demographics were presented via the aid of descriptive tables and charts.

3.6.1 Spearman's rank correlation

Correlation is a statistical tool used to measure the relationship between two or more variables. The Spearman Ranked Order correlation measures the direction and monotonic (when one number increases, so does the other, or vice versa) between two variables. It is a non-parametric alternative of the Pearson moment correlation. The following assumptions were checked before adopting this technique;

- The data violate Pearson's assumptions
- One or both of the variables are ordinal (Likert scale) or scale (interval or ratio)
- Data is not normally distributed
- Outlier exist in the data set

3.6.2 Mann-Whitney Test

The Mann Whitney Test is a non-parametric substitute to the independent samples t-test which compares the difference between two independent groups when the dependent variable is either ordinal or continuous. It is also called the Mann Whitney Wilcoxon Test or the Wilcoxon Rank Sum Test (WRST).

Assumptions;

- The dependent variable be measured as ordinal or continuous data.
- Two categorical independent groups should make up the independent variable
- Independence of observations
- Both independent variable should have the same shape/variability

3.6.3 Kruskal Wallis H Test

The Kruskal Wallis test is an alternative for one way ANOVA test for normally distributed data (Neupane, 2016). It is used to test the hypothesis that a number of unpaired samples originate from the same population. In addition, it can be used for three or more independent samples unlike the Mann-Whitney Test that tests for only two groups. The assumptions are similar to those of the Mann-Whitney Test, the only difference is that two or more categorical independent groups make up the independent variable.

3.6.4 Regression model

A regression model is used to investigate the relationship between a dependent variable (y) and one or more independent variables (x). According to Chatterjee and Simonoff (2013), regression analysis can typically be used for modeling the relationship between x and y; forecasting; and hypotheses testing. The author adopted the multiple regression model since data set were normally distributed.

The equation model of the study is presented below:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon \qquad \text{(Eqn. 3.3)}$$

Where Y = Adequate Geotechnical Investigation,
B_0 = constant
$\beta_1 – \beta_6$ = regression coefficients
X_1 = Client Awareness,
X_2 = Financial Constraint,
X_3 = Result presentation,
X_4 = Supervision,
X_5 = Sampling technique,
X_6 = Equipment,
ε = stochastic disturbance error term

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Demographics of Respondents

4.1.1 Gender of respondents

The gender distribution of the respondents are shown in Table 4.1. Survey result showed that a total number of 181 representing 75.7% were male, while 58 (24.3%) were female.

Table 4.1: Gender of respondents

Gender	Frequency	Percent
Male	181	75.7
Female	58	24.3
Total	239	100.0

4.1.2 Educational qualification of respondents

The highest educational qualification of respondents is presented in Table 4.2. Survey result showed 15% (12) of the respondents have National Diploma qualification, 54.4% (130) of the respondents have Bachelor's degree, 31.8% (76) have Master's degree, and 8.8% (21) had PhD. Hence, the educational qualification of respondents was regarded fit and adequate, as they are expected to have the basic knowledge about issues raised.

Table 4.2: Highest qualification of respondents

Qualification	Frequency	Percent
ND	12	5
Bachelor's Degree	130	54.4
Master's Degree	76	31.8
PhD	21	8.8
Total	239	100

4.1.3 Profession of respondents

Table 4.3 shows the professional qualification of respondents. Survey result showed that 23% (55) of the respondents were Civil engineers, 14.6% (35) were Project managers, and 13.8% (33) were Geotechnical engineers. Other representative professions include Architecture (12.6%), Surveying and Geo-informatics (12.6%), Quantity Surveyor (11.3%), Engineering Geologist (7.9%), and Builder (4.2%). Hence, the professional qualification of respondents was regarded fit and adequate, as they are expected to have the basic knowledge about issues raised.

Table 4.3: Profession of respondents

Profession	Frequency	Percent
Civil Engineer	55	23
Geotechnical Engineer	33	13.8
Engineering Geologist	19	7.9
Project Manager	35	14.6
Builder	10	4.2
Architect	30	12.6
Quantity Surveyor	27	11.3
Surveying and Geo-informatics	30	12.6
Total	239	100

4.1.4 State of respondents

The North-central geopolitical zone of Nigeria was selected as the study area. Table 4.4 presents the resident states of the respondents. Study result revealed that 30.5% (55) of the respondents are resident in FCT, 26.8% (64) were from Kwara, 24.3% (58) were from Niger, and while 18.4% (44) were from Kogi.

Table 4.4: State of respondents

State	Frequency	Percent
Kogi state	44	18.4
Kwara state	64	26.8
Niger state	58	24.3
FCT	73	30.5
Total	239	100

4.1.5 Type of organization

Three (3) major organizations was selected for the purpose of the study. Table 4.5 shows the frequency distribution of respondents based on the organization type. Results showed that 44.8% (107) of the respondents fell into the contracting firm organization category, 29.3% (70) represented client organizations, and 25.9% (62) practice in consulting firms.

Table 4.5: Type of organization

Organization category	Frequency	Percent
Client Organization	70	29.3
Contracting Firm	107	44.8
Consulting Firm	62	25.9
Total	239	100

4.1.6 Professional practice experience

Tables 4.6 shows the frequency distribution for years of practice experience in building and road construction respectively. Results showed that about 46.4% (111) had at least 10years practice experience in building construction while the other 53.6% (128) had years of experience in building construction ranging between 1-10 years. In addition, 53.2% (127) of the respondents also had practice experience ranging between 1-10 years in road construction while 46.8% (112) had at least 10years practice experience in road construction.

Table 4.6: Years of experience in building construction and road construction

	Building Construction		Road Construction	
Years	**Frequency**	**Percent**	**Frequency**	**Percent**
1 – 5	65	27.2	84	35.1
5 – 10	63	26.4	43	18.1
10 – 15	47	19.7	78	32.6
15 – Above	64	26.7	34	14.2
Total	239	100	239	100

4.2 Results and Discussions Regarding Building Construction

4.2.1 Descriptive statistics on geotechnical investigation issues in building projects.

The respondents were asked a total of twelve (12) key questions regarding the issue of geotechnical investigation in building projects. These questions sought to explore the practice level of geotechnical investigation in building projects, the use of geotechnical design standards, methods of subsurface investigation/parameters tested, causes of inadequate geotechnical investigation, impact of geotechnical investigation related issues on project cost, schedule and performance.

4.2.2 Frequency of geotechnical investigation Practice in building construction

Respondents were asked how often they carry out geotechnical investigation in their practice of building construction. Results presented in Table 4.7 showed that 76.1% of the respondents usually conduct geotechnical investigation in their building construction practice, while 23.9% of the respondent seldom conduct geotechnical investigation in their practice.

Table 4.7: Frequency of geotechnical investigation Practice in building construction

Frequency of practice	Frequency	Percent
Never	10	4.2
Sometimes	47	19.7
Often	83	34.7
Very often	70	29.3
Always	29	12.1
Total	239	100.0

4.2.3 Designated group or personnel responsible for geotechnical investigation

The respondents were asked if there is a designated group or personnel responsible for overseeing the issues of geotechnical investigation in their organization. Results presented in Table 4.8 showed that 51.5% of the respondents actually do, while 8.8% do not designate this responsibility. However, further interview with respondents revealed that some of the organizations (e.g contracting firms and client organizations) out-source or sub-contract geotechnical investigation to specialized firms for efficiency. This is contrary to results presented by Wood and Ashton (2007) where 100% of respondents stated that they always conduct site investigation for new projects.

Table 4.8: Frequency of designated group or personnel responsible for geotechnical investigation

Frequency of designated group	Frequency	Percent
No	21	8.8
Sometimes	95	39.7
Yes	123	51.5
Total	239	100.0

4.2.4 Sampling technique and methods of soil observation in building construction

The results presented below Figure 4.1 and Figure 4.2 showed the frequency distribution of respondents' responses to the question asked regarding methods of sampling and sample observation adopted. Although there are numerous sampling techniques, this study restricted methods of sample collection to three (3). Findings showed that 49.8% of the respondents adopted the hand augers method of sampling, 33% use the excavation method, and 17% use borehole drilling method of sample collection. In addition, 53.56% of the respondents conduct both the laboratory testing and in-situ testing while 25.1% and 21.3% conduct only laboratory testing and in-situ testing respectively. Both methods are most times used together depending on the parameter being tested. This explains the high percentage of 53.56% for 'Both' category while the value of 21.3% for in-situ testing indicates the absence of required in-situ testing equipment.

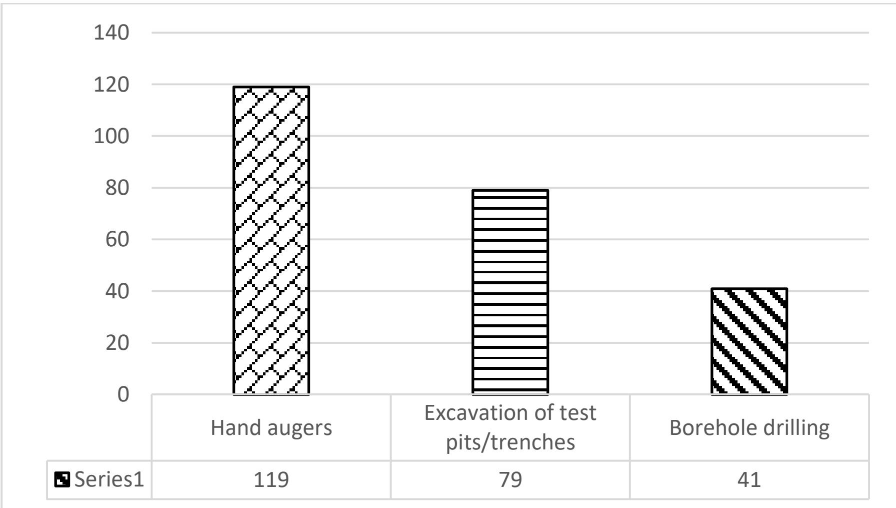


Figure 4.1: Descriptive Statistics for methods of sampling techniques in building construction

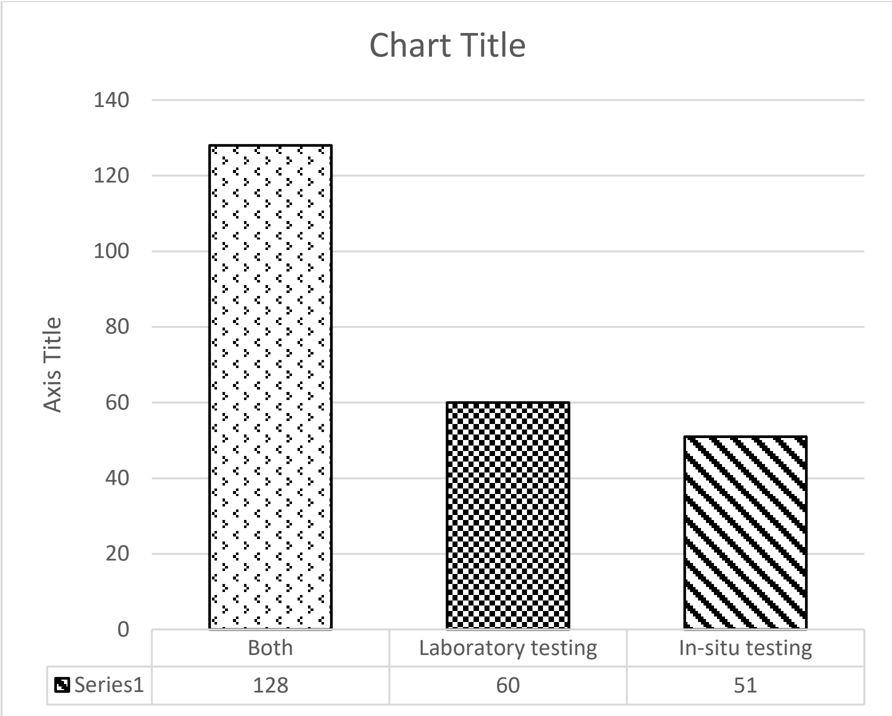


Figure 4.2: Descriptive Statistics for methods of observing the soil in building construction

4.2.5 Adherence to the results acquired from geotechnical investigation in the design and construction of building projects

Frequency distribution of adherence to results from geotechnical investigation as presented in Table 4.9 showed that majority of the respondents often adhere to the results while only a little proportion (4.6%) sometimes adhere. This is contrary to results presented by Wood and Ashton (2007) where 100% of respondents stated that they always adhere to information from site investigation.

Table 4.9: Frequency of adherence to the results acquired from geotechnical investigation in the design and construction of building projects

Frequency of adherence	Frequency	Percent
Sometimes	11	4.6
Often	67	28.0
Very often	31	13.0
Always	130	54.4
Total	239	100.0

4.2.6 Examining the difference in awareness level among clients, contractors, and consultants about geotechnical investigation practices in building projects.

The study adopted Kruskal-Wallis Test as an alternative to ANOVA test because the data set was not normally distributed. Details of this test was presented in chapter 3. Hence, the author tested the following hypotheses

$H0_1$ There is no significant difference across categories of organization type on geotechnical investigation Practice in building construction

$H0_2$ There is no significant difference across categories of organization type regarding designated group or personnel responsible for geotechnical investigation

$H0_3$ There is no significant difference across categories of organization type regarding adherence to the results acquired from geotechnical investigation in the design and construction of building projects

$H0_4$ There is no significant difference across categories of organization type regarding sampling techniques

$H0_5$ There is no significant difference across categories of organization type regarding method of soil observation

The summaries of Kruskal-Wallis H Test for hypotheses one, two, and three are presented in Table 4.10. Results showed that $H0_1$ was rejected and Ha_1 was accepted, that 'there is a significant difference across categories of organization type on geotechnical investigation practice in building construction'. $H0_2$ and $H0_3$ were also rejected as they both had significant values less than .05; thus, the study retained the alternate hypotheses Ha_1, Ha_2 and Ha_3 respectively. Additional statistical charts are presented under the Appendix B section.

Table 4.10: Hypothesis 1 – 3 testing summary (using the Independent-Samples Kruskal-Wallis H Test)

Null Hypothesis	Sig.	Decision
The distribution of 'geotechnical investigation practice in building construction' is not statistically different across categories organization type.	.000	Reject the null hypothesis.
The distribution of 'designated group or personnel responsible for geotechnical investigation' is not statistically different across categories of organization type.	.000	Reject the null hypothesis.
The distribution of 'adherence to the results acquired from geotechnical investigation in the design and construction of building projects' is not statistically different across categories of organization type.	.000	Reject the null hypothesis.

Table 4.11 presents a summary of the Kruskal-Wallis H Test for sampling technique and methods of soil observation. With a significant values .256 and .263 which are greater than 0.05, the researcher retained the null hypotheses 4 and 5 respectively. Additional charts on this hypothesis are presented under the Appendix B section.

Table 4.11: Hypothesis 4 and 5 testing summary (using the Independent-Samples Kruskal-Wallis H Test)

Null Hypothesis	Sig.	Decision
The distribution of 'Sampling technique' is not statistically different across categories of organization type.	.256	Retain the null hypothesis.
The distribution of 'Method of soil observation' is not statistically different across categories of organization type.	.263	Retain the null hypothesis.

4.2.7 Geotechnical investigation standard code of practice in use

Findings in Table 4.12 showed that majority of the respondents adopt the American Association of State Highways and Transportation (AASHTO), Unified soil classification system (USCS), and American Society for Testing and Materials (ASTM) with mean values of 3.92, 3.65, and 3.55 respectively. In addition, West Africa Standard (WAS), and Adaptive Network Fuzzy Inference System - Site Investigation Model (ANFIS-SI) ranked lowest with mean values 2.10 and 1.66 respectively. This implies that majority of the respondents are more familiar to some standard code of practice than others.

Table 4.12: Descriptive Statistics of geotechnical investigation standard code of practice in use

Code	Mean	Std. Deviation	Rank
American Association of State Highways and Transportation (AASHTO)	3.92	.965	1
Unified soil classification system (USCS)	3.65	1.178	2
American Society for Testing and Materials (ASTM)	3.55	1.211	3
British Standard (BS)	2.58	1.676	4
West Africa Standard (WAS)	2.10	1.661	5
Adaptive Network Fuzzy Inference System - Site Investigation Model (ANFIS-SI)	1.66	1.141	6

4.2.8 Subsurface geotechnical investigation in building projects

This sub-section seeks to investigate what subsurface geotechnical investigation are mostly carried out in building projects. Results in Table 4.13 revealed that Cone penetration test (CPT), Plasticity index, Liquid limit, Optimum moisture content (OMC) and maximum dry density (MDD), Specific gravity with mean values 4.55, 4.41, 4.34, 4.20, and 4.15, ranked 1st, 2nd, 3rd, 4th, and 5th respectively. Linear shrinkage, and Consolidation test ranked lowest with mean values 3.85 and 3.82 respectively.

Table 4.13: Descriptive Statistics of subsurface geotechnical investigation in building construction

Parameters	(1)	(2)	(3)	(4)	(5)	Mean	Std. Dev.	Rank
Cone penetration test (CPT)	10	11	44	62	112	4.55	.919	1
Plasticity index	10	11	12	45	161	4.41	1.060	2
Liquid limit	10	11	10	65	143	4.34	1.044	3
Optimum moisture content (OMC) and maximum dry density (MDD)	10	11	23	73	122	4.20	1.065	4
Specific gravity	21	11	14	57	136	4.15	1.259	5
Aggregate Impact Value (AIV)	12	11	45	39	132	4.12	1.169	6
Engineering classification	0	10	48	87	94	4.11	.868	7
Compaction (standard or modified proctor test)	10	11	44	62	112	4.07	1.102	8
Atterberg Limit	21	0	23	104	91	4.02	1.128	9
Standard penetration test (SPT)	21	4	43	57	114	4.00	1.233	10
Aggregate Abrasion Value (AAV)	12	11	65	37	114	3.96	1.179	11
Linear shrinkage	21	24	37	45	112	3.85	1.342	12
Consolidation test	10	35	29	79	86	3.82	1.190	13

4.2.9 Causes of inadequate geotechnical investigation in building projects

Another major objective of this study was to identify the causes of inadequate geotechnical investigation in construction projects. Some of these causes were identified in literature, while others were identified through interactions with professionals. Thus, this subsection analyzed identified variables for building projects using respondent inputs. Table 4.14 showed that Client Awareness, Equipment, Sampling technique, and Financial Constraints were the major causes of inadequate geotechnical investigation in building projects according to respondents. In addition, Lack of geotechnical expertise and Lack of integration ranked lowest with mean values 3.46 and 3.42 respectively.

Table 4.14 also showed that all the identified variables are statistically significant with *p*-values ranging from 0.00 - 0.017; and has correlation coefficient 'r' ranging from -0.185 – 0.956. This result implies that majority of clients, especially for residential buildings have very low awareness about the importance of conducting geotechnical investigation. Equipment as a major causes of inadequate geotechnical investigation in building projects also implies that the lack of adequate equipment and machines significantly affect the adequacy of geotechnical investigation. Furthermore, there are certain unidentified challenges regarding sampling techniques adopted in building projects which justifies the high mean score of 4.38. Findings also showed that financial constraint with a mean value of 4.13 implies that there is usually no budget for geotechnical investigation or the allocated cost is insignificant.

Summarily, the trend of the presented result revealed that little or attention is given to geotechnical investigation in building projects, especially in residential projects.

Table 4.14: Causes of inadequate geotechnical investigation in building projects

Causes	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**Mean**	**Std. Dev.**	**Rank**	***p*-value**	**r**
Client Awareness	0	6	14	55	164	4.59	.710	1	.000	.494
Equipment	0	0	33	53	153	4.50	.727	2	.000	.902
Sampling technique	20	0	13	42	164	4.38	1.164	3	.000	.894
Financial constraint	0	36	38	25	140	4.13	1.156	4	.004	-.185
Supervision	20	2	26	102	89	4.00	1.128	5	.017	.115
Result presentation	20	0	46	117	56	3.79	1.068	6	.000	.295
Time constraint	0	10	88	94	47	3.74	.818	7	.003	.822
Lack of geotechnical expertise	20	30	58	92	39	3.46	1.222	8	.005	.874
Lack of integration	33	10	48	109	39	3.42	1.153	9	.000	.956

4.2.10 Multiple regression analysis

A regression analysis was conducted using the identified independent variables in **section 4.2.9**. The choice of the multiple regression model as well as assumptions to be met had been previously justified in Chapter 3. However, an initial analysis showed high multicollinearity among the independent variables. Hence, three independent variables were excluded from the final regression analysis. Those removed were Time constraint, Lack of geotechnical expertise, Lack of integration.

All six (6) independent variables have tolerance values ranging between 0.26 – 0. 69 as shown in Table 4.15; which is greater than 0.10. In addition, the variance inflection factor (VIF) values ranging between 1.04 and 3.81 was higher in the initial analysis are now less than 10 in the collinearity statistic tests. This indicates that the problem of multicollinearity between the independent variables has been resolved. The Durbin-Watson value in this analysis is 1.749, which is within the range of 1.5 - 2.5, indicates that there is no autocorrelation in the residual.

Table 4.15: Collinearity Statistics Test

Model	Collinearity Statistics	
	Tolerance	**VIF**
Client awareness	.697	1.436
Financial constraint	.959	1.043
Result presentation	.263	3.801
Supervision	.281	3.558
Sampling technique	.289	3.456
Equipment	.262	3.818

The equation model of the study is presented below:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon \qquad \text{(Eqn. 4.1)}$$

Where Y = Adequate Geotechnical Investigation,
B_0 = constant
$\beta_1 – \beta_6$ = regression coefficients
X_1 = Client Awareness,
X_2 = Financial Constraint,
X_3 = Result presentation,
X_4 = Supervision,
X_5 = Sampling technique,
X_6 = Equipment,
ε = stochastic disturbance error term

Table 4.16 show that all the 6 independent variables were entered in the regression model. The results of the multiple regression using statistical package for social sciences (SPSS) 23 are presented in Tables 4.17, 4.18, and 4.19. The result showed a multiple correlation (R = 0.947) of the six independent variables with the dependent variable as presented in Table 4.17. The adjusted R Square value of .894 indicates that 89.4% of the variance in the dependent variable was explained by the six independent variables.

Table 4.16: Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Equipment, Supervision, Financial constraint, Client Awareness, Sampling technique, Result presentation[b]	.	Enter

a. Dependent Variable: Y b. All requested variables entered.

Table 4.17: Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.947[a]	.897	.894	.301	1.749

b. Dependent Variable: Y

The ANOVA table below, showed that the findings are statistically significant with *p*-value less than 0.05. As such, all six independent variables are effective at explaining the dependent variable.

Table 4.18: ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	182.620	6	30.437	336.065	.000[b]
	Residual	21.012	232	.091		
	Total	203.632	238			

a. Dependent Variable: Y

b. Predictors: (Constant), Equipment, Supervision, Financial constraint, Client Awareness, Sampling technique, Result presentation

4.2.10.1 Client awareness (*X1*)

Client Awareness has a statistically significant value of .008 (p-value < .05), hence this independent variable has a statistically significant impact on the dependent variable. In addition, the value of .089 unstandardized coefficient indicates that for every unit change X_1 will cause a 0.089 change in the dependent variable. Hence, an increase in the level of client awareness will lead to an increase in the adequacy of geotechnical investigation in building projects. In terms of the standardized coefficients, for every one standard deviation of movement in client awareness, the dependent variable increases by .068 standard deviations.

4.2.10.2 Financial constraint (*X2*)

A statistically significant value of .027 (p-value < .05) means that this independent variable has a statistically significant impact on the dependent variable. Unstandardized coefficient value of -.038 for this variable implies that a unit increase in X_2 will cause a decrease of about -.038 in the dependent variable. Hence, increase in financial constraint will decrease the adequacy of geotechnical investigation in building projects. In terms of the standardized coefficients, for every one standard deviation of movement in financial constraint, the dependent variable decreases by -.048 standard deviations.

4.2.10.3 Result presentation (*X3*)

The *p*-value for r***esult presentation*** is not statistically significant value at .721 (*p*-value > .05). This implies that this independent variable has no statistically significant impact on the dependent variable. Unstandardized coefficient value of .013 for this variable implies that a unit increase in X_3 will cause an increase of about .013 in the dependent variable. Hence, increase in clarity of result presentation will increase the adequacy of geotechnical investigation in building projects. In terms of the standardized coefficients, for every one standard deviation of movement in result presentation, the dependent variable increases by .015 standard deviations.

4.2.10.4 Supervision (*X4*)

Just like ***Result presentation***, this independent variable is not statistically significant at .743 (*p*-value > .05). This indicates that that ***Supervision*** has no statistically significant impact on the dependent variable. Unstandardized coefficient value of .011 for this variable implies that a unit increase in X_4 will cause an increase of about .011 in the dependent variable. Hence, increase in supervision will increase the adequacy of geotechnical investigation in building projects. In terms of the standardized coefficients, for every one standard deviation of movement in supervision, the dependent variable increases by .011 standard deviations.

4.2.10.5 Sampling technique (X5)

Sampling technique has a statistically significant value of .000 (p-value < .05), hence this independent variable has a statistically significant impact on the dependent variable. Unstandardized coefficient value of .387 for this variable implies that a unit increase in X_5 will cause an increase of about .387 in the dependent variable. Hence, increase in the quality of sampling technique will increase the adequacy of geotechnical investigation in building projects. In terms of the standardized coefficients, for every one standard deviation of movement in sampling technique, the dependent variable increases by .487 standard deviations.

4.2.10.6 Equipment (*X6*)

Equipment is statistically significant (p-value < .05), hence this independent variable has a statistically significant impact on the dependent variable. Unstandardized coefficient value of .582 for this variable implies that a unit increase in X_6 will cause an increase of .582 in the dependent variable. Hence, increase in equipment will increase the adequacy of geotechnical investigation in building projects. In respect to the standardized coefficients, for every one standard deviation of movement in supervision, the dependent variable increases by .457 standard deviations.

Table 4.19: Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-.250	.181		-1.379	.169
	Client Awareness	.089	.033	.068	2.695	.008
	Financial constraint	-.038	.017	-.048	-2.222	.027
	Error in result presentation	.013	.036	.015	.358	.721
	Supervision	.011	.033	.013	.329	.743
	Sampling	.387	.031	.487	12.430	.000
	Equipment	.582	.052	.457	11.094	.000

[a]. Dependent Variable: Y

To increase the desirability of the regression model, independent variables with *p*-values greater than .05 will not be included in the equation, because they have little or no impact on the dependent variable. In this case, X_3 and X_4 were excluded from the regression model. Thus, based on findings presented in Table 4.18, the regression equation is as follows:

$$Y = -.250 + .089X_1 - .038X_2 + .387X_5 + .582X_6 \quad \text{(Eqn. 4.2)}$$

Where Y = Adequate Geotechnical Investigation,
X_1 = Client Awareness,
X_2 = Financial Constraint,
X_5 = Sampling technique,
X_6 = Equipment

4.2.11 The impact of inadequate geotechnical investigation on building projects

4.2.11.1 The Impact on project cost

Descriptive statistics in Figures 4.3 and 4.4 presents the cost and schedule implications of geotechnical investigation related changes in building projects. Findings showed a significant impact on building cost. About 5% of the respondents was of the opinion that even with geotechnical related changes, the project will still remain on budget. A larger proportion of the respondents (58%) opined that the impact of geotechnical related changes on building projects amount to cost overrun ranging between 5% - 15%, while 24% of the respondents supported that the cost overrun is not usually more than 5%, and 13% agreed that cost overrun is over 25% of the project cost.

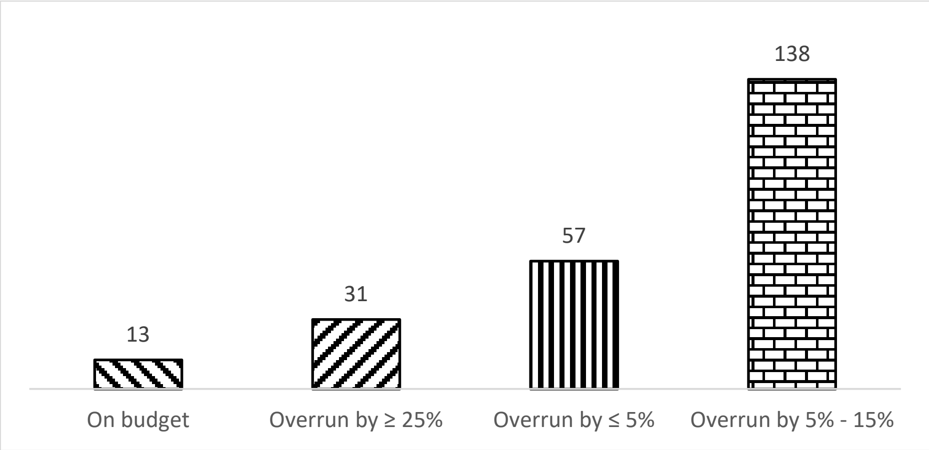


Figure 4.3: Cost implication of geotechnical investigation changes on building projects

4.2.11.2 The Impact on project schedule

Findings in Figure 4.4 shows that geotechnical related changes adversely impact on schedule of building projects. 67% of the respondents agreed that geotechnical related changes caused schedule overrun ranging between 5% - 25%. Another 13% of the respondent was of the opinion that geotechnical related changes amount to a schedule overrun greater than 25%, as 14% of the respondents agreed that the overrun is less than 5%.

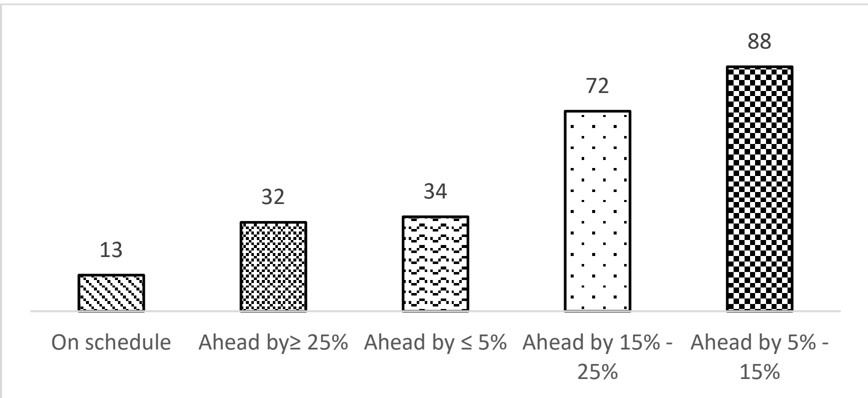


Figure 4.4: Schedule implication of geotechnical investigation changes on building projects

4.2.11.3 Impact on building project performance

Using a 5-points Likert scale of 'very low impact – very high impact', the findings presented in Table 4.20 below presents descriptive statistics of identified geotechnical related defects based on the opinion of respondents. Settlement ranked first with a mean score of 4.49, reduction in bearing capacity due to ground failures ranked second with mean score of 4.50, and cracks on structural elements (beam, slab, column) ranked third with mean score 4.48. Furthermore, kinematic forces acting on deep foundations due to shear deformation of soils and overturning moments imposed on the foundation from the superstructures ranked fourth with mean scores 4.46; collapsed foundations and tilting of buildings ranked sixth with mean score 4.41, while cracks on wall took the last position.

Table 4.20: Impact of geotechnical investigation related defects on building project performance

Defects	(1)	(2)	(3)	(4)	(5)	Mean	Std. Dev.	Rank	*p*-value	r
Settlement	0	20	13	13	193	4.59	.926	1	.000	.659
Reduction in bearing capacity due to ground failures	0	0	33	53	153	4.50	.727	2	.000	.708
Cracks on structural elements (beam, slab, column)	0	0	33	59	147	4.48	.727	3	.000	.403
Kinematic forces acting on deep foundations due to shear deformation of soils	0	20	13	42	164	4.46	.929	4	.000	.735
Overturning moments imposed on the foundation from the superstructures	0	20	13	43	163	4.46	.929	4	.000	.767
Collapsed foundations	0	20	13	54	152	4.41	.926	6	.000	.741
Tilting of buildings	0	20	13	56	150	4.41	.925	6	.000	.839
Collapsing soils/liquefaction	20	0	13	42	164	4.38	1.164	8	.000	.599
Cracks on wall	0	36	36	13	154	4.19	1.169	9	.000	-.079

4.2.12 Correlation analysis

Correlation analysis as previously described in chapter 3, is used to determine the relationship between an independent variable(s) and a dependent variable. Thus, this section addresses the set research hypotheses of this study. An initial normality test was conducted to determine the correlation analysis technique to adopt, and the result showed that the data set was not normally distributed. Hence, the Spearman Ranked Order correlation technique was used for analysis using SPSS 23. Table 4.21 presents a hypothesis testing summary for three hypotheses.

Table 4.21: Hypothesis 1 – 3 testing summary (using the Spearman Correlation Test)

S/No	Null Hypothesis	Decision
1	There exist no significant relationship between geotechnical investigation related defects and cost overrun in building projects	Reject the null hypothesis.
2	There exist no significant relationship between geotechnical investigation related defects and time overrun in building projects	Reject the null hypothesis.
3	There is no significant relationship between geotechnical investigation related defects and building construction projects' performance	Reject the null hypothesis.

4.2.12.1 Cost overrun

Table 1 under the Appendix C section showed multiple variable Spearman Ranked Order correlation matrix of earlier identified geotechnical related defects (**4.2.11.3**) in building projects as independent variables, and 'Building Project Cost Overrun' as dependent variable. Findings showed that all the variables are statistically significant to the dependent variable. In addition, there exist a very strong positive relationship between V_1-V_6, V_8, V_9 and building Project cost overrun. This indicates that an increase in any of these variables will increase the project cost. Therefore, the null hypothesis will be rejected, and accept the alternate hypothesis that there exists a significant relationship between geotechnical investigation related defects and cost overrun in building projects.

4.2.12.2 Schedule overrun

Variables identified in section **4.2.11.3** was also used to test the correlation between inadequate geotechnical investigation and building project schedule overrun. Table 2 under the Appendix C section showed multiple variable Spearman Ranked Order correlation matrix using geotechnical related defects in building projects as independent variables, and 'Building Project Schedule Overrun' as dependent variable. Findings showed that all the variables are statistically significant to the dependent variable except variable 7 (cracks on wall). In addition, there exist a very strong positive relationship between all variables and building project schedule overrun, except for V_7 with correlation coefficient of -.0.66. This indicates that an increase in any of these variables will increase the project completion time. Therefore, the null hypothesis will be rejected, and accept the alternate hypothesis that there exists a significant relationship between geotechnical investigation related defects and schedule overrun in building projects.

4.2.12.3 Project performance

The correlation analysis to test the relationship between inadequate geotechnical investigation and building project performance followed a similar approach adopted in sections **4.2.12.1 and 4.2.12.2**. Table 3 under the Appendix C section showed multiple variable Spearman Ranked Order correlation analysis using geotechnical related defects in building projects as independent variables, and 'Building Project Performance' as dependent variable. Findings showed that all the variables are statistically significant. In addition, there exist a very strong positive relationship between all variables and building project performance, except for V_7 with correlation coefficient of -.157. This indicates that an increase in any of these variables will increase the project completion time. Therefore, the null hypothesis will be rejected, and accept the alternate hypothesis that there exists a significant relationship between geotechnical investigation related defects and performance of building projects.

4.3 Results and Discussions Regarding Road Construction

4.3.1 Descriptive statistics on geotechnical investigation issues in road projects.

The respondents were asked a total of twelve (12) key questions regarding the issue of geotechnical investigation in road projects. These questions sought to explore the practice level geotechnical investigation in road projects, the use of geotechnical design standards, methods of subsurface investigation/parameters tested, causes of inadequate geotechnical investigation, impact of geotechnical investigation related issues on project cost, schedule and performance.

4.3.2 Frequency of geotechnical investigation practice in road construction

Respondents were asked how often they carry out geotechnical investigation in their practice of road construction. Results presented in Table 4.22 showed that 95.9% of the respondents usually conduct geotechnical investigation in their road construction practice, while 12.3% of the respondent seldom conduct geotechnical investigation in their practice.

Table 4.22: Frequency of geotechnical investigation Practice in road construction

Frequency of practice	Frequency	Percent
Never	10	4.2
Often	20	8.4
Very often	74	31.0
Always	135	56.5
Total	239	100.0

4.3.3 Designated group or personnel responsible for geotechnical investigation

The respondents were asked if there is a designated group or personnel responsible for overseeing the issues of geotechnical investigation in their organization. Results presented in Table 4.23 showed that majority of the respondents (90%) assign the responsibility of geotechnical investigation, while only about 6% of the respondents do not. However, further interview with respondents revealed that some of the organizations (e.g contracting firms and client organizations) out-source or sub-contract geotechnical investigation to specialized firms for efficiency.

Table 4.23: Frequency of designated group or personnel responsible for geotechnical investigation

Frequency of designated group	Frequency	Percent
No	14	5.9
Sometimes	10	4.2
Yes	215	90.0
Total	239	100.0

4.3.4 Sampling technique and methods of soil observation in road construction

The results presented below in Figures 4.5 and Figure 4.6 showed the frequency distribution of respondents' responses to the question asked regarding methods of sampling and sample observation adopted in road construction. Findings showed that

71% of the respondents adopted the use of hand augers and borehole drilling sampling techniques, while 29% used the excavation method. In addition, 54% of the respondents conduct both the laboratory testing and in-situ testing as 19% each either used laboratory testing or in-situ testing only.

Figure 4.5: Descriptive Statistics for methods of sampling techniques in road construction

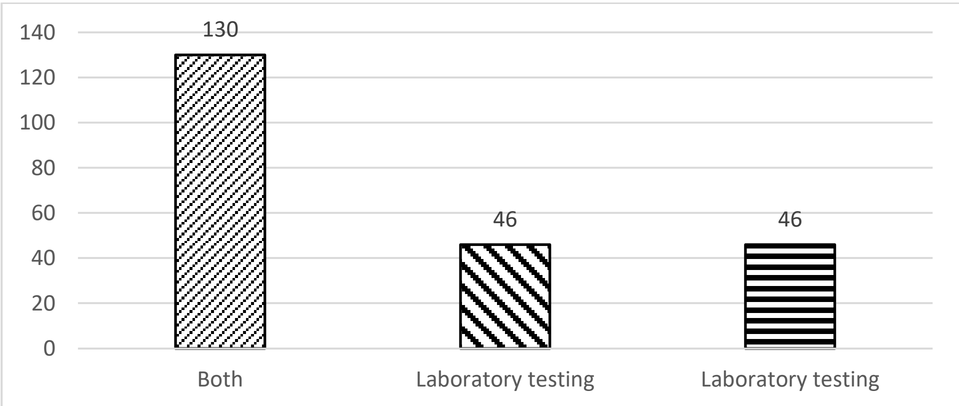


Figure 4.6: Descriptive Statistics for methods of soil observation in road construction

4.3.5 Adherence to the results acquired from geotechnical investigation in the design and construction of road projects

Frequency distribution of adherence to results from geotechnical investigation as presented in Table 4.24 showed that majority of the respondents (91.6%) often adhere to the results while only a little proportion (4.6%) sometimes adhere.

Table 4.24: Frequency of adherence to the results acquired from geotechnical investigation in the design and construction of road projects

Frequency of adherence	Frequency	Percent
Never	10	4.2
Very often	10	4.2
Always	219	91.6
Total	239	100.0

4.3.6 Examining the difference in awareness level among clients, contractors, and consultants about geotechnical investigation practices in road projects.

As presented in section 4.2.6, the study adopted Kruskal-Wallis H Test to test the following hypotheses:

$H0_1$ There is no significant difference across categories of organization type on geotechnical investigation practice in road construction

$H0_2$ There is no significant difference across categories of organization type regarding designated group or personnel responsible for geotechnical investigation

$H0_3$ There is no significant difference across categories of organization type regarding adherence to the results acquired from geotechnical investigation in the design and construction of road projects

$H0_4$ There is no significant difference across categories of organization type regarding sampling techniques

$H0_5$ There is no significant difference across categories of organization type regarding method of soil observation

The summaries of Kruskal-Wallis H Test for hypotheses one, two, and three were presented in Table 4.25. The analysis rejected all the three null hypotheses thus, the study retained the alternate hypotheses Ha_1, Ha_2, and Ha_3 respectively. Addition charts are presented under the Appendix D section.

Table 4.25: Hypothesis 1 – 3 testing summary (using the Independent-Samples Kruskal-Wallis H Test)

S/No	Null Hypothesis	Sig.	Decision
1	The distribution of 'geotechnical investigation practice in road construction' is not statistically different across categories organization type.	.000	Reject the null hypothesis.
2	The distribution of 'designated group or personnel responsible for geotechnical investigation' is not statistically different across categories of organization type.	.000	Reject the null hypothesis.
3	The distribution of 'adherence to the results acquired from geotechnical investigation in the design and construction of road projects' is not statistically different across categories of organization type.	.000	Reject the null hypothesis.

Table 4.26 presents a summary of the Kruskal-Wallis H Test for sampling technique and methods of soil observation. With significant values less than 0.05 (sampling technique = 0.046), the researcher reject the null hypothesis and accepts the alternate hypothesis $H_1 4$. However, null hypothesis 5 was retained as it had significant value above .05. Additional statistical charts on these hypotheses are presented under the Appendix D section.

Table 4.26: Hypothesis 4 and 5 testing summary (using the Independent-Samples Kruskal-Wallis H Test)

S/No	Null Hypothesis	Sig.	Decision
4	The distribution of 'Sampling technique' is not statistically different across categories of organization type.	.046	Reject the null hypothesis.
5	The distribution of 'Methods of soil observation' is not statistically different across categories of organization type.	.627	Retain the null hypothesis.

4.3.7 Geotechnical investigation standard code of practice in use

Findings in Table 4.27 showed that majority of the respondents adopt the American Association of State Highways and Transportation (AASHTO), Unified soil classification system (USCS), and American Society for Testing and Materials (ASTM) with mean values of 4.83, 4.54, and 4.02 respectively. In addition, West Africa Standard

(WAS), and Adaptive Network Fuzzy Inference System - Site Investigation Model (ANFIS-SI) ranked lowest with mean values 2.15 and 1.97 respectively.

Table 4.27: Descriptive Statistics of geotechnical investigation standard code of practice in use

Standard code of practice	Mean	Std. Deviation	Rank
American Association of State Highways and Transportation (AASHTO)	4.83	.803	1
American Society for Testing and Materials (ASTM)	4.54	1.122	2
Unified soil classification system (USCS)	4.02	1.512	3
British Standard (BS)	3.44	1.706	4
West Africa Standard (WAS)	2.15	1.582	5
Adaptive Network Fuzzy Inference System – Site Investigation Model (ANFIS-SI)	1.97	1.432	6

4.3.8 Subsurface geotechnical investigation in road projects

This sub-section seeks to investigate the subsurface geotechnical investigation mostly prevalent in building projects. Results in Table 4.28 revealed that Compaction (standard or modified proctor test), Optimum moisture content (OMC) and maximum dry density (MDD), Plasticity index, Liquid limit, and Aggregate Impact Value (AIV) and Standard penetration test (SPT) ranked top 3.

Table 4.28: Descriptive Statistics of subsurface geotechnical investigation in road construction

Parameters	(1)	(2)	(3)	(4)	(5)	Mean	Std. Dev.	Rank
Compaction (standard or modified proctor test)	10	0	0	31	198	4.70	.845	1
Optimum moisture content (OMC) and maximum dry density (MDD)	10	0	0	41	188	4.66	.854	2
Plasticity index	10	0	0	41	188	4.66	.854	2
Liquid limit	10	0	0	41	188	4.66	.854	2
Aggregate Impact Value (AIV)	10	0	0	43	186	4.65	.855	3
Standard penetration test (SPT)	10	0	0	44	185	4.65	.856	3
Consolidation test	10	0	0	51	178	4.62	.861	4
Aggregate Abrasion Value (AAV)	10	0	0	54	175	4.61	.862	5
Specific gravity	10	0	30	11	188	4.54	1.003	6
Linear shrinkage	10	0	10	54	165	4.52	.916	7
Atterberg Limit	10	0	10	67	152	4.47	.916	8
Engineering classification	10	0	20	48	161	4.46	.960	9
Cone penetration test (CPT)	10	10	20	31	168	4.41	1.080	10

4.3.9 Causes of inadequate geotechnical investigation in road projects

Table 4.29 showed that Sampling, Equipment, Financial constraint, Lack of geotechnical expertise and Supervision were the major causes of inadequate geotechnical investigation in road projects according to respondents. In addition, Client awareness and Lack of integration ranked lowest with mean values 3.48 and 3.21 respectively.

The Table 4.17 also showed that all the identified variables are statistically significant with *p*-values ranging from 0.00 - 0.013; and has correlation coefficient 'r' ranging from .160 – .471. This result implies that lapses in method of sampling impacts significantly on geotechnical investigation. Equipment as another major cause of inadequate geotechnical investigation in road projects implies that lack of adequate equipment and machines adversely affect the adequacy of geotechnical investigation. Findings also showed that financial constraint with a mean value of 3.86 implies that the budget for geotechnical investigation is usually not sufficient. Access to qualified and experienced geotechnics specialists was also a major factor according to findings, as well as lack of supervision.

Table 4.29: Causes of inadequate geotechnical investigation in road projects.

Causes	(1)	(2)	(3)	(4)	(5)	Mean	Std. Dev.	Rank	*p*-value	r
Sampling technique	14	12	24	47	142	4.22	1.175	1	.000	.226
Equipment	0	28	43	53	115	4.07	1.063	2	.003	.188
Financial constraint	1	50	42	35	111	3.86	1.225	3	.000	.270
Lack of geotechnical expertise	16	8	41	116	58	3.80	1.057	4	.004	.347
Supervision	16	21	35	90	77	3.80	1.178	4	.013	.160
Results Presentation	10	18	43	110	58	3.79	1.029	6	.000	.294
Client Awareness	4	88	21	42	84	3.48	1.340	7	.000	.331
Lack of integration	20	49	58	85	27	3.21	1.144	8	.001	.471
Time Constraint	23	43	74	67	32	3.18	1.164	9	0.00	.454

4.3.10 Multiple regression analysis

A regression model using 6 of the identified variables in **section 4.3.9** was developed to show their influence on the adequacy of geotechnical investigation (Y). The choice of the multiple regression model as well as assumptions to be met had been previously justified in Chapter 3. Just like the regression analysis in section **4.2.10**, 3 variables was also dropped to avoid multicollinearity.

All six (6) independent variables have tolerance values ranging between .737 – .970 as shown in Table 4.30 below; which is greater than 0.10. In addition, the variance inflection factor (VIF) values ranging between 1.031 and 1.357 was higher in the initial analysis are now less than 10 in the collinearity statistic tests. This indicates that the removal of 3 variables solved the problem of multicollinearity between the independent variables. The Durbin-Watson value in this analysis is 1.877, which falls within the range of 1.5 - 2.5, indicates that there is no autocorrelation in the residual.

Table 4.30: Collinearity Statistics Test

Model	**Collinearity Statistics**	
	Tolerance	**VIF**
Client awareness	.957	1.044
Financial constraint	.970	1.031
Result presentation	.737	1.357
Supervision	.744	1.343
Sampling technique	.823	1.215
Equipment	.844	1.185

Table 4.31 show that all the 6 independent variables were entered in the regression model. The results of the multiple regression using statistical package for social sciences (SPSS) 23 are presented in Tables 4.32, 4.33, 4.34. The result showed a multiple correlation (*R* = 0.748) of the six independent variables with the dependent variable as presented in Table 4.32. The adjusted *R* Square value of .548 indicates that 54.8% of the variance in the dependent variable was explained by the six independent variables.

Table 4.31: Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Equipment, Supervision, Financial constraint, Client Awareness, Sampling technique, Results Presentation[b]	.	Enter

a. Dependent Variable: Y

b. All requested variables entered.

Table 4.32: Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.748[a]	.559	.548	.62200	1.877

a. Predictors: (Constant), Equipment, Supervision, Financial constrain, Client Awareness, Sampling technique, Results Presentation

b. Dependent Variable: Y

The ANOVA table below, showed that the findings are statistically significant with *p*-value less than 0.05. As such, all six independent variables are effective at explaining the dependent variable.

Table 4.33: ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	113.874	6	18.979	49.055	.000[b]
	Residual	89.758	232	.387		
	Total	203.632	238			

a. Dependent Variable: Y

b. Predictors: (Constant), Equipment, Supervision, Financial constrain, Client Awareness, Sampling technique, Results Presentation

4.3.10.1 Client Awareness (*X1*)

Client Awareness is not statistically significant (.249 *p*-value > .05), hence this independent variable has no statistically significant impact on the dependent variable. In addition, the value of .036 unstandardized coefficient indicates that for every unit change X_1 will cause a .036 change in the dependent variable. Hence, an increase in the level of client awareness will lead to an increase in the adequacy of geotechnical investigation in road projects. In terms of the standardized coefficients, for every one standard deviation of movement in client awareness, the dependent variable increases by .052 standard deviations.

4.3.10.2 Financial constraint (*X2*)

A statistically significant value of .092 (p-value < .05) means that this independent variable has a statistically significant impact on the dependent variable. Unstandardized coefficient value of -.055 for this variable implies that a unit increase in X_2 will cause a decrease of about -.055 in the dependent variable. Hence, increase in financial constraint will decrease the adequacy of geotechnical investigation in road projects. In terms of the standardized coefficients, for every one standard deviation of movement in financial constraint, the dependent variable decreases by -.075 standard deviations.

4.3.10.3 Result presentation (X3)

The p-value for ***result presentation*** is statistically significant value at .011 (p-value > .05). This implies that this independent variable has statistically significant impact on the dependent variable. Unstandardized coefficient value of .106 for this variable implies that a unit increase in X_3 will cause an increase of about .106 in the dependent variable. Hence, increase in clarity of result presentation will increase the adequacy of geotechnical investigation in road projects. In terms of the standardized coefficients, for every one standard deviation of movement in result presentation, the dependent variable increases by .131 standard deviations.

4.3.10.4 Supervision (X4)

Just like in ***Client Awareness***, this independent variable is not statistically significant at .772 (p-value > .05). This indicates that that X_4 has no statistically significant impact on the dependent variable. Unstandardized coefficient value of -.011 for this variable implies that a unit increase in X_4 will cause an decrease of about -.011 in the dependent variable. Hence, lack of supervision will decrease the adequacy of geotechnical investigation in road projects. In terms of the standardized coefficients, for every one standard deviation of movement in supervision, the dependent variable increases by -.015 standard deviations.

4.3.10.5 Sampling technique (X5)

Sampling technique has a statistically significant value of .000 (p-value < .05), hence this independent variable has a statistically significant impact on the dependent variable. Unstandardized coefficient value of .486 for this variable implies that a unit increase in X_5 will cause an increase of about .486 in the dependent variable. Hence, increase in the quality of sampling technique will increase the adequacy of geotechnical investigation in road projects. In terms of the standardized coefficients, for every one standard deviation of movement in sampling technique, the dependent variable increases by .617 standard deviations.

4.3.10.6 Equipment (X6)

Equipment is statistically significant (.001 p-value < .05), hence this independent variable has a statistically significant impact on the dependent variable. Unstandardized coefficient value of .139 for this variable implies that a unit increase in X_6 will cause an increase of .139 in the dependent variable. Hence, increase in equipment will increase the adequacy of geotechnical investigation in road projects. In respect to the standardized coefficients, for every one standard deviation of movement in supervision, the dependent variable increases by .160 standard deviations.

Table 4.34: Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	**Std. Error**	**Beta**	**t**	**Sig.**
1	(Constant)	1.533	.297		5.167	.000
	Client Awareness	.036	.031	.052	1.156	.249
	Financial constraint	-.055	.033	-.075	-1.691	.092
	Results Presentation	.106	.041	.131	2.573	.011
	Supervision	-.011	.039	-.015	-.290	.772
	Sampling technique	.486	.038	.617	12.843	.000
	Equipment	.139	.041	.160	3.374	.001

a. Dependent Variable: Y

To increase the desirability of the regression model, independent variables with *p*-values greater than .05 will not be included in the equation, because they have little or no impact on the dependent variable. In this case, X_1 and X_4 were excluded from the regression model. Thus, based on findings presented in Table 4.34 above, the regression equation is as follows:

$$Y = 1.533 - .055X_2 + .106X_3 + .486X_5 + .139X_6 \quad \text{(Eqn. 4.3)}$$

Where Y = Adequate Geotechnical Investigation,
X_2 = Financial Constraint,
X_3 = Results Presentation
X_5 = Sampling technique,
X_6 = Equipment

4.3.11 The impact of inadequate geotechnical investigation on road projects.

4.3.11.1 The impact on project cost

Descriptive statistics in Figures 4.7 and 4.8 presents the cost and schedule implications of geotechnical investigation related changes in road projects. Findings showed a significant impact on road construction cost. About 90.38% of the respondents was of the opinion that even with geotechnical related changes amount to cost overrun ranging between 5% to over 25% of the project cost. Only a very small proportion of the respondents (9%) chose that cost overrun is usually less than or equal to 5%.

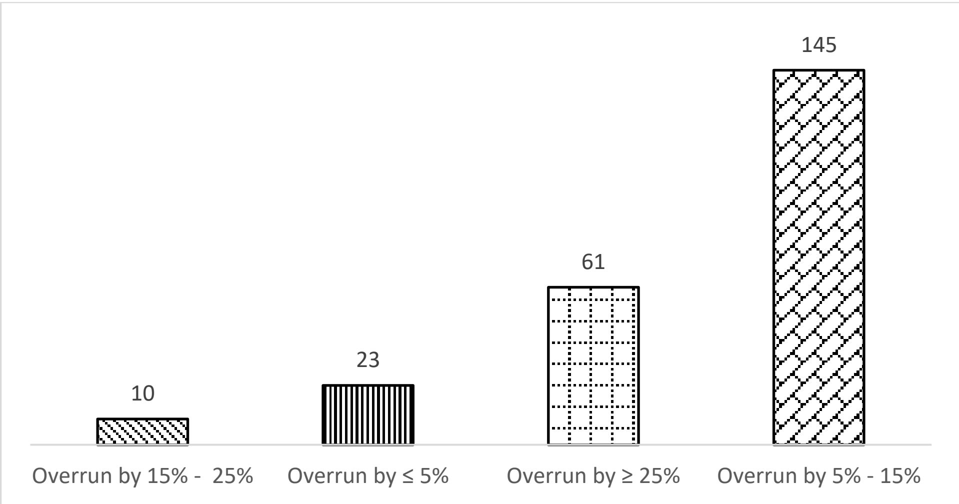


Figure 4.7: Cost implication of geotechnical investigation changes in road projects

4.3.11.2 The impact on project schedule

Findings in Figure 4.8 show that geotechnical related changes adversely impact on schedule of building projects. 38% of the respondents agreed that geotechnical related changes caused schedule overrun ranging between 5% - 15%. Another 30.5% of the respondent was of the opinion that geotechnical related changes amount to a schedule overrun greater than 25%, as 20% of the respondents agreed that geotechnical related changes do not impact on schedule or less that cause a little overrun which is less than 5%.

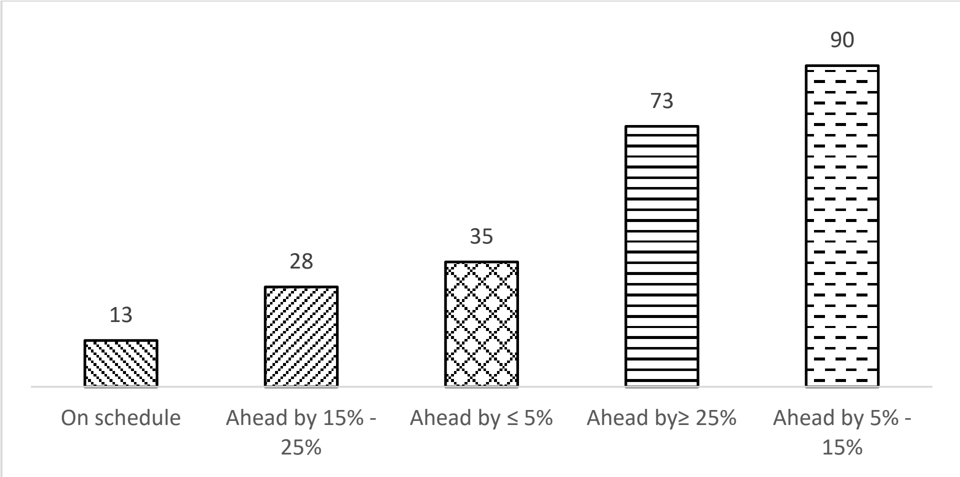


Figure 4.8: Schedule implication of geotechnical investigation changes in road projects

4.3.11.3 Impact of geotechnical related defects on road project performance

Using a 5-ponts Likert scale of 'very low impact – very high impact', the findings presented in Table 4.35 below include the descriptive statistics of identified geotechnical related defects in road projects based on the opinion of respondents. Premature pavement failure ranked first with a mean score of 4.87, potholes ranked second with mean score of 4.77, and collapsing soils/liquefaction ranked third with mean score 4.56. Furthermore, fatigue cracking and depressions ranked fourth and fifth with mean scores 4.45 and 4.41 respectively. Heave, rutting, and bumps ranked sixth, seventh, and eighth respectively, while roughness took the last position.

Table 4.35: Impact of geotechnical investigation related defects on road project performance

Defects	(1)	(2)	(3)	(4)	(5)	Mean	Std. Dev.	Rank	*p*-value	r
Premature pavement failure	0	0	2	28	209	4.87	.365	1	.078	.114
Potholes	0	0	0	54	185	4.77	.419	2	.000	.364
Collapsing soils/liquefaction	0	13	13	41	172	4.56	.828	3	.000	.455
Fatigue Cracking	0	4	23	74	138	4.45	.736	4	.000	.289
Depressions	0	0	44	54	141	4.41	.782	5	.000	.509
Heave	4	0	36	69	130	4.34	.855	6	.000	.424
Rutting	0	14	31	74	120	4.26	.897	7	.000	.371
Bumps	0	4	65	50	120	4.20	.898	8	.000	.386
Corrugation	0	10	53	56	120	4.20	.925	8	.000	.422
Roughness	0	20	54	52	113	4.08	1.016	10	.000	.337

4.3.12 Correlation analysis

Due to the peculiar nature of both projects (building and road projects), identified geotechnical related defects are quite different. Hence the motive behind running two different correlation analysis. The Spearman Ranked Order correlation technique was also used for analysis using SPSS 23 and Table 4.36 presents a hypothesis testing summary for three hypotheses.

Table 4.36: Hypothesis 1 – 3 testing summary (using the Pearson Moment Correlation Test)

S/No	Null Hypothesis	Decision
1	There exist no significant relationship between geotechnical investigation related defects and cost overrun in road projects	Reject the null hypothesis.
2	There exist no significant relationship between geotechnical investigation related defects and time overrun in road projects	Reject the null hypothesis.
3	There is no significant relationship between geotechnical investigation related defects and road construction projects'	Reject the null hypothesis.

performance

4.3.12.1 Cost overrun

Table 1 under the Appendix E section showed multiple variable Spearman Ranked Order correlation matrix of earlier identified geotechnical related defects (**4.3.11.3**) in road projects as independent variables, and 'Road Project Cost Overrun' as dependent variable. Findings showed that all the variables are statistically significant to the dependent variable. In addition, there exist a moderate positive relationship between the independent variables and road project cost overrun. This indicates that an increase in any of these variables will increase the project cost. Therefore, the null hypothesis will be rejected, and accept the alternate hypothesis that there exists a significant relationship between geotechnical investigation related defects and cost overrun in road projects.

4.3.12.2 Schedule overrun

Variables identified in section **4.3.11.3** was also used to test the correlation between inadequate geotechnical investigation and road project schedule overrun. Table 2 under the Appendix E section showed multiple variable Spearman Ranked Order correlation analysis using geotechnical related defects in road projects as independent variables, and 'Road Project Schedule Overrun' as dependent variable. Findings showed that all the variables are statistically significant to the dependent variable except V_1 and V_3 (premature pavement failure = .239; and potholes = .190). In addition, there exist a moderate positive relationship between all variables and the dependent variable. This indicates that an increase in any of these variables will increase the project completion time. Therefore, the null hypothesis will be rejected, and accept the alternate hypothesis that there exists a significant relationship between geotechnical investigation related defects and schedule overrun in road projects.

4.3.12.3 Project performance

The correlation analysis to test the relationship between inadequate geotechnical investigation and road project performance followed the similar approach adopted in sections **4.3.12.1 and 4.3.12.2**. Table 3 under the Appendix E section showed multiple variable Spearman Ranked Order correlation analysis using geotechnical related defects in road projects as independent variables, and 'Road Project Performance' as dependent variable. Findings showed that all the variables are statistically significant (except V_1 with .195). In addition, there exist a moderate positive relationship between all variables and road project performance. This indicates that an increase in any of these variables will improve project performance. Therefore, the null hypothesis will be rejected, and accept the alternate hypothesis that there exists a significant relationship between geotechnical investigation related defects and performance of road projects.

4.3.13 Strategies to mitigate the impact of inadequate geotechnical investigation on construction projects

Findings presented in Table 4.37 shows that adequate sample management, strict adherence to results from geotechnical investigations, and assignation of skilled personnel to conduct geotechnical investigation are the most prevalent strategies based on data collected.

Table 4.37: Strategies to Mitigate the Impact of Inadequate Geotechnical Investigation on Construction Projects

Strategies	(1)	(2)	(3)	(4)	(5)	Mean	Std. Dev.	Rank
Adequate sample management	0	0	0	15	224	4.94	.243	1
Strict adherence to results from geotechnical investigations	0	0	0	36	203	4.85	.358	2
Assign skilled personnel to conduct geotechnical investigation	0	0	18	10	211	4.81	.554	3
Provision of sufficient boring location	0	0	0	71	168	4.70	.458	4
Government policies to enforce detailed and standard practice of geotechnical investigation	0	0	18	43	178	4.67	.611	5
Efficient Presentation of investigation result	0	0	0	15	224	4.60	.848	6
Adequate sampling technique	0	13	0	59	167	4.59	.755	7

4.4 Summary of findings

The research instrument of this study involved the use of a structured questionnaire to acquire primary data from construction industry professionals regarding geotechnical investigation related issues in construction projects. A copy of the geotechnical investigation survey questionnaire is attached in Appendix A. This was designed in such a way that the four objectives of the study were addressed. This sections summarized and compared findings regarding geotechnical investigation practice, the causes of inadequate geotechnical investigation, and the impact of inadequate geotechnical investigation in the context of building and road projects.

4.4.1 Geotechnical investigation practices in the construction industry

Results presented in sections 4.2.2 and 4.3.2 showed that majority of the respondents conduct geotechnical investigation in construction projects (76.1% conduct in road projects as 95.9% conduct for road projects). This is an indication that geotechnical investigation practice is higher in road construction than in building construction. Results for designated group or personnel responsible for the conduct of geotechnical investigation revealed that; in road projects, there is usually a designated group or personnel responsible either through sub-contracting or out-sourcing. However, for building projects, only about 50% of the respondents agreed that responsibility of geotechnical investigation is assigned to a group personnel. The findings on the sampling technique adopted in building projects revealed that the use of hand augers and excavation was prevalent while borehole drilling and hand augers were common with road projects. Furthermore, over 50% of the respondents used both the laboratory and in-situ method of sample observation. As part of investigation on the geotechnical investigation in construction projects, the author measured the level of adherence to results acquired from this investigation. Findings showed that the level of adherence is lower in building projects (54.4%) and higher in road projects (91.6%).

In view of the above paragraph, the author addressed the first research objective of this study which was *'to examine the difference in awareness level among clients, contractors, and consultants about geotechnical investigation practices in construction projects'.* This was achieved through hypothesis using Kruskal-Wallis H Test which is an alternative to ANOVA (see sections 4.2.6 and 4.3.6 for hypotheses tested). Finding revealed that there exists a disparity in the perception level among the three groups in practice, designation of responsibility, and adherence to results of geotechnical investigation in both building and road projects. Consequently, findings also revealed that there exist no significant difference in sampling technique and methods of sample observation in building projects among the groups. For road projects, there is a difference in sampling technique adoption and none in methods of sample observation among the three groups. These results is an indication of a heterogeneous practice of geotechnical investigation among the contracting firms, consulting firms, and client organizations in Nigeria.

Geotechnical investigation cannot be practiced without following internationally approved standard code of practice. Hence, findings of this study revealed that the commonly used standard code of practice for both building and road projects were American Association of State Highways and Transportation (AASHTO), American Society for Testing and Materials (ASTM), Unified soil classification system (USCS), and the British Standard (BS). In addition, the commonly tested parameters in building projects were cone penetration test (CPT), plasticity index, liquid limit, optimum moisture content (OMC) and maximum dry density (MDD), and specific gravity; while for road projects were compaction (standard or modified proctor test), optimum moisture content (OMC) and maximum dry density (MDD), plasticity index, liquid limit, and aggregate Impact Value (AIV).

4.4.2 Causes of inadequate geotechnical investigation in road projects

The study was able to identify nine (9) causes of inadequate geotechnical investigation in construction projects. These variables were then ranked based on findings in the context of building and road projects. In the former, client awareness, equipment, sampling technique, financial constraint, supervision, down to lack of geotechnical expertise, and lack of integration was the ranking order. Conversely, the ranking of the variables was quite difference for road projects. Sampling technique, equipment, finance, lack of geotechnical expertise, supervision, down to client awareness, and lack of integration was the order of ranking.

Furthermore, a multiple regression model was formulated based on the findings above for both building and road projects. The essence of this model was to establish how these variables influence the adequacy of geotechnical investigation. Summarily, the final regression model for statistically significant variables on adequate geotechnical investigation in building project was "$Y = -.250 + .089X_1 - .038X_2 + .387X_5 + .582X_6$": While the final multiple regression model for statistically significant variables on adequate geotechnical investigation in road project was "$Y = 1.533 - .055X_2 + .106X_3 + .486X_5 + .139X_6$". The interpretations of these models as presented in sections 4.2.10 and 4.3.10 implies they could be used to improve the adequacy of geotechnical investigation in construction projects.

4.4.3 The impact of inadequate geotechnical investigation on construction projects.

The impact of inadequate geotechnical investigation was limited to cost, schedule, and performance of construction projects based on the scope of study. Results presented in sections 4.2.11.1 and 4.3.11.1 revealed that inadequate geotechnical investigation adversely impact on cost of construction projects. The cost implication due to geotechnical related issues in building and road projects ranged between 5% to as high as 25% of the project cost. Similarly, schedule of construction projects is also adversely affected due to inadequate geotechnical investigation. Findings showed that schedule overrun due to inadequate geotechnical investigation in building and road projects cause additional 5% to over 25% to the initial project schedule. To measure the impact of inadequate geotechnical investigation on construction project performance, this study identified geotechnical investigation related defects in both building and road projects. Findings in sections 4.2.11.3 showed that settlement, reduction in bearing capacity due to ground failures, cracks on structural elements (beam, slab, and column), and kinematic forces acting on deep foundations due to shear deformation of soils has the most adverse impact on the performance of building projects. In addition, findings in sections 4.2.11.3 revealed that premature pavement failure, potholes, collapsing soils/liquefaction, and fatigue cracking has the most adverse impact on the performance of road projects.

4.4.4 Correlation analysis

The Spearman Ranked Order correlation technique, a non-parametric test for data sets that failed the normality test was used for hypotheses testing. Findings revealed the existence of a positive relationship between the identified geotechnical related defects with project cost overrun, project schedule overrun, and project performance alike for building and road projects. This indicates the positive relationship between inadequate geotechnical investigation with project cost overrun, project schedule overrun, and project performance for building and road projects. A unit increase in the inadequacy of geotechnical investigation will lead to consequential increase in project cost overrun, project schedule overrun, and poor project performance.

4.4.5 Strategies to mitigate the impact of inadequate geotechnical investigation on construction projects.

To mitigate the problems related to inadequate geotechnical investigation in construction project, the fourth objective of this research seek to identify these strategies to reduce to impact of inadequate geotechnical investigation. The results earlier presented in Table 4.37, section 4.3.13 revealed that adequate sample management, strict adherence to results from geotechnical investigations, assigning skilled personnel to conduct geotechnical investigation, provision of sufficient boring location, and government intervention are the foremost strategies to mitigate the impact of inadequate geotechnical investigation on construction projects.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main aim of this research was to assess the impact of inadequate geotechnical investigation on construction projects' performance in Nigeria. This was realized using four (4) research objectives, with four (4) corresponding research questions, and three (3) research hypotheses. Discussion of findings of this research as presented in Chapter four formed basis for conclusion and recommendation. The following sections show how the aim and objectives of this research were achieved.

Objective 1: To examine the difference in awareness level among clients, contractors, and consultants about geotechnical investigation practices in construction projects

This objective was achieved through the background of study in Chapter one, and the detailed literature review on geotechnical investigation practice presented in Chapter two. In addition results presented in Chapter four (sections 4.2.1 – 4.2.6 and 4.3.1 – 4.3.6) using the Kruskal-Wallis H Test specifically addressed this objective. Additional results presented in Appendix B and D also addressed this objective. Hence, the study concludes that there exist a heterogeneous practice of geotechnical investigation for building and road projects among the contracting firms, consulting firms, and client organizations in Nigeria.

Objective 2: To identify the causes of inadequate geotechnical investigation on construction projects

This particular objective was satisfied through a detailed review of literature in Chapter two, as well as discussion of findings in Chapter four (sections 4.2.9 and 4.3.9). The study concludes that the major causes of inadequate geotechnical investigation in building and road projects are sampling technique, equipment, financial constraint, lack of geotechnical expertise, supervision, results presentation, and client awareness. In addition, the research also developed a regression model as presented in Chapter four (see sections 4.2.10 and 4.3.10) for adequate geotechnical investigation in construction projects. For building projects "$Y = -.250 + .089X_1 - .038X_2 + .387X_5 + .582X_6$"; while in road projects "$Y = 1.533 - .055X_2 + .106X_3 + .486X_5 + .139X_6$"

Objective 3: To assess the impact of inadequate geotechnical investigation on construction project performance

Objective three was satisfied through a detailed review of literature on the impact of inadequate geotechnical investigation on cost, schedule, and performance of construction projects in Chapter 2, as well as discussion of findings in Chapter four (sections 4.2.11 and 4.3.11). In addition, discussion of results in Chapter four (sections 4.2.11.1 - 4.2.11.3 and 4.3.11.1 - 4.3.11.3). Based on these findings, the study concludes that the impact of inadequate geotechnical investigation on cost, schedule, and performance alike are adversely affected through overruns and poor performance.

Objective 4: ***To identify strategies to mitigate the impact of inadequate geotechnical investigation on construction projects***

The forth research objective of this study was also satisfied through literature review in Chapter two and descriptive analysis in Chapter four (section 4.3.13). The research concludes that adequate sample management, strict adherence to results from geotechnical investigations, assign skilled personnel to conduct geotechnical investigation, provision of sufficient boring location, government policies to enforce detailed and standard practice of geotechnical investigation, efficient Presentation of investigation result, adequate sampling technique are strategies to mitigate the impact of inadequate geotechnical investigation on construction projects.

Null Hypothesis 1: ***There exist no significant relationship between geotechnical investigation related defects and project cost overrun.***

The research hypotheses was tested using the Spearman Ranked Order correlation. Analysis and discussion of findings in Chapter four (section 4.2.12.1 and 4.3.12.1) and Appendix C and E addressed this hypothesis. The study rejected this null hypothesis and retained the alternate hypothesis that "there exists a significant relationship between geotechnical investigation related defects and project cost overrun"

Null Hypothesis 2: ***There exist no significant relationship between geotechnical investigation related defects and project schedule overrun.***

This hypothesis was achieved through analysis and discussion of findings in Chapter four (section 4.2.12.2 and 4.3.12.2) and Appendix C and E addressed this hypothesis. The study rejected this null hypothesis and retained the alternate hypothesis that "there exists a significant relationship between geotechnical investigation related defects and project schedule overrun”

Null Hypothesis 3: ***There is no significant relationship between geotechnical investigation related defects and project performance***

This hypothesis was achieved through analysis and discussion of findings in Chapter four (section 4.2.12.2 and 4.3.12.2) and Appendix C and E addressed this hypothesis. The study rejected this null hypothesis and retained the alternate hypothesis that “there exists a significant relationship between geotechnical investigation related defects and project performance”

5.2 Recommendations

The study adopted the findings in objective four as recommendations of this research to improve the practice of geotechnical investigation in construction projects.

1. Adequate sample management
2. Strict adherence to results from geotechnical investigations
3. Assign skilled personnel to conduct geotechnical investigation
4. Provision of sufficient boring location
5. Government policies to enforce detailed and standard practice of geotechnical investigation
6. Efficient presentation of investigation result
7. Adequate sampling technique
8. Provide an adequate budget plan to explore subsurface conditions.

9. Retain qualified and experienced design consultants to investigate, and evaluate potential risks.
10. Allocation of sufficient time and financial resources

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APPENDIX A: Sample of research instrument

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STAE

DEPARTMENT OF PROJECT MANAGEMENT TECHNOLOGY

SCHOOL OF ENTREPRENEURESHIP AND MANAGEMENT TECHNOLOGY (SEMT)

Sir/Ma,

REQUEST FOR PARTICIPATION IN RESEARCH SURVEY

I am carrying out a research on "**Analysis of the Causes and Impact of Inadequate Geotechnical Investigation on Construction Projects' Performance in Nigeria"**.

To achieve this aim and objectives of this research, I am conducting a survey of construction industry practitioners (contracting and consulting firms), and client organizations and would like you to complete the attached questionnaire.

Please, kindly help me provide answers to questions and note that your cooperation and contribution to this questionnaire is important for the success of this research.

Your privacy will be kept in the strictest confidence and use for statistical purposes only.

Thank you for your co-operation.

Yours sincerely,

Yusuf, Saheed Olanrewaju

SECTION 1: Bio-Data form

<u>Instruction:</u> Please mark **(√)** in the appropriate column/box as it applies to you

1	Gender	Male	
		Female	
2	Academic Qualification	National Diploma (ND/)	
		Bachelor's Degree	
		Master's Degree	
		PhD	
3	State	Niger state	
		Kwara state	
		Kogi state	
		FCT	
3	Profession	Civil Engineer	
		Geotechnical Engineer	
		Engineering Geologist	
		Project Manager	
		Builder	
		Architect	
		Quantity Surveyor	
		Surveying and Geo-informatics	
4	Type of Organization	Client Organization	
		Contracting Firm	
		Consulting Firm	
5	Years of Experience in Building Construction	1 – 5	
		5 – 10	
		10 – 15	
		15 – Above	
6	Years of Experience in Road Construction	1 – 5	
		5 – 10	
		10 – 15	
		15 – Above	

SECTION 2: BUILDING PROJECTS

Instruction: Please enter (√) in the appropriate column/box as it applies to you

1. How often do you carry out geotechnical investigation in your building construction practice?

	Always	**Very Often**	**Often**	**Sometimes**	**Never**
Geotechnical investigation in building construction					

2. In your organization, is there a designated group or personnel responsible for geotechnical investigation?

	No	**Sometimes**	**Yes**
Responsibility of geotechnical investigation			

3. How often do you use the following sampling technique for geotechnical investigation in building construction?
    1. Borehole drilling ( )
    2. Excavation of test pits/trenches ( )
    3. Hand augers ( )

4. How often do you use the following methods of soil observation samples for geotechnical investigation in building construction?
    1. Material sampling and laboratory testing ( )
    2. In-situ testing ( )
    3. Both ( )

5. Do you adhere to the results acquired from geotechnical investigation in the design and construction of building projects?

	Always	**Very Often**	**Often**	**Sometimes**	**Never**
Adherence to Geotechnical Investigation result					

6. How often do you use the following geotechnical investigation standard code of practice?

S/No	**Standard practice code**	**Always**	**Very Often**	**Often**	**Sometimes**	**Never**
1	American Association of State Highways and Transportation (AASHTO)					
2	Unified soil classification system (USCS)					
3	American Society for Testing and Materials (ASTM)					
4	British Standard (BS)					
5	West Africa Standard (WAS)					
6	Adaptive Network Fuzzy Inference System – Site Investigation Model (ANFIS-SI)					

7. How often do you carry out the following subsurface geotechnical investigation in building construction?

S/No	**Standard geotechnical tests**	**Always**	**Very Often**	**Often**	**Sometimes**	**Never**
1	Engineering classification					
2	Specific gravity					
3	Optimum moisture content (OMC) and maximum dry density (MDD)					
4	Linear shrinkage					
5	Compaction (standard or modified proctor test)					
6	Atterberg Limit					
7	Standard penetration test (SPT)					
8	Cone penetration test (CPT)					

9	Aggregate Impact Value (AIV)					
10	Aggregate Abrasion Value (AAV)					
11	Consolidation test					
12	Liquid limit					
13	Plasticity index					

8. Rate the following causes of inadequate geotechnical investigation in building construction

S/No	**Causes of inadequate geotechnical investigation**	**Strongly Agree**	**Agree**	**Undecided**	**Strongly Disagree**	**Disagree**
1	Client Awareness					
2	Equipment					
3	Sampling technique					
4	Financial constraint					
5	Supervision					
6	Result presentation					
7	Time constraint					
8	Lack of geotechnical expertise					
9	Lack of integration					

9. Rate the effect of the following variables on the effectiveness of geotechnical investigation

		Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Y	There is a significant impact of identified variables on geotechnical investigation					
X1	Client awareness has an effect on geotechnical investigation					
X2	Finance has an effect on geotechnical investigation					
X3	Time constraint has an effect on geotechnical investigation					
X4	Lack of geotechnical expertise has an effect on geotechnical investigation					
X5	Result presentation has an effect on geotechnical investigation					
X6	Integration with project lifecycle has an effect on geotechnical investigation					
X7	supervision has an effect on geotechnical investigation					
X8	Sampling difficulties has an effect on geotechnical investigation					

X9	Equipment has an effect on geotechnical investigation					

10. Rate the impact of the following geotechnical related issues on building project performance

S/No	Geotechnical related defects	Very High	High	Medium	Low	Very Low
1	Tilting of buildings					
2	Settlement					
3	Overturning moments imposed on the foundation from the superstructures					
4	Kinematic forces acting on deep foundations due to shear deformation of soils					
5	Reduction in bearing capacity due to ground failures					
6	Collapsed foundations					
7	Cracks on wall					
8	Cracks on structural elements (beam, slab, column)					
9	Collapsing soils/liquefaction					

11. Based on your experience, what is the effect of geotechnical related changes on cost range in building projects?

	Overrun by ≥ 25%	Overrun by 15% - 25%	Overrun by 5% - 15%	Overrun by ≤ 5%	On budget	Under budget by ≤ 1%	Under budget by ≤ 1% - 5%	Under budget by ≤ 5% - 10%	Under budget by ≥ 10%
Cost performance									

12. Based on your experience, what is the effect of geotechnical changes on completion time in road pavement projects?

	Ahead by≥ 25%	Ahead by 15% - 25%	Ahead by 5% - 15%	Ahead by ≤ 5%	On schedule	Behind schedule by ≤ 1%	Behind schedule by ≤ 1% - 5%	Behind schedule by ≤ 5% - 10%	Behind schedule by ≥

									10%
Schedule performance									

13. Rate the following strategies for mitigating the impact of inadequate geotechnical investigation on construction projects

S/No	Mitigating strategies	Strongly Agree	Agree	Undecided	Strongly Disagree	Disagree
1	Assign skilled personnel to conduct geotechnical investigation					
2	Provision of sufficient boring location					
3	Strict adherence to results from geotechnical investigations					
4	Government policies to enforce detailed and standard practice of geotechnical investigation					
5	Adequate sampling technique					
6	Adequate sample management					
7	Efficient Presentation of investigation result					

SECTION 3: ROAD PAVEMENT PROJECTS

Instruction: Please enter **(√)** in the appropriate column/box as it applies to you

14. How often do you carry out geotechnical investigation in your road pavement construction practice?

	Always	Very Often	Often	Sometimes	Never
Geotechnical investigation in road					

pavement construction					

15. In your organization, is there a designated group or personnel responsible for geotechnical investigation?

	No	Sometimes	Yes
Responsibility of geotechnical investigation			

16. How often do you use the following sampling technique for geotechnical investigation in building construction?
    1. Borehole drilling ( )
    2. Excavation of test pits/trenches ( )
    3. Hand augers ( )

17. How often do you use the following methods of soil observation samples for geotechnical investigation in building construction?
    1. Material sampling and laboratory testing ( )
    2. In-situ testing ( )

18. Do you adhere to the results acquired from geotechnical investigation in the design and construction of road pavement projects?

	Always	Very Often	Often	Sometimes	Never
Adherence to Geotechnical Investigation result					

19. How often do you use the following geotechnical investigation standard code of practice?

S/No	Standard practice code	Always	Very Often	Often	Sometimes	Never
1	American Association of State Highways and Transportation (AASHTO)					
2	Unified soil classification system (USCS)					
3	American Society for Testing and Materials (ASTM)					
4	British Standard (BS)					
5	West Africa Standard (WAS)					
6	Adaptive Network Fuzzy Inference					

	System – Site Investigation Model (ANFIS-SI)					
7	Others, (Please specify)					

20. How often do you carry out the following subsurface geotechnical investigation in road pavement construction?

S/No	Standard geotechnical tests	Always	Very Often	Often	Sometimes	Never
1	Engineering classification					
2	Specific gravity					
3	Optimum moisture content (OMC) and maximum dry density (MDD)					
4	Linear shrinkage					
5	Compaction (standard or modified proctor test)					
6	Atterberg Limit					
7	Standard penetration test (SPT)					
8	Cone penetration test (CPT)					
9	Aggregate Impact Value (AIV)					
10	Aggregate Abrasion Value (AAV)					
11	Consolidation test					
12	Liquid limit					
13	Plasticity index					
14	Others, (Please specify)					

21. Rate the following causes of inadequate geotechnical investigation in road pavement construction

S/No	Causes of inadequate geotechnical investigation	Strongly Agree	Agree	Undecided	Strongly Disagree	Disagree
1	Client Awareness					
2	Equipment					
3	Sampling technique					
4	Financial constraint					
5	Supervision					
6	Result presentation					
7	Time constraint					

8	Lack of geotechnical expertise					
9	Lack of integration					

22. Rate the effect of the following variables on the effectiveness of geotechnical investigation in road pavement construction

		Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Y	There is a significant impact of identified variables on geotechnical investigation					
X1	Client awareness has an effect on geotechnical investigation					
X2	Finance has an effect on geotechnical investigation					
X3	Time constraint has an effect on geotechnical investigation					
X4	Lack of geotechnical expertise has an effect on geotechnical investigation					
X5	Result presentation has an effect on geotechnical investigation					
X6	Integration with project lifecycle has an effect on geotechnical investigation					
X7	supervision has an effect on geotechnical investigation					
X8	Sampling difficulties has an effect on geotechnical investigation					
X9	Equipment has an effect on geotechnical investigation					

23. Rate the impact of the following geotechnical related issues on road pavement performance

S/No	Geotechnical related defects	**Very High**	**High**	**Medium**	**Low**	**Very Low**
1	Premature pavement failure					
2	Fatigue Cracking					

3	Potholes					
4	Heave					
5	Depressions					
6	Rutting					
7	Corrugation					
8	Bumps					
9	Roughness					
10	Collapsing soils/liquefaction					

24. Based on your experience, what is the effect of geotechnical changes on cost range in building projects?

	Overrun by ≥ 25%	Overrun by 15% - 25%	Overrun by 5% - 15%	Overrun by ≤ 5%	On budget	Under budget by ≤ 1%	Under budget by ≤ 1% - 5%	Under budget by ≤ 5% - 10%	Under budget by ≥ 10%
Cost performance									

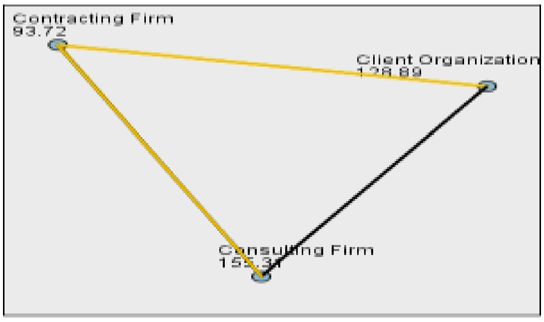
25. Based on your experience, what is the effect of geotechnical changes on completion time in road pavement projects?

	Ahead by≥ 25%	Ahead by 15% - 25%	Ahead by 5% - 15%	Ahead by ≤ 5%	On schedule	Behind schedule by ≤ 1%	Behind schedule by ≤ 1% - 5%	Behind schedule by ≤ 5% - 10%	Behind schedule by ≥ 10%
Schedule performance									

APPENDIX B: Independent-Samples Kruskal-Wallis Hypothesis testing (Research Hypothesis 1 – 3) for building projects

Frequency of geotechnical investigation Practice in building construction

Pairwise Comparisons of Type of Organization



Each node shows the sample average rank of Type of Organization.

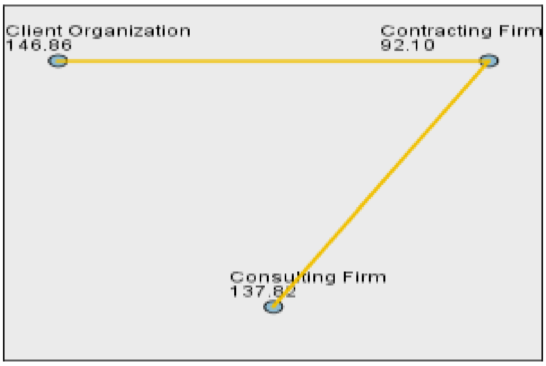
Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Contracting Firm-Client Organization	35.169	10.214	3.443	.001	.002
Contracting Firm-Consulting Firm	-61.582	10.605	-5.807	.000	.000
Client Organization-Consulting Firm	-26.414	11.587	-2.280	.023	.068

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 1: Kruskal-Wallis Hypothesis testing (Frequency of geotechnical investigation Practice in building construction)

Designated group to conduct geotechnical investigation

Pairwise Comparisons of Type of Organization



Each node shows the sample average rank of Type of Organization.

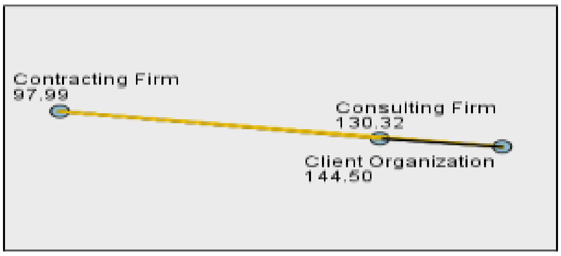
Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Contracting Firm-Consulting Firm	-45.720	9.871	-4.632	.000	.000
Contracting Firm-Client Organization	54.754	9.507	5.759	.000	.000
Consulting Firm-Client Organization	9.035	10.786	.838	.402	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 2: Kruskal-Wallis Hypothesis testing (Designated group to conduct geotechnical investigation)

Adherence to geotechnical investigation result

Pairwise Comparisons of Type of Organization



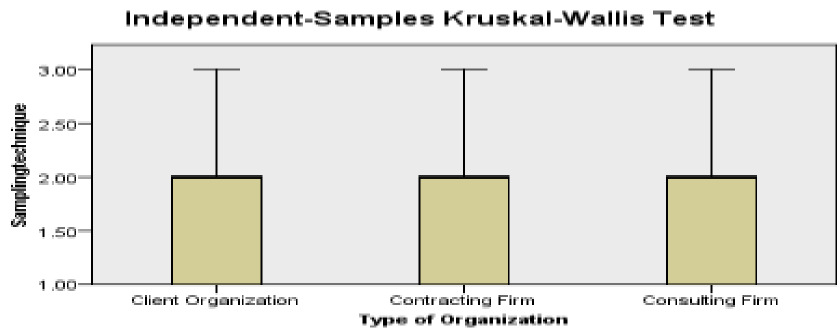
Each node shows the sample average rank of Type of Organization.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Contracting Firm-Consulting Firm	-32.332	9.961	-3.246	.001	.004
Contracting Firm-Client Organization	46.509	9.594	4.848	.000	.000
Consulting Firm-Client Organization	14.177	10.884	1.303	.193	.578

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 3: Kruskal-Wallis Hypothesis testing (Adherence to geotechnical investigation result)

Sampling technique

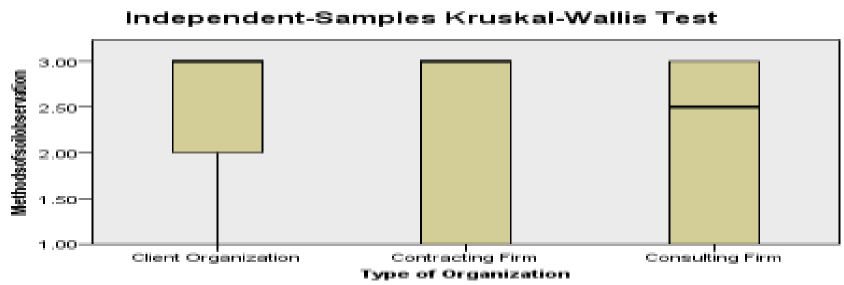


Total N	239
Test Statistic	2.671
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.263

1. The test statistic is adjusted for ties.
2. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Figure 4: Kruskal-Wallis Hypothesis testing (Sampling technique)

Methods of soil observation



Total N	239
Test Statistic	2.721
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.256

1. The test statistic is adjusted for ties.
2. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Figure 5: Kruskal-Wallis Hypothesis testing (Methods of soil observation)

APPENDIX C: Spearman correlation matrix of the relationship between geotechnical related defects and building project performance

Table 1: Spearman correlation between geotechnical related defects and building cost overrun

		BPCO	V1	V2	V3	V4	V5	V6	V7	V8	V9
BPCO	r	1									
	p-value										
V1	r	.850**	1								
	p-value	.000									
V2	r	.842**	.913**	1							
	p-value	.000	.000								
V3	r	.867**	.970**	.936**	1						
	p-value	.000	.000	.000							
V4	r	.812**	.948**	.938**	.915**	1					
	p-value	.000	.000	.000	.000						
V5	r	.800**	.902**	.847**	.938**	.829**	1				
	p-value	.000	.000	.000	.000	.000					
V6	r	.822**	.946**	.917**	.916**	.894**	.895**	1			
	p-value	.000	.000	.000	.000	.000	.000				
V7	r	-.155*	-.205**	-.209**	-.163*	-.114	-.169**	-.338**	1		

	p-value	.016	.001	.001	.012	.080	.009	.000			
V8	r	.620**	.692**	.751**	.651**	.735**	.555**	.698**	.134*	1	
	p-value	.000	.000	.000	.000	.000	.000	.000	.039		
V9	r	.813**	.894**	.950**	.922**	.939**	.811**	.851**	-.128*	.679**	1
	p-value	.000	.000	.000	.000	.000	.000	.000	.048	.000	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Where BPCO = Building Project Cost Overrun; V1 = Tilting of buildings; V2 = Settlement; V3 = Overturning moments imposed on the foundation from the superstructures; V4 = Kinematic forces acting on deep foundations due to shear deformation of soils; V5 = Reduction in bearing capacity due to ground failures; V6 = Collapsed foundations; V7 = Cracks on wall; V8 = Cracks on structural elements (beam, slab, column); V9 = Collapsing soils/liquefaction

Table 2: Spearman correlation between geotechnical related defects and building schedule overrun

		BPSO	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**
BPSO	r	1									
	p-value										
V1	r	.869**	1								
	p-value	.000									
V2	r	.873**	.913**	1							
	p-value	.000	.000								
V3	r	.843**	.970**	.936**	1						
	p-value	.000	.000	.000							
V4	r	.909**	.948**	.938**	.915**	1					
	p-value	.000	.000	.000	.000						
V5	r	.755**	.902**	.847**	.938**	.829**	1				
	p-value	.000	.000	.000	.000	.000					
V6	r	.821**	.946**	.917**	.916**	.894**	.895**	1			
	p-value	.000	.000	.000	.000	.000	.000				
V7	r	-.066	-.205**	-.209**	-.163*	-.114	-.169**	-.338**	1		
	p-value	.312	.001	.001	.012	.080	.009	.000			
V8	r	.719**	.692**	.751**	.651**	.735**	.555**	.698**	.134*	1	
	p-value	.000	.000	.000	.000	.000	.000	.000	.039		
V9	r	.872**	.894**	.950**	.922**	.939**	.811**	.851**	-.128*	.679**	1
	p-value	.000	.000	.000	.000	.000	.000	.000	.048	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Where BPSO = Building Project Schedule Overrun; V1 = Tilting of buildings; V2 = Settlement; V3 = Overturning moments imposed on the foundation from the superstructures; V4 = Kinematic forces acting on deep foundations due to shear deformation of soils; V5 = Reduction in bearing capacity due to ground failures; V6 = Collapsed foundations; V7 = Cracks on wall; V8 = Cracks on structural elements (beam, slab, column); V9 = Collapsing soils/liquefaction

Table 3: Spearman correlation between geotechnical related defects and building project performance

		BPP	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**
BPP	r	1									
	p-value										
V1	r	.901**	1								
	p-value	.000									
V2	r	.838**	.913**	1							
	p-value	.000	.000								
V3	r	.874**	.970**	.936**	1						
	p-value	.000	.000	.000							
V4	r	.862**	.948**	.938**	.915**	1					
	p-value	.000	.000	.000	.000						
V5	r	.802**	.902**	.847**	.938**	.829**	1				
	p-value	.000	.000	.000	.000	.000					
V6	r	.862**	.946**	.917**	.916**	.894**	.895**	1			
	p-value	.000	.000	.000	.000	.000	.000				
V7	r	-.157*	-.205**	-.209**	-.163*	-.114	-.169**	-.338**	1		
	p-value	.015	.001	.001	.012	.080	.009	.000			
V8	r	.638**	.692**	.751**	.651**	.735**	.555**	.698**	.134*	1	
	p-value	.000	.000	.000	.000	.000	.000	.000	.039		
V9	r	.824**	.894**	.950**	.922**	.939**	.811**	.851**	-.128*	.679**	1
	p-value	.000	.000	.000	.000	.000	.000	.000	.048	.000	

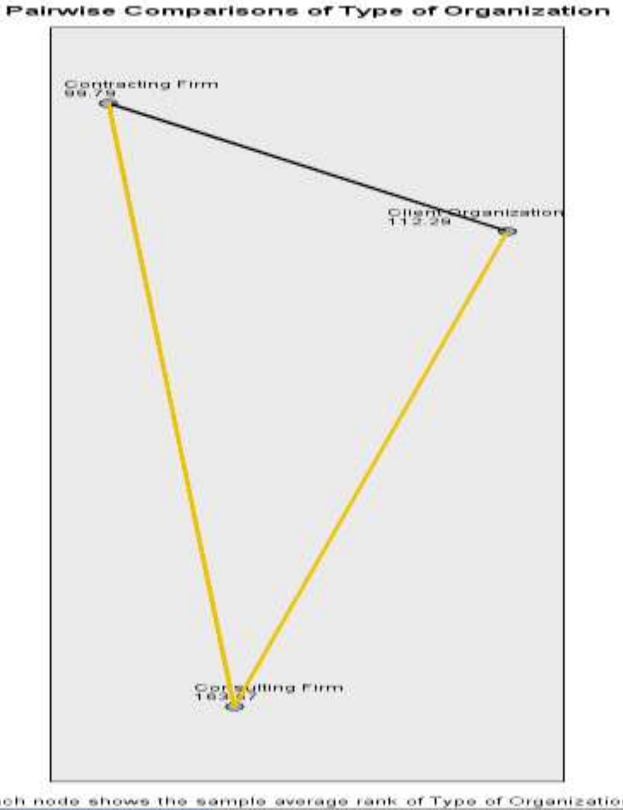
**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Where BPP = Building Project Performance; V1 = Tilting of buildings; V2 = Settlement; V3 = Overturning moments imposed on the foundation from the superstructures; V4 = Kinematic forces acting on deep foundations due to shear deformation of soils; V5 = Reduction in bearing capacity due to ground failures; V6 = Collapsed foundations; V7 = Cracks on wall; V8 = Cracks on structural elements (beam, slab, column); V9 = Collapsing soils/liquefaction

APPENDIX D: Independent-Samples Kruskal-Wallis Hypothesis testing (Research Hypothesis 1 – 3) for road projects

Frequency of geotechnical investigation Practice in road construction



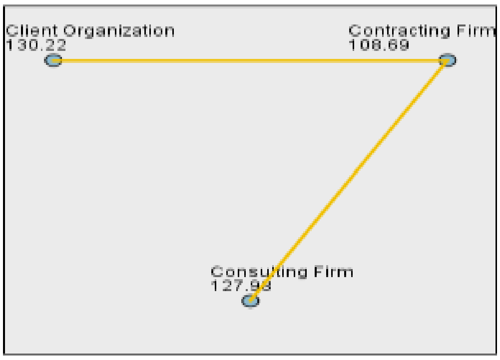
Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Contracting Firm-Client Organization	12.498	9.443	1.324	.186	.557
Contracting Firm-Consulting Firm	-63.778	9.805	-6.505	.000	.000
Client Organization-Consulting Firm	-51.290	10.713	-4.787	.000	.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 1: Kruskal-Wallis Hypothesis testing (Frequency of geotechnical investigation Practice in road construction)

Designated group to conduct geotechnical investigation

Pairwise Comparisons of Type of Organization



Each node shows the sample average rank of Type of Organization.

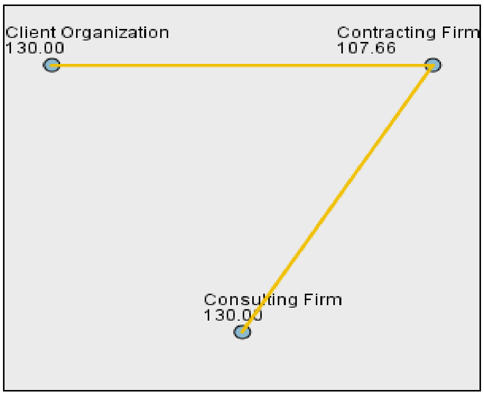
Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Contracting Firm-Consulting Firm	-19.297	5.752	-3.355	.001	.002
Contracting Firm-Client Organization	21.535	5.540	3.887	.000	.000
Consulting Firm-Client Organization	2.238	6.285	.356	.722	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 2: Kruskal-Wallis Hypothesis testing (Designated group to conduct geotechnical investigation)

Adherence to geotechnical investigation result

Pairwise Comparisons of Type of Organization



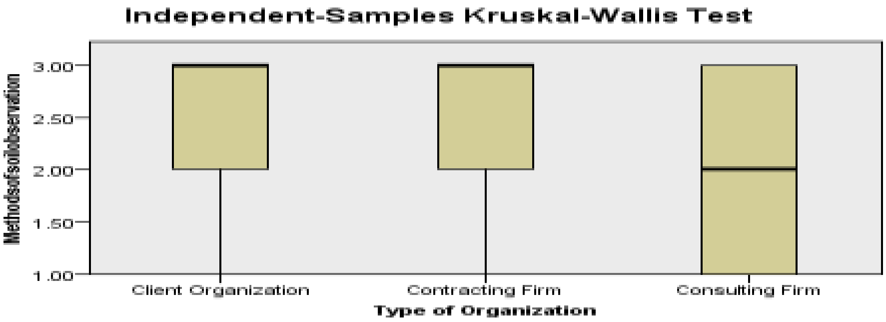
Each node shows the sample average rank of Type of Organization.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Contracting Firm-Client Organization	22.336	5.102	4.378	.000	.000
Contracting Firm-Consulting Firm	-22.336	5.298	-4.216	.000	.000
Client Organization-Consulting Firm	.000	5.789	.000	1.000	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 3: Kruskal-Wallis Hypothesis testing (Adherence to geotechnical investigation result)

Method of soil observation

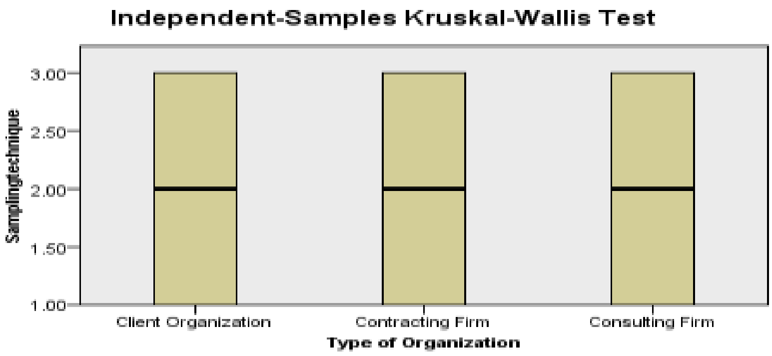


Total N	239
Test Statistic	6.177
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.046

1. The test statistic is adjusted for ties.

Figure 4: Kruskal-Wallis Hypothesis testing (Methods of soil observation)

Sampling technique



Total N	239
Test Statistic	.934
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.627

1. The test statistic is adjusted for ties.
2. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Figure 5: Kruskal-Wallis Hypothesis testing (Sampling technique)

APPENDIX E: Spearman correlation matrix of the relationship between geotechnical related defects and road project pavement performance

Table 1: Spearman correlation between geotechnical related defects and road project cost overrun

		RPCO	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
RPCO	r	1										
	p-value											
V1	r	.127*	1									
	p-value	.049										
V2	r	.326**	.083	1								
	p-value	.000	.200									
V3	r	.222**	.323**	.261**	1							
	p-value	.001	.000	.000								
V4	r	.309**	.229**	.596**	.405**	1						
	p-value	.000	.000	.000	.000							
V5	r	.461**	.309**	.303**	.845**	.646**	1					
	p-value	.000	.000	.000	.000	.000						
V6	r	.280**	.041	.335**	.389**	.855**	.696**	1				
	p-value	.000	.532	.000	.000	.000	.000					
V7	r	.466**	.016	.438**	.364**	.621**	.603**	.714**	1			
	p-value	.000	.805	.000	.000	.000	.000	.000				
V8	r	.320**	.465**	.559**	.610**	.722**	.682**	.642**	.515**	1		
	p-value	.000	.000	.000	.000	.000	.000	.000	.000			
V9	r	.403**	.221**	.413**	.171**	.157*	.335**	.222**	.480**	.421**	1	
	p-value	.000	.001	.000	.008	.015	.000	.001	.000	.000		
V10	r	.433**	.484**	.431**	.497**	.602**	.565**	.300**	.312**	.423**	.222**	1
	p-value	.000	.000	.000	.000	.000	.000	.000	.000	.000	.001	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Where RPCO = Road Project Cost Overrun; V_1 = Premature pavement failure; V_2 = Fatigue Cracking; V_3 = Potholes; V_4 = Heave; V5 = Depressions; V6 = Rutting; V7 = Corrugation; V8 = Bumps; V9 = Roughness; V10 = Collapsing soils/liquefaction.

Table 2: Spearman correlation between geotechnical related defects and road project schedule overrun

		RPSO	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**
RPSO	r	1										
	p-value											
V1	r	.076	1									
	p-value	.239										
V2	r	.348**	.083	1								
	p-value	.000	.200									
V3	r	.085	.323**	.261**	1							
	p-value	.190	.000	.000								
V4	r	.294**	.229**	.596**	.405**	1						
	p-value	.000	.000	.000	.000							
V5	r	.325**	.309**	.303**	.845**	.646**	1					
	p-value	.000	.000	.000	.000	.000						
V6	r	.162*	.041	.335**	.389**	.855**	.696**	1				
	p-value	.012	.532	.000	.000	.000	.000					
V7	r	.413**	.016	.438**	.364**	.621**	.603**	.714**	1			
	p-value	.000	.805	.000	.000	.000	.000	.000				
V8	r	.172**	.465**	.559**	.610**	.722**	.682**	.642**	.515**	1		
	p-value	.008	.000	.000	.000	.000	.000	.000	.000			
V9	r	.309**	.221**	.413**	.171**	.157*	.335**	.222**	.480**	.421**	1	
	p-value	.000	.001	.000	.008	.015	.000	.001	.000	.000		
V10	r	.466**	.484**	.431**	.497**	.602**	.565**	.300**	.312**	.423**	.222**	1
	p-value	.000	.000	.000	.000	.000	.000	.000	.000	.000	.001	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Where RPSO = Road Project Schedule Overrun; V_1 = Premature pavement failure; V_2 = Fatigue Cracking; V_3 = Potholes; V_4 = Heave; V5 = Depressions; V6 = Rutting; V7 = Corrugation; V8 = Bumps; V9 = Roughness; V10 = Collapsing soils/liquefaction.

Table 3: Spearman correlation between geotechnical related defects and road project performance

		RPP	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
RPP	r	1										
	p-value											
V1	r	.084	1									
	p-value	.195										
V2	r	.314**	.083	1								
	p-value	.000	.200									
V3	r	.227**	.323**	.261**	1							
	p-value	.000	.000	.000								
V4	r	.325**	.229**	.596**	.405**	1						
	p-value	.000	.000	.000	.000							
V5	r	.458**	.309**	.303**	.845**	.646**	1					
	p-value	.000	.000	.000	.000	.000						
V6	r	.272**	.041	.335**	.389**	.855**	.696**	1				
	p-value	.000	.532	.000	.000	.000	.000					
V7	r	.453**	.016	.438**	.364**	.621**	.603**	.714**	1			
	p-value	.000	.805	.000	.000	.000	.000	.000				
V8	r	.313**	.465**	.559**	.610**	.722**	.682**	.642**	.515**	1		
	p-value	.000	.000	.000	.000	.000	.000	.000	.000			
V9	R	.364**	.221**	.413**	.171**	.157*	.335**	.222**	.480**	.421**	1	
	p-value	.000	.001	.000	.008	.015	.000	.001	.000	.000		
V10	r	.427**	.484**	.431**	.497**	.602**	.565**	.300**	.312**	.423**	.222**	1
	p-value	.000	.000	.000	.000	.000	.000	.000	.000	.000	.001	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Where RPP = Road Project Performance; V_1 = Premature pavement failure; V_2 = Fatigue Cracking; V_3 = Potholes; V_4 = Heave; V5 = Depressions; V6 = Rutting; V7 = Corrugation; V8 = Bumps; V9 = Roughness; V10 = Collapsing soils/liquefaction.