ANALYSIS OF IMPACTS OF GEOTECHNICAL INVESTIGATION ON PERFORMANCE OF CONSTRUCTION PROJECTS IN RWANDA

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Analysis of Impacts of Geotechnical Investigation on Performance of Construction Projects in Rwanda

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

Signature……………………………………………Date………………………………

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DEDICATION

I dedicate this work to the Almighty God and to my family members - my beloved wife UWERA Sylvie, and my two kids, Abisha and Nolan. And to Father RUCOGOZA Anastase, Mr BIZUMUREMYI Félix, my classmates and the team of research supervisors who contributed to the successful completion of this work.

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ACRONYMS AND ABBREVIATIONS

AEC	Architectural, Engineering and Construction
BIM	Building Information Modelling
KPI	Key Performance Indicators
LABVs	Local Asset Backed Vehicles
MOCT	Ministry of Construction and Transportation
MOMF	Maritime Affairs and Fisheries
NCDOT	North Carolina Department of Transportation
NEC	New Engineering Contract
PCM	Professional Construction Management
PED	Preconstruction Engineering and Design
PFI	Private Finance Initiative
Rwf	Rwandan Franc
SP	Standard Penetration

ABSTRACT

Construction industry is a huge sector where many investments have been made so far and will continue to be so in the foreseeable future. However, unpredictable project costs and durations remain a challenge in the sector. Particularly, excessive changes during the construction phase generate cost growth, quality changes, schedule delays, scope changes and claims in the majority of construction projects. One of the areas that cause major variations relates to the geotechnical characteristics of the construction site(s), which have various impacts on the costs, schedules, quality and claims in the construction projects. Actually, no deep analysis or thorough investigation has been done in this area, in the construction industry of Rwanda. The aim of this study was to assess the impact of geotechnical investigation-related issues on the project performance. Specific objectives of the study were: (i) to assess the extent to which geotechnical study affects construction project performance; (ii) to identify parameters of geotechnical nature that highly affect project quality, time, cost and scope; (iii) to find out the usage of geotechnical information throughout the project lifecycle; (iv) to evaluate the geotechnical risks associated with each parameter and scale at a which it affects construction project performance; and (v) to formulate a framework for mitigating the adverse effect of poor usage of geotechnical information in the construction project. A survey was conducted on 102 engineers from the public and private sectors of the industry, over a period of three months ending in March 2019, using a semi-structured questionnaire and the data analyzed using frequencies. Data analysis results showed that geotechnical investigation affects not only the quality of construction project but also cost, time and scope of the project. Additionally, the root causes of the impact arise from misunderstandings and negligence related to the initial investment required during predesign and implementation phases, to cater for the geotechnical factors at play. The most affected aspects of project performance identified are quality, schedule and scope, which result to project claims. Most of the respondents stated that these geotechnical-related parameters such as shear strength of soil, soil particle distribution, compaction, soil permeability, soil bearing capacity, standard penetration (SP) and borehole cause negative impacts on cost and schedule growth of projects during construction. When asked about a geotechnical guide document necessary to facilitate them to predetermine the needful parameters and cost implications in the pre-design phase(s), only 15% had acquired such a document. The majority did not have any such document or guide, hence resulting to bypassing the practice, and securing project funds that at the end of the day would be spent with a lot of remedial works and cost implications. From the data analysis results, a framework for mitigating the adverse effect of poor usage of geotechnical information in the construction project was created. It is a schematic model integrating the relevant laws and regulations, institutions and stakeholder awareness creation, in a structured manner. Finally, the researcher recommends adoption of the organizational framework developed in this study and formulation of the necessary industry policies and professional practices to create an enabling environment for the framework adoption. By implementing the framework, Rwanda can strengthen its geotechnical practices in construction industry and enhance usage of geotechnical information in order to boost project performance in the industry.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

To some degree each construction project is unique; no two jobs are the same. Each project specifications and structure is enrolled to suit the unique environment and should be arranged to perform its own particular function, and designed to reflect personal, client or institutional tastes and preferences. The vagaries of the construction site and the possibilities for creative and utilitarian variation of even the most standardized building product combine to make each construction project a new and different experience. For this reason, the contractor sets up its ‘‘factory’’ on the site and, largely custom builds each structure. The construction process is subject to the influence of highly variable and sometimes unpredictable factors. The construction team, which includes architects, engineers, building tradesmen, subcontractors, material dealers, and others, changes from one job to the next. As elaborated by Keoki et al. (2015), all the complexities inherent in different construction sites such as subsoil conditions, surface topography, weather, transportation, material supply, utilities and services and project stakeholders, local subcontractors, labor conditions, and available technologies are innate part of construction, (Keoki, Sears, Clough, & Rounds, 2015).

Consequently, construction projects are typified by their complexity and diversity and by the non-standardized nature of their production. The use of factory-made modular units may diminish this individuality somewhat, but it is unlikely that field construction will ever be able to adapt completely to the standardized methods and product uniformity of assembly line production. On the contrary, many manufacturing processes are moving toward ‘‘one-off’’ production and adopting many of the project management tools originating in the construction industry (Keoki, Sears, Clough, & Rounds, 2015).

There have been many significant changes in the construction sector within the past decade. Notably, the sector has witnessed the growth of partnering and alliancing which require better management of the supply chains, and an increasing use of the NEC Contract (NEC3) which requires a team-based proactive approach to project delivery.

New financial models have been developed including Private Finance Initiative (PFI), Local Asset Backed Vehicles (LABVs) and variants of these in which private sector consortia; design, build, own and operate public facilities in partnership with the public sector. Great advances have been made on the technical front with the growth of Building Information Modeling (BIM) and other web or cloud-based project management platforms. Enlightened clients have also been demanding more sustainable developments and construction projects. Yet the same fundamentals apply – clients wish to obtain their increasingly more complex projects within budget and on time and to the necessary quality. Cost management, a function traditionally undertaken by quantity surveyors, therefore remains of critical importance to project success. One of the pioneer quantity surveyor construction project managers was Francis Graves who undertook the task of Project Controller in 1972 on the massive 5-year-long Birmingham NEC Exhibition Centre project. He considered his terms of reference on this project very straightforward - get it finished on time and get value for money! This maxim still resonates today and forms the core of the services offered by all quantity surveying firms on construction and engineering projects (Keoki, Sears, Clough, & Rounds, 2015).

It is significant to observe however that the practice of cost management and the role of the quantity surveyor are changing in response to all the pressures highlighted above. Indeed, many are moving on from the core skills of contractual and financial management to embrace the key role of the client’s strategic adviser and project manager. Evidence of this development can be seen from an analysis of three of the top quantity surveying consultants’ websites which show their involvement in a wide range of strategic services which are increasingly being offered throughout the life of the asset (Potts, 2013).

Major Projects Association (2003), identifies the major reasons for project failure as: Poor project definition, unclear objectives, unrealistic targets, inadequate risk evaluation, client inexperience, poor forecasting on demand, lack of effective sponsor and strong leadership, poor communication and lack of openness, inadequate stakeholder management, management focus wrongly targeted at the back end rather than at the front-end of the project. On the other hand, poor design resulted from applying assumptions due to inaccurate geotechnical investigation can be a higher potential to result in project successfully executed with more variations that affect construction project quality, cost and time regardless of how smart and tough the project management is applied, (Major Projects Association, 2003).

Construction projects are intricate, time-consuming undertakings. The total development of a project normally consists of several phases requiring a diverse range of specialized services. In progressing from initial planning to project completion, the typical job passes through successive and distinct stages that demand input from such disparate areas as financial organizations, governmental agencies, engineers, architects, lawyers, insurance and surety companies, contractors, material manufacturers and suppliers, and building tradesmen (Smith, 2008).

During the construction process itself, even a structure of modest pro-portions involves many skills, materials, and literally hundreds of different operations. The assembly process must follow a natural order of events that constitutes a complicated pattern of individual time requirements and restrictive sequential relationships among the structure's many segments.

The management of construction is an enterprise that involves many people with diverse interests, talents and backgrounds. The owner, the design professional and the contractor comprise the primary triad of parties, but others, such as subcontractors, material suppliers, bankers, insurance and bonding companies, attorneys and public agency officials, are vital elements of the project team whose interrelated roles must be coordinated to assure a successful project. Throughout the project life cycle, from the time the owner first contemplates launching a construction project to that celebrated time, many months or years later, when the completed project is ready for use, the tasks carried out by the various parties vary in type and intensity. Many consider the roles and responsibilities of the many parties at each phase of the construction project life cycle focusing on the construction contractor, who carries the lead responsibility for the on-site installation work and all of the associated planning and follow up. However, it is important, at the same time, to understand how other people and organizations contribute to project success (Bennett, 2016).

A unique element of risk in the construction industry is the manner in which disputes and claims are woven from the fiber of the construction process. The type of contract used, is often based on an overall attempt to allocate (often shifting) the risks of the work to the parties involved and deciding what must always be recognized and accepted. Risk can only be mitigated if it cannot be eliminated (Hendrickson, 2008). Delays occur in every construction project, and the magnitudes of these delays vary considerably from project to project. Some projects delay by a few days while others delay for over a year. At the onset, it is essential to define the actual causes of delay in order to minimize associated costs in any construction project (Hendrickson, 2008)). Hirsch (2012) argued that late in the past, intellectuals such as Plato (427-347 BC) believed in human incapacity to predict the future, (Hirsch, 2012). His assertions show how skeptical they were to the idea of setting up plans for the future and implementing project ideas efficiently. Researchers have argued that there is no construction project without risk, implying that in some instances, construction projects are completely unpredictable. Risk can be managed, minimized, shared, transferred, or accepted but it cannot be ignored (Hendrickson, 2008).

The concept of success in a construction project can be evaluated only when risk dimensions are adequately defined. In most projects, the evaluation of project success or failure dimensions corresponds to the traditional constraints of time, cost, and quality parameters. Jaselskis, (1987), opines that project success will be evaluated in terms of cost, schedule, quality, safety, and participant satisfaction. To achieve construction project success, one must understand behavior/patterns of construction project variables and their relationship, and future monitoring control techniques will be of great importance, (Jaselskis, 1987).

Gasabo is one of the three districts in Rwanda’s capital city, Kigali. The district covers a surface about 50% of the capital city’s land area. In a report by Rukirande, (2012), the national budget of the Government of Rwanda for the fiscal year 2012/2013 emphasized a scaling up of infrastructure projects in order to enhance growth and poverty reduction strategies, and this development will see an increase in construction and rehabilitation investment projects in local governments to Rwf 79 billion compared to Rwf 25 billion in the previous year (Musilikare, 2016), (Rukirande, 2012).

A twenty three percent (23%) share of the entire budget compared to the twenty-one (21%) budget in the previous fiscal year 2011/12 was also observed. A considerable number of international literatures opine that the inability to complete projects on time and within budget continues to be a chronic problem worldwide and a far worsening case, (Ahmed, Azher, & Castillo, 2002). However, as the trend of construction projects cost overrun becomes severe, a number of adverse consequences such as project failure, reduction of profit margin, loss of belief of citizen in government-funded projects, would certainly take place. In Vietnam for example, a developing country in Asia, many problems had arisen during implementation of construction projects, out of which two main concerns were delay and cost overruns, and the frequently faced consequences were also project failure, reduction of profit margin, and loss of belief of citizen in government funded projects among others (Le-Hoai & Lee, 2008).

1.2 Statement of the Problem

Performance of construction projects is vital for the economic development and infrastructural growth of any nation. In Rwanda, the construction industry encounters numerous challenges, particularly regarding the impact of geotechnical investigations on project performance. Geotechnical investigations are crucial for understanding subsurface conditions, which directly influence the safe and efficient design of foundations and other structural elements. According to Clayton & Matthews (2014), early acquisition of reliable geotechnical data can help prevent costly design changes and mitigate risks associated with unforeseen site conditions. Additionally, Mukarurinda and Uwizeye (2021) emphasized that integrating geotechnical information during the planning phase is particularly important due to the diverse and often challenging geological conditions in Rwanda, as observed at the Kigali Convention Centre construction site. Therefore, inaccurate or poorly conducted geotechnical studies lead to significant project delays, cost overruns, and quality issues, exacerbated by insufficient integration of the geotechnical information throughout the project lifecycle and a lack of comprehensive risk assessments in project management practices. That is the problem investigated in this study.

While existing literature suggests a correlation between inadequate geotechnical investigations and construction project failures, comprehensive studies specifically addressing this relationship within the Rwandan context are limited. Past research has primarily focused on identifying general causes of project delays and cost overruns, often relying on quantitative measures without adequately considering qualitative insights. Consequently, there remains a gap in understanding how geotechnical parameters specifically influence project outcomes in the Rwanda's unique construction environment (Das, 2013). This gap underscores the necessity for localized research work that explores these dynamics and provides actionable insights for practitioners in the field.

Furthermore, the financial context in Rwanda adds another layer of complexity to this issue. In the 2012/13 national budget, 46% was donor-funded, which was a significant decrease from its level of 85% in the year 2000. That reduction had been achieved through concerted government efforts to increase taxpayers' contributions to the budget, which were very challenging, and which seriously complicated the process of public development projects. This required responsibility and accountability on the part of the construction professionals. In such circumstances, absence of reliable measures for assessing risks in the construction projects hinders effective risk management, and compromises project performance. This research aims to identify key geotechnical parameters that influence project outcomes and to explain the practical use of geotechnical information. By addressing these issues, the study seeks to enhance project management practices and develop effective mitigation strategies, ultimately contributing to the success of construction projects and supporting Rwanda's development goals.

1.3 Objectives of the Study

The aim of this study was to analyze impacts of geotechnical investigation on the performance of construction projects in Rwanda, for the purpose of enhancing performance of construction project in the country.

The specific objectives of the study are:

1. To assess the extent to which geotechnical study affects construction project performance;
2. To identify parameters of geotechnical nature that highly affect project quality, time, cost and scope;
3. To find out the usage of geotechnical information throughout the project lifecycle;
4. To evaluate the geotechnical risks associated with each parameter and the scale at which it impacts construction project performance;
5. To formulate a framework for mitigating the adverse effect of poor usage of geotechnical information in the construction project.

1.4 Research Questions

The following research questions guided this study: -

1. To what extent does a geotechnical study in a construction project affect performance of the project?
2. To identify parameters of geotechnical nature that highly affect project quality, time, cost and scope;
3. How is the usage of geotechnical information throughout the project lifecycle?

4. What are the geotechnical risks associated with project parameters of quality, time, cost and scope and the extent to which they affect construction project performance?
5. What organizational framework can help to mitigate the adverse effect of poor usage of geotechnical information in the construction project?

1.5 Justification of the study

The construction industry is generally considered to have underperformed compared to other industries. In response to calls for continuous improvement in performance, many key performance indicators (KPIs) have been developed which include: construction cost; construction time; defects; client satisfaction with the product and service; profitability and productivity; all promote result-oriented thinking, (Takim, 2002). But still the linkup between project performance and ground conditions has been left behind.

It has been stipulated in this study, that the issue related to poor performance of construction projects related to geotechnical study after being addressed, the failures of poor performance caused by factors related geotechnical studies in the construction project design and execution shall be addressed. In effect, this will contribute as a mitigation measure to project failure before project implementation.

1.6 Significance of the Study

This research aims to address aspects of geotechnical investigation in construction projects in Rwanda, focusing on their adverse effects on the performance of both public and private projects. This study will prove useful to stakeholders within the Architectural, Engineering and Construction community interested in applying geotechnical guidelines for the purpose of enhancing performance of construction projects in Rwanda. Furthermore, it will be useful in providing a basis for developing a manual/guideline on the usage of geotechnical information in construction projects.

1.7 Scope of the Study

The focus of this study was ongoing as well as completed construction sites in Kigali City both in the private and public sectors. These were taken to be typical of similar projects spread-out all-over the country, Rwanda. More specifically, the focus was on projects that require relatively deeper excavation of the soil and rock in the project implementation.

1.8 Limitations of the Study

One of the key limitations of this study is the relatively low response rate, which may impact the generalizability of the findings. Out of the 200 questionnaires distributed, only 102 were returned, which is just over half of the target. Consequently, there is a possibility that the results may not fully capture perspectives of engineering professionals in Rwanda regarding the research problem.

Reluctance of many respondents to share feedback on their projects - by completing the research questionnaire - posed a major challenge in the data collection. Apparently, they considered the requested project data to be classified information. Additionally, the data collection period coincided with the COVID-19 pandemic, which posed another challenge. Many professionals were preoccupied with immediate challenges related to their projects or were unable to respond due to health and safety concerns.

This non-response bias could influence the study's conclusions, as the views of those who chose not to participate may differ from those who did. As such, the findings should be interpreted with caution, acknowledging that the data may not be entirely representative of the broader population of engineers involved in construction projects in Rwanda.

Finally, a repeat of this study - with a more representative sample - is suggested as an area for further research. Better data collection should be achievable in this post COVID-19 era.

1.9 Definition of Technical Terms

1.9.1 Compaction

Refers to the hardening of soil due to continuous wheel or foot traffic which squeezes the air from the soil particles.

1.9.2 Geotechnical Engineering

This is the study of the behavior of soils under the influence of loading forces and soil water interactions. This knowledge is applied to the design of foundations, retaining walls, earth dams and clay liners

1.9.3 Shear Strength

This is the maximum shear stress that the soil may sustain without experiencing failure. Soil that has greater shear strength will have more cohesion between particles and more friction or interlocking to prevent particles sliding over each other.

1.9.4 Soil Particle Distribution

This refers to the proportions by dry mass of a soil distributed over specified particle-size ranges. This gradation is used to classify soils for engineering and agricultural purposes, since particle size influences how fast or slow water and other fluid moves through soil.

1.9.5 Soil Permeability

This is the capacity of the soil to allow water to pass through it. Water moves very easily through highly permeable soil and very slowly through soils with low permeability.

1.9.6 Soil Bearing Capacity

It is the capacity of soil to support the loads that are applied to the ground above. This depends primarily on the type of soil, its shear strength and its density.

1.9.7 SP & Borehole

The standard penetration test (SPT) is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. This test is most frequently used for subsurface exploration drilling test. On the other hand, a borehole is a hole bored beneath the ground during the course of geotechnical evaluation of a design pathway for the installation of underground services.

1.10 Outline of the Study

The study is presented in five chapters. Chapter one (1) discusses the analysis of impacts of geotechnical investigation on performance of construction projects in Rwanda. It also addresses the research problem in general, the objectives of the study, research questions, limitations and scope are stated, and the study is justified. Chapter two (2) presents related studies on use of geotechnical investigation date in the construction industry in general. It also discusses various aspect of geotechnical data and their effective usage, guidance, performance, considerations, history, trends, benefits, tools used, risks associated, and policies globally and narrates in the Rwandan context. Concepts and theories informing the study are identified. Chapter three (3) discusses the methodology used in conducting the study comprising the research design, population, data collection procedures and analysis. Chapter four (4) presents analysis of the data, and the results observed as well as discusses them. Chapter five (5) covers conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of the literature related to performance of construction projects and the effect of geotechnical investigation on various aspects of the performance. It is organized in four main sections, namely: project performance, geotechnical investigation cost and schedule growth and effect of geotechnical on the cost and schedule growth. Finally, the literature gap, theoretical framework and conceptual framework are presented.

2.2 Geotechnical Investigation

2.2.1 Rationale and Process

Geotechnical investigations are performed to evaluate those geologic, seismologic, and soils conditions that affect the safety, cost effectiveness, design, and execution of a proposed engineering project. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs; delays in construction schedules, costly construction modifications, and use of substandard borrow material, environmental damage to the site, post-construction remedial work, and even failure of a structure and subsequent litigation.

Investigations performed to determine the geologic setting of the project include: the geologic, seismologic, and soil conditions that influence selection of the project site; the characteristics of the foundation soils and rocks; geotechnical conditions which influence project safety, design, and construction; critical geomorphic processes; and sources of construction materials. A close relationship exists between the geologic sciences and other physical sciences used in the determination of project environmental impact and mitigation of that impact. Those individuals performing geotechnical investigations are among the first to assess the physical setting of a project. Hence, senior-level, experienced personnel are required to plan and supervise the execution of a geotechnical investigation. Geotechnical investigations are to be carried out by engineering geologists, geological engineers, geotechnical engineers, and geologists and civil engineers with education and experience in geotechnical investigations. Geologic conditions at a site are a major influence on the environmental impact and impact mitigation design, and therefore a primary portion of geotechnical investigations is to observe and report potential conditions relating to environmental impact (Department of the Army, 2001).

1. Geological Investigation Pre-Review

Geological Investigations should be conducted for new projects and reviewed for existing structures to determine the following:

- The general geologic setting of the area at and near the project.
- The geologic conditions related to selection of the site.
- The characteristics of the foundation soils and rocks. • Any other geologic conditions that may influence design, construction, and long-term operation.
- Seismicity of the area.
- The sources of construction material.

The extent of the investigations will depend on whether the project is proposed or existing and/or the design and the complexity of the local geology. The methods used for the investigations are dependent on the data that needs to be obtained to fully understand the foundation for both constructed and proposed projects. These investigative methods also depend on the types and size of the structures involved, and on the extent and quality of the information needed.

2. Intensity of Geotechnical Investigations

The extent of required investigations should be dictated by hazard classification, nature of structures, and quantity of data already available. Existing dams without adequate data should be evaluated as carefully as proposed structures; not to do so is to be dangerously presumptive.

Geotechnical investigations for proposed sites should be generally divided into three separate phases to minimize costs and for developing the necessary data at each stage of the approval, design, and construction of a project:

1. Preliminary Investigations (adequate information to justify site selection and preliminary cost estimates).
2. Initial Design Investigations (information necessary to obtain regulatory approvals, refine cost estimates, and develop engineering and environmental data).
3. Final Design Investigations (information necessary for developing plans and specifications, obtaining bids, and constructing the project).

For existing structures, the extent of data needed may be relatively limited, depending upon the adequacy of existing data and construction documentation. Evaluation of an existing structure generally requires detailed foundation data that may only be obtained by drilling, sampling, and testing that is concentrated on specific site areas or problems. Such investigations, when needed, should be planned to provide the engineer with information and data to answer questions on specific dam safety problems and to perform dam safety analyses

1. *Preliminary Investigations:* (Adequate information to justify site selection and preliminary cost estimates). This investigation should provide a first general impression of the engineering and geological aspects of the proposed site, and should determine if further study of the site is warranted. The field work generally would include preliminary field geologic mapping, some preliminary hand auger

holes for soil and overburden sampling, a limited number of core holes into rock and possibly some preliminary seismic refraction lines. This information would be used to answer questions raised by an office study. The data would also be used to plan the type, location, and amount of explorations and laboratory testing required for future, more detailed investigations.

2. *Initial Design Investigations*: (Information necessary to obtain regulatory approvals, refine cost estimates, and develop engineering and environmental data). These investigations would be undertaken to provide more detailed information on foundation characteristics on a particular site or several sites, and to provide data for preliminary considerations of the design requirements and construction methods. This type of information is usually developed for inclusion in the license application or in reports providing conceptual analyses of existing project structures. This phase of field investigation should include surface and subsurface exploration and sampling through borings, test pits, test trenches, material testing, geologic mapping, and additional geophysical surveys to supplement drilling. Data developed from these activities should be used to compare alternative sites, to analyze different types of structures that might serve the same purpose, and to develop economic evaluations of the sites. An end product of this investigation usually is an application for license, which includes a specifically identified site and appurtenant structures.
3. *Final Design Investigations:* (Information necessary for developing plans and specifications, obtaining bids and constructing projects). These investigations would be primarily composed of detailed drilling, sampling, and testing concentrated on specific features at the selected project site; and should be specifically planned to provide the engineer with information that is necessary to design structures, estimate quantities, determine rates of construction progress, develop cost estimates, prepare plans and specifications, and obtain bids.

2.2.2 Factors Influencing the Selection of Methods of Investigation

According to the Department of the Army (2001) Manual, the factors influencing the investigation approach to be used include:

a. Nature of subsurface materials and groundwater conditions.
b. Size of structure to be built or investigated.
c. Scope of the investigation, e.g., feasibility study, formulation of plans and specifications.
d. Purpose of the investigation, e.g., evaluate stability of existing structure or design a new structure.
e. Complexity of site and structure.
f. Topographic constraints.
g. Difficulty of application.
h. Degree to which method disturbs the samples or surrounding grounds.
i. Budget constraints.
j. Time constraints.
k. Environment requirements/consequences.
l. Political constraints

2.2.3 Scope of Investigations

From project conception through construction and all along the operation and maintenance phase, geotechnical investigations are designed to provide the level of information appropriate to the particular project development stage. In most instances, initial geotechnical investigations will be general and will cover broad geographic areas. As project development continues, geotechnical investigations become more detailed and cover smaller, more specific areas. For large, complex projects, the geotechnical investigation can involve highly detailed geologic mapping such as a rock surface for a structure foundation. The scopes of the various increments of investigation are described in the following paragraphs. Although some material is presented in detail, rigid adherence to an inflexible program is not intended. It is the responsibility of the geotechnical personnel in the field operating activities to design individual geotechnical investigations to the particular project requirements and local conditions. However, there are minimum requirements for geotechnical investigations to be performed as part of the project development stages, and this manual serves to outline these basic standards. All geotechnical investigations should be planned and conducted by the district element having geotechnical design responsibility. No geotechnical investigation should be contracted out unless the district geotechnical design element reviews and approves the scope of work (Civil Engineer Educators LLC, 2001).

2.3 Impact of Geotechnical Studies on Construction Project Performance

Success of construction projects depends mainly on success of performance. Many previous researches have been studied performance of construction projects. Dissanayaka & Kumaraswamy (1999), remarked that one of the principal reasons for the construction industry's poor performance has been attributed to the inappropriateness of the chosen procurement system, (Dissanayaka & Kumaraswamy, 1999); Reichelt & Lyneis (1999), observed three important structures underlying the dynamic of a project performance which are: the work accomplishment structure, feedback effects on productivity and work quality and effects from upstream phases to downstream phases, (Reichelt & Lyneis, 1999). Thomas et al. (2002) identified the main performance criteria of construction projects as financial stability, progress of work, standard of quality, health and safety, resources, relationship with clients, relationship with consultants, management capabilities, claim and contractual disputes, relationship with subcontractors, reputation and amount of subcontracting, (Thomas, Palaneeswaran, & Kumaraswamy, 2002). Chan et al. (2002) stated that construction time is increasingly important because it often serves as a crucial benchmarking for assessing the performance of a project and the efficiency of the project organization, (Chan & Kumaraswamy, 2002). In the manual, Measurement the Efficiency of Building project performance categories are identified as people, cost, time, quality, safety and health, environment, client satisfaction, and communication, (Elhaniash, 2016). Navon (2005) stated that a control system is an important element to identify factors affecting construction project effort to obtain. For each of the project goals, one or more Project Performance Indicators (PPI) is needed, (Navon, 2005). Abiodum (2017) observed that human factors played an important role in determining the performance of a project, (Abiodum, 2017).

Ugwu (2007) observed that both early contractor involvement (ECI) and early supplier involvement (ESI) would minimize constructability-related performance problems including costs associated with delays, claims, wastages and rework, etc, (Ugwu, 2007). Zwikael et al. (2021) obtained that the most important of practices relating to scope management are controlling the quality of the contract document, quality of response to perceived variations and extent of changes to the contract, (Zwikael, Pathak, & Ling, 2021). It was recommended for foreign firms to adopt some of the project management practices highlighted to help them to achieve better project performance in China (Alias, 2015). As observed much has not be brought forth on how geotechnical investigation can aid in improving the performance of construction projects.

Geotechnical studies play a critical role in the success of construction projects, as they provide essential information about the subsurface conditions of a construction site. The quality and comprehensiveness of these studies can significantly impact various aspects of project performance, including cost, time, quality, and scope.

2.3.1 Influence on Cost and Time Performance

One of the most direct impacts of geotechnical studies is on the cost and time performance of construction projects. Accurate and comprehensive geotechnical investigations can help in predicting potential subsurface challenges, thereby enabling better planning and budgeting. According to Zhang et al. (2019), insufficient geotechnical investigations often lead to unforeseen ground conditions, which can result in project delays, cost overruns, and the need for design changes during the construction phase, . (Zhang, Cheng, & & Xu, 2019) For instance, the discovery of unsuitable soil conditions during construction can necessitate expensive remedial measures such as soil stabilization, additional excavation, or the redesign of foundations.

Chan et al (2002) stated that a number of unexpected problems and changes from original design arise during the construction phase, leading to problems in cost and time performance. It is found that poor site management, unforeseen ground conditions and low speed of decision making involving all project teams are the three most significant factors causing delays and problems of time performance in local building works, (Chan & Kumaraswamy, 2002). Okuwoga (1998) stated that cost and time performance has been identified as general problems in the construction industry worldwide, (Okuwoga, 1998). Dissanayaka & Kumaraswamy (1999) also remarked that project complexity, client type, experience of team and communication are highly correlated with the time performance; whilst project complexity, client characteristics and contractor characteristics are highly correlated with the cost performance, (Dissanayaka & Kumaraswamy, 1999). Reichelt & Lyneis (1999) observed that project schedule and budget performance are controlled by the dynamic feedback process, (Reichelt & Lyneis, 1999). Those processes include the rework cycle, feedback loops creating changes in productivity and quality, and effects between work phases (Enshassi & Abdul, 2014). Complexity is one distinctive characteristic of many projects to manage to enable successful projects. The complexity in construction projects is mentioned by (Chan & David & Chan, 2004). Complexity in terms of turbulent environment in large scale engineering projects is emphasized by (Floricel, 2001) and (Takim, 2001).

Key Performance Indicators (KPIs) may be used to monitor performance and measure how successful certain projects are. For instance, Chan et al. (2004) stated that it is essential to define what project success means, or it will not be feasible to discuss performance measurement. Further, they conclude that both qualitative and quantitative KPIs are desirable, (Chan & Chan, 2004). A set of methods on how to measure the performance is presented by (Salminen, 2005) , and that the criteria cost, schedule deviation, quality and safety form a coherent description of construction project success.

Often failure in one aspect indicates failure in more of the aspects, though this dependency is not necessary (Takim, 2001).

In Rwanda, where construction projects often encounter diverse and challenging geological conditions, the importance of thorough geotechnical investigations cannot be overstated. Ngabonziza and Habimana (2020) emphasize that the lack of detailed geotechnical studies in many Rwandan construction projects has led to significant schedule overruns and increased costs, (Ngabonziza, 2020). Their study highlights several cases where inadequate subsurface investigation resulted in unexpected challenges that could have been mitigated with more thorough geotechnical analysis.

2.3.2 Impact on Quality and Structural Integrity

The quality of construction is heavily dependent on the understanding of the subsurface conditions. Geotechnical studies provide critical data that informs the design of foundations and other structural elements, ensuring that they are suitable for the site-specific conditions. Poor geotechnical investigations can lead to structural failures, as the foundations may not be adequately designed to withstand the actual soil conditions. For example, a study by Kramer and Smith (2017) found that many structural failures in construction projects are linked to inadequate geotechnical information, leading to improper foundation design and ultimately, structural deficiencies, (Kramer, 2017).

In the Rwandan context, where construction is booming and high-rise buildings are increasingly common, ensuring the structural integrity of these buildings through proper geotechnical investigation is crucial. Mukarurinda & Uwizeye (2021) highlight that in several Rwandan cities, rapid urbanization has led to construction in areas with complex geological conditions, making detailed geotechnical studies even more important to avoid compromising the quality and safety of buildings, (Mukarurinda & Uwizeye, 2021).

2.3.3 Scope Definition and Management

Geotechnical studies also play a vital role in defining and managing the scope of construction projects. A comprehensive geotechnical investigation helps to identify potential risks and challenges early in the project lifecycle, allowing for a more accurate definition of the project scope. This early identification of risks can prevent scope creep, where unforeseen issues lead to changes in project scope that increase complexity and cost. According to the findings of Boscardin and Cording (2022), projects that incorporate thorough geotechnical studies into their planning phase are more likely to stay within their original scope and avoid costly scope changes during construction, (Boscardin, 2022).

In Rwanda, the challenge of managing scope in construction projects is particularly acute due to the variable and often unpredictable subsurface conditions. Uwizeye et al. (2018) argue that many construction projects in Rwanda have experienced significant scope changes due to inadequate geotechnical studies, leading to increased project costs and extended timelines, (Uwizeye & Niyonzima, 2018). Their research suggests that a more rigorous approach to geotechnical investigation during the planning phase could mitigate these issues.

2.3.4 Risk Management and Mitigation

Geotechnical studies are fundamental to effective risk management in construction projects. They provide the data necessary to assess and mitigate risks associated with subsurface conditions, such as soil instability, groundwater issues, or seismic activity. Without this information, projects are more vulnerable to unforeseen risks that can jeopardize their success. A study by Duncan and Wright (2020) highlights that the most successful construction projects are those that integrate geotechnical risk management throughout the project lifecycle, from planning through to execution, (Duncan, 2020).

In Rwanda, the management of geotechnical risks is particularly important given the country's varied topography and the prevalence of seismic activity. Niyonzima and

Musoni (2019) conducted a study on geotechnical risk management in Rwandan construction projects and found that many projects suffered from inadequate risk assessment due to insufficient geotechnical investigations, (Niyonzima, 2019). Their study recommends a more proactive approach to geotechnical risk management to improve project outcomes.

2.3.5 Environmental Considerations

Geotechnical studies also contribute to the environmental sustainability of construction projects. By understanding the subsurface conditions, project teams can develop strategies to minimize environmental impacts, such as soil erosion, groundwater contamination, and habitat disruption. Proper geotechnical investigations can lead to the selection of construction methods that are less invasive and more environmentally friendly. This is particularly important in Rwanda, where environmental conservation is a national priority.

According to a study by Kamanzi et al. (2020), many construction projects in Rwanda have faced environmental challenges due to insufficient geotechnical studies, leading to issues such as landslides and erosion, (Kamanzi & Uwizeye, 2020). The study suggests that integrating environmental considerations into geotechnical investigations can help mitigate these impacts and contribute to more sustainable construction practices.

2.4 Geotechnical Parameters Affecting Project Quality, Time, Cost and Scope

Geotechnical parameters are critical determinants of the overall performance of construction projects. These parameters directly influence the quality, time, cost, and scope of a project by defining the subsurface conditions that construction teams must navigate. Understanding these parameters allows for more accurate project planning and risk management, ultimately leading to better project outcomes.

2.4.1 Soil Composition and Properties

One of the most significant geotechnical parameters that affect construction projects is soil composition and properties. Soil type, bearing capacity, and compressibility are critical factors that determine the design and stability of foundations. Poor soil conditions, such as high plasticity clays or loose sands, can lead to differential settlement, foundation instability, and, in extreme cases, structural failure. According to Zhang et al. (2020), projects built on unsuitable soil types often face increased costs due to the need for additional foundation work or soil improvement techniques, which can also lead to project delays and scope changes, (Zhang & Cheng, 2020).

In Rwanda, where diverse soil conditions are prevalent, proper characterization of soil properties is essential to avoid unexpected issues during construction. Mukarurinda and Uwizeye (2021) note that many construction projects in Rwanda have experienced significant cost overruns and delays due to the underestimation of soil-related risks, (Mukarurinda & Uwizeye, 2021). Their study emphasizes the importance of conducting comprehensive geotechnical investigations to accurately assess soil properties and mitigate these risks.

2.4.2 Groundwater Conditions

Groundwater is another critical geotechnical parameter that can significantly impact construction projects. High groundwater levels or the presence of aggressive chemical constituents in groundwater can complicate foundation design and construction, increase the cost of dewatering, and introduce long-term maintenance challenges. High groundwater levels can lead to water ingress during excavation, necessitating expensive and time-consuming dewatering measures. Additionally, aggressive groundwater can corrode buried structures, necessitating special protective measures that increase project costs.

In the Rwandan context, where many construction sites are located in areas with fluctuating water tables, understanding groundwater conditions is crucial for effective project planning. A study by Niyonzima et al. (2019) highlighted the challenges faced by construction projects in Kigali, where high groundwater levels led to unexpected complications during foundation construction, resulting in project delays and increased costs, (Niyonzima & Habimana, 2019). The study recommends that groundwater conditions be thoroughly investigated during the project's early stages to avoid such issues.

2.4.3 Seismic Activity

Seismic activity is a geotechnical parameter that affects construction projects, particularly in regions prone to earthquakes. Seismic considerations influence the design of foundations and structural systems, with the potential to significantly impact project costs and timelines. Structures in seismically active areas must be designed to withstand ground shaking, which often requires the use of specialized construction techniques and materials. This can lead to increased project costs and extended construction schedules.

Rwanda is situated in a region with seismic activity, and as such, seismic considerations are critical for construction projects. Mukashema and Uwizeye (2020) discuss the importance of incorporating seismic design principles into construction projects in Rwanda, particularly in urban areas, (Mukashema, 2020). Their research found that projects that failed to adequately consider seismic risks often faced significant design changes and increased costs during construction. They recommend that seismic risk assessments be integrated into the early stages of project planning to ensure that projects are designed to withstand potential seismic events.

2.4.4 Slope Stability and Landslide Risk

Slope stability is another geotechnical parameter that can have a major impact on construction projects, particularly in hilly or mountainous regions. The risk of landslides or slope failure can affect the safety, cost, and schedule of a project. Projects built on or near slopes must consider the potential for slope instability, which may necessitate the use of retaining structures, slope reinforcement, or other stabilization measures. These requirements can increase project costs and extend timelines.

In Rwanda, where construction in hilly areas is common, slope stability is a critical concern. Habimana and Mukarurinda (2018) conducted a study on slope stability issues in Rwandan construction projects and found that many projects were delayed or faced cost increases due to unanticipated slope instability, (Habimana, 2018). Their research underscores the need for detailed slope stability analysis during the geotechnical investigation phase to ensure that appropriate mitigation measures are incorporated into the project design.

2.4.5 Rock Excavation and Blasting Requirements

The presence of bedrock or hard rock formations at a construction site can significantly impact project quality, time, cost, and scope. Rock excavation requires specialized equipment and techniques, such as blasting, which can be costly and time-consuming. Moreover, the need for blasting can introduce additional risks, such as vibrations that could affect nearby structures or the environment.

In Rwanda, where construction projects often encounter hard rock formations, the impact of rock excavation on project performance is significant. Nduwumwami et al. (2017) examined several Rwandan construction projects and found that those requiring extensive rock excavation experienced notable cost increases and schedule delays, (Nduwumwani & Habimana, 2017). The study suggests that early identification of rock formations through geotechnical investigations can help in planning and budgeting for these challenges, thereby reducing their impact on the project.

2.5 Usage of geotechnical Information Throughout the Project Lifecycle

Geotechnical information plays a pivotal role throughout the entire lifecycle of a construction project, from initial planning and design to construction, operation, and maintenance. The effective use of this information is crucial for mitigating risks, optimizing design solutions, and ensuring the overall success of the project. This subchapter discusses how geotechnical data is utilized at various stages of the project lifecycle, emphasizing the importance of continuous integration and updating of geotechnical knowledge.

2.5.1 Project Planning and Feasibility Studies

During the planning phase, geotechnical information is essential for conducting feasibility studies and making informed decisions about project viability. Geotechnical investigations conducted at this stage provide critical data on soil, rock, groundwater, and seismic conditions that influence site selection, design parameters, and cost estimates. According to Clayton et al. (2014), the early acquisition of reliable geotechnical data can prevent costly design changes later in the project and reduce the risk of unforeseen site conditions that could compromise the project, (Clayton & Matthews, 2014).

In the context of Rwandan construction projects, Mukarurinda and Uwizeye (2021) argue that integrating geotechnical information during the planning phase is particularly crucial due to the diverse and often challenging geological conditions in the region, (Mukarurinda C. &., 2021). They emphasize that thorough geotechnical investigations help identify potential site challenges early, allowing for more accurate project scoping and budgeting.

2.5.2 Design and Engineering

Geotechnical information is integral to the design and engineering phases of a construction project. It informs the design of foundations, retaining structures, earthworks, and other critical components by providing data on load-bearing capacities, slope stability, and potential ground movement. Utilizing this information ensures that the designs are safe, efficient, and cost-effective. A study by Ng et al. (2016) highlights that geotechnical data is essential for optimizing design solutions, as it allows engineers to tailor designs to specific site conditions, thus minimizing the need for conservative design approaches that can inflate costs, (Ng & Chen, 2016).

In Rwanda, where seismic activity and variable soil conditions pose significant challenges, the importance of geotechnical information in design cannot be overstated. Mukashema and Uwizeye (2020) discuss how incorporating detailed geotechnical data into the design process has been key to the success of many Rwandan construction projects, (Mukashema, 2020). They cite examples where the use of accurate geotechnical data enabled the design of earthquake-resistant structures that met both safety and budgetary requirements.

2.5.3 Construction Phase

During the construction phase, geotechnical information continues to be critical, guiding excavation, foundation construction, and soil stabilization efforts. Real-time geotechnical monitoring may be employed to detect any deviations from expected conditions, allowing for prompt corrective actions. According to Zhang et al. (2017), the integration of geotechnical data into construction processes helps manage risks related to ground conditions, reducing the likelihood of delays, cost overruns, and structural failures, (Zhang & Cheng, Impact of Soil Properties on Construction Project Performance, 2017).

In Rwanda, Niyonzima et al. (2019) found that projects that closely followed geotechnical recommendations during construction experienced fewer complications and maintained better control over costs and schedules, (Niyonzima & Habimana, 2019). Their study emphasizes the importance of continuous geotechnical assessment and adaptation during construction, particularly in regions with complex geological settings, such as Kigali.

2.5.4 Operation and Maintenance

Geotechnical information is also critical during the operation and maintenance phase of a project. It informs the development of maintenance plans and the monitoring of potential geotechnical risks over time, such as settlement, erosion, or landslides. Maintenance strategies based on geotechnical data can prevent minor issues from escalating into major problems that could threaten the structural integrity of the project. Wang et al. (2018) argue that ongoing geotechnical monitoring and maintenance are essential for ensuring the long-term performance and safety of infrastructure, (Wang & Li, 2018).

In Rwanda, where infrastructure often faces challenges related to soil erosion and slope stability, the use of geotechnical information in maintenance planning is particularly important. Habimana and Mukarurinda (2018) discuss how the ongoing monitoring of slopes and foundations, informed by initial geotechnical studies, has been crucial for maintaining the safety and functionality of several Rwandan infrastructure projects, (Habimana, 2018).

2.5.5 Project Closeout and Lessons Learnt

At the project closeout stage, geotechnical information is reviewed as part of the overall assessment of project performance. This review includes analyzing how well the geotechnical data was integrated into the project and identifying any discrepancies between predicted and actual site conditions. The lessons learned from this analysis are vital for improving future geotechnical investigations and project planning processes. Turner (2015) notes that the feedback loop created by analyzing geotechnical performance data contributes to the development of best practices and the refinement of geotechnical methodologies, (Turner, 2015).

In Rwanda, Mukarurinda and Uwizeye (2021) highlight the importance of incorporating lessons learned from geotechnical experiences into future projects, (Mukarurinda C. &., 2021). They suggest that documenting and sharing these experiences can help improve the accuracy of geotechnical predictions and the effectiveness of project designs, ultimately leading to better outcomes for the construction industry in the region.

2.6 Geotechnical Risks and their Impact on Project Performance

Geotechnical risks are among the most significant uncertainties in construction projects, often leading to delays, cost overruns, and compromised project quality. These risks arise from the inherent variability in subsurface conditions and the complex interactions between soil, water, and structural elements. This subchapter explores the various geotechnical risks encountered in construction projects, their potential impacts on project performance, and strategies for managing these risks effectively.

2.6.1 Types of Geotechnical Risks

Geotechnical risks can be broadly categorized into several types, each with distinct implications for construction projects. These include:

a) Soil-Related Risks: Variability in soil properties, such as compressibility, shear strength, and permeability, can significantly affect foundation design and earthworks. Unforeseen weak soils or high groundwater levels can lead to settlement, instability, or failure of structures. According to Phoon and Kulhawy (1999), the unpredictability of soil behavior is a major source of risk, especially in projects involving deep excavations or large loads, (Phoon, 1999).
b) Slope Stability Risks: Slope failures or landslides can occur due to natural or construction-induced changes in slope geometry, water content, or loading conditions. These events can cause severe damage to infrastructure and pose significant safety hazards. Terzaghi (1943) emphasize that slope stability analysis must account for both the immediate and long-term effects of construction activities on slope conditions.
c) Groundwater-Related Risks: High groundwater levels or fluctuating water tables can lead to issues such as seepage, erosion, and hydraulic failure of retaining

structures. Inadequate assessment of groundwater conditions can result in costly dewatering operations or unexpected flooding during construction.

d) Seismic Risks: Seismic activity poses a significant risk in geotechnically challenging areas, particularly in regions prone to earthquakes. Seismic risks include soil liquefaction, ground shaking, and fault movements, all of which can severely impact the stability and integrity of structures. Kramer (1996) notes that geotechnical seismic risks require specialized design considerations, such as the use of base isolators or deep foundations, (Kramer S. , 1996)

2.6.2 Impact on Project Quality, Time and Cost

Geotechnical risks can have profound impacts on the quality, time, and cost of construction projects. Unanticipated geotechnical challenges often require design modifications, additional resources, or changes in construction methods, leading to delays and cost overruns. For example, a study by Love et al. (2015) found that geotechnical-related changes accounted for a significant portion of cost overruns in large infrastructure projects, (Love & Ahiaga-Dagbui, 2015).

a) Quality Impacts: Poor geotechnical conditions can lead to structural defects, such as excessive settlement, cracking, or tilting of buildings, which compromise the quality and safety of the project. Inadequate ground improvement or foundation design can result in long-term performance issues, requiring costly remediation measures. Early identification and mitigation of geotechnical risks are essential to maintaining project quality.

b) Time Impacts: Geotechnical risks often lead to project delays due to the need for additional investigations, redesign, or remedial works. For instance, unexpected soil conditions may necessitate deeper excavations or alternative foundation solutions, extending the project timeline. Doloi et al. (2012) report that geotechnical delays are a common cause of schedule overruns, particularly in complex urban projects where access to the site and logistics are challenging, (Doloi, Sawhney, & Lyer, 2012).

c) Cost Impacts: The financial implications of geotechnical risks can be substantial, as they often result in increased construction costs due to additional materials, labor, and equipment. The need for specialized geotechnical solutions, such as ground stabilization or deep foundations, can further inflate project costs. A case study by Chulkov (2017) demonstrated that geotechnical uncertainties were a primary driver of cost escalation in several major infrastructure projects in Russia, (Chulkov, 2017).

2.6.3 Geotechnical Risk Assessment and Management

Effective management of geotechnical risks is critical for minimizing their impact on project performance. This involves comprehensive geotechnical investigations, risk assessments, and the implementation of appropriate mitigation strategies.

a) Risk Identification: The first step in managing geotechnical risks is to identify potential hazards through detailed site investigations and geotechnical studies. This process involves drilling, sampling, and laboratory testing to characterize subsurface conditions and identify potential risks. Peck et al. (1974) argue that early and thorough site investigation is the most effective way to reduce geotechnical risks, (Peck & Hanson, 1974).
b) Risk Quantification: Quantifying geotechnical risks involves assessing the likelihood and potential consequences of identified hazards. This can be done using probabilistic models or empirical methods based on historical data. Duncan and Wright (2005) highlight the importance of combining qualitative judgment with quantitative analysis to accurately assess geotechnical risks, (Duncan, 2005).
c) Mitigation Strategies: Once risks are identified and quantified, appropriate mitigation strategies must be implemented. These may include design modifications, such as using piled foundations or reinforced earth structures, or construction techniques like dewatering or ground improvement. O’Rourke et al. (1990) emphasize the need for continuous monitoring and adaptive management

during construction to address emerging geotechnical risks effectively, (O'Rourke & McCabe, 1990).

2.6.4 Case Studies of Geotechnical Risk Impacts

Several case studies illustrate the significant impact that geotechnical risks can have on construction projects and the importance of effective risk management.

1) The Leaning Tower of Pisa: One of the most famous examples of geotechnical failure is the Leaning Tower of Pisa, where inadequate foundation design on weak soils led to significant tilting. Burland et al. (2003) discuss how modern geotechnical techniques, such as soil extraction and underpinning, have been used to stabilize the structure and prevent further tilting, (Burland & Jamiolkowski, 2003).
2) Boston Central Artery/Tunnel Project: Commonly known as the Big Dig, this project encountered numerous geotechnical challenges, including soft ground, high water tables, and contaminated soils. Cost overruns and delays were largely attributed to these unforeseen geotechnical conditions. Gallagher et al. (2005) highlight how real-time monitoring and adaptive construction techniques were critical in addressing these risks, (Gallagher & Mitchell, 2005).
3) Kigali Convention Center, Rwanda: In Rwanda, the Kigali Convention Center project faced significant geotechnical challenges due to the site's volcanic soil and high groundwater levels. Mukarurinda et al. (2019) report that the project required extensive ground improvement measures, including soil stabilization and dewatering, which added to the cost and duration of the project, (Mukarurinda & Uwizeye, 1990).

Geotechnical risks are an inherent part of construction projects, particularly in regions with complex geological conditions. These risks can significantly impact project quality, time, and cost if not properly managed. Through comprehensive site investigations, rigorous risk assessment, and the implementation of appropriate mitigation strategies, the adverse effects of geotechnical risks can be minimized. The lessons learned from past projects underscore the importance of early and continuous integration of geotechnical information into the project lifecycle, from planning to construction and beyond.

2.7 Knowledge Gap

From the literature reviewed, it can be concluded that unexpected problems and changes from original design arise during the construction phase, leading to failures in cost and time performance, such as delays, claims, wastages and rework. Moreover, minimization of the constructability-related performance problems is necessary. Minimum requirements for geotechnical investigations to be performed as part of the project development and design stages carry many unforeseen site conditions and eventually cause cost overruns and delays arising from geotechnical causes. Another conclusion is that much reseach work has been done on the imppacts of the ground surface conditions on the cost of contractual claims, change orders and cost overruns, but little research work has been done on the cost and time implications of sub-surface conditions - the domain of geotechnical engineering – in order to show the impact of geotechnical parameters on the project performance. Additionally, structured ways of mitigating the adverse – budgetary and time - effects of geotechnical eventualities were not found in the literature reviewed. This is the knowledge gap the research aimed to fill.

2.8 Theories Related to Geotechnical Engineering

This research makes use of two theories that are foundational to geotechnical engineering and provides essential frameworks for understanding soil behavior, designing foundations and ensuring slope stability in construction projects.

a) **Terzaghi's Soil Mechanics Theory** – Karl Terzaghi, known as the "father of soil mechanics" developed this theory which forms the basis for many geotechnical design principles. Fundamentally, this theory in geotechnical engineering relates to the behavior of soils under the influence of applied loads, (Terzaghi, 1943). The aim of this research is to evaluate the use of geotechnical investigation in enhancing project performance. This theory will be useful in providing a good assessment of the ground conditions likely to be encountered and thus offering assurance that the site is suitable for intended development.

b) **Bearing Capacity Theory** – this theory deals with the calculation and prediction of the maximum load a foundation soil can support without failure. It considers the strength and stability of the soil, as well as the factors such as soil type, groundwater conditions and shape of the foundation, (Meyerhof, 1963). Similarly, to the theory above, this theory will provide suitable parameters to assist design and construction in accordance with good engineering practices. This will assist in all project budgeting, allowing efficient design and forewarn builders of the likely risks that may occur on site.

2.9 Theoretical Framework

The performance of construction projects is significantly influenced by geotechnical investigations, which are essential for understanding the properties of soil and rock at construction sites. In Rwanda, both public and private construction projects face challenges related to geotechnical conditions that can adversely affect their performance. This research aims to analyze these impacts and enhance the performance of construction projects in the country by applying Terzaghi's Soil Mechanics Theory and Bearing Capacity Theory. Karl Terzaghi's Soil Mechanics Theory is a foundational concept in geotechnical engineering. It provides a framework for understanding the behavior of soil under various conditions and is crucial for predicting how soil will respond to construction activities. Bearing Capacity Theory deals with the ability of soil to support the loads applied by foundations without undergoing shear failure. This theory is critical for designing safe and effective foundations.

These theories can be applied to the research in a number of ways;

a) Geotechnical Investigation and Effective Stress: By conducting thorough geotechnical investigations, the effective stress conditions at construction sites can be accurately determined. This helps in predicting and mitigating settlement issues, ensuring the long-term stability and performance of construction projects.
b) Consolidation Analysis for Performance Enhancement: Understanding consolidation behavior through Terzaghi's theory allows for better prediction of time-dependent settlement. This can inform construction schedules and post-construction monitoring plans, enhancing project performance.
c) Shear Strength and Stability Assessments: Utilizing Terzaghi's principles to evaluate shear strength can help in designing stable slopes and retaining structures, preventing failures that can disrupt construction projects.
d) Foundation Design Using Bearing Capacity Theory: Applying bearing capacity theory to foundation design ensures that structures are supported safely. This includes selecting appropriate foundation types and dimensions based on soil conditions identified during geotechnical investigations.

The integration of Terzaghi's Soil Mechanics Theory and Bearing Capacity Theory into the analysis of geotechnical investigation impacts provides a robust theoretical framework for enhancing the performance of construction projects in Rwanda. By leveraging these theories, the research aims to develop practical recommendations for improving geotechnical practices, ultimately leading to more successful and resilient construction projects in the country.

2.10 Conceptual Framework

The concept framework shows the variables in the scrutiny of the relationship between geotechnical investigations and project performance. As shown in Figure 2.2 overleaf, the geotechnical parameters investigated are: shear strength, particle distribution of soil, soil permeability, soil bearing capacity, and organic matters. Considerations of these factors or lack thereof, have implications on the project cost, schedule and scope. The researcher posits that carrying out geotechnical investigation during the preliminary stages of the project enhances performance of construction projects in Rwanda.

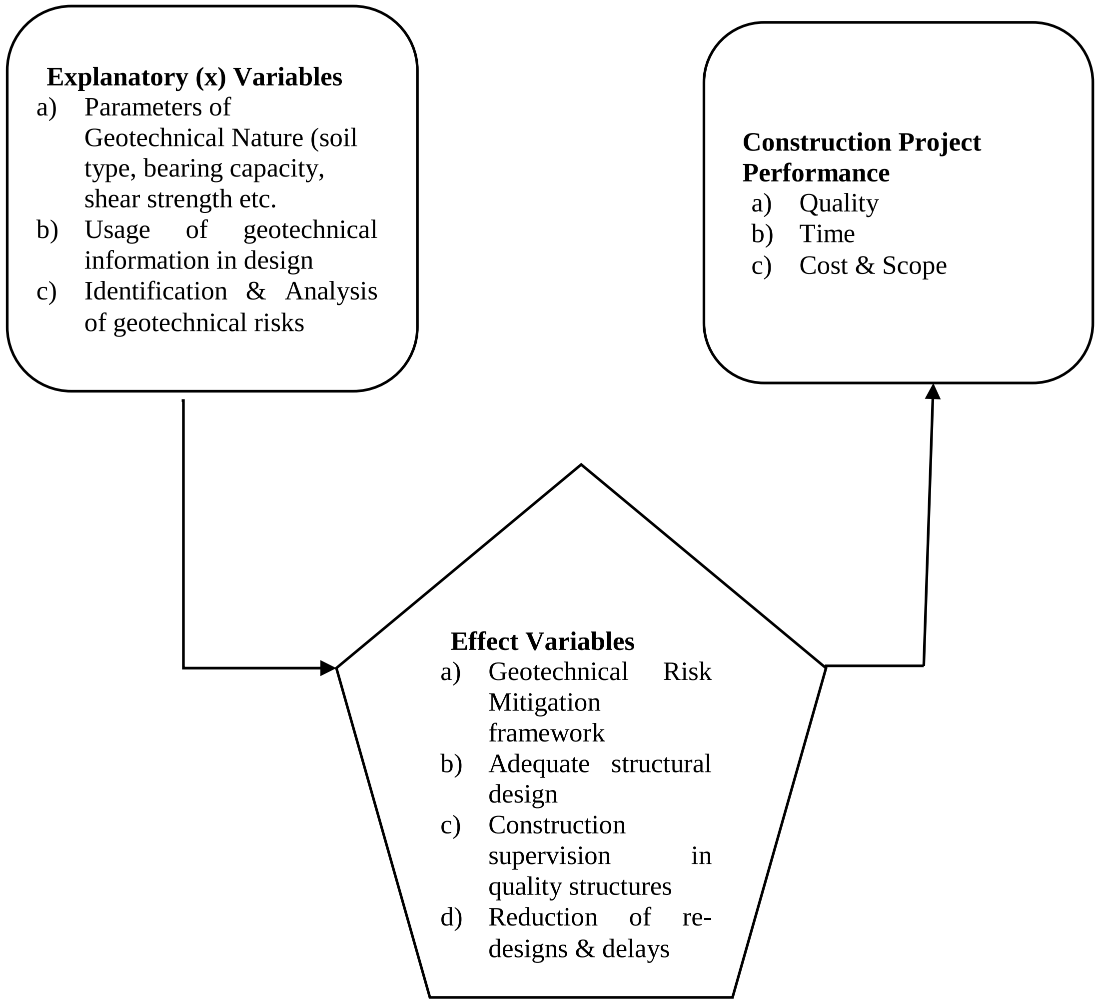

Figure 2.1: Conceptual Framework

Source: (Researcher, 2019)

Key:

→ Leads to

The conceptual framework presents the relationship between geotechnical variables and construction project performance. The explanatory (x) variables include parameters of geotechnical nature (such as soil type and bearing capacity), the usage of geotechnical information in design, and the identification and analysis of geotechnical risks. These factors influence effect variables such as geotechnical risk mitigation frameworks, adequate structural design, construction supervision, and reducing re-designs and delays. Ultimately, these variables impact construction project performance in terms of quality, time, cost, and scope. This framework demonstrates how effective management of geotechnical risks and designs can improve overall project outcomes.

CHAPTER THREE

RESEARH METHODOLOGY

3.1 Introduction

This chapter presents the research design, the target population, sampling method and sampling size. It also presents source of data, data collection methods, and data analysis and presentation procedures. Finally, ethical consideration made in the study are presented.

3.2 Research Strategy

Quantitative research strategy was used for this study. This approach seeks to address questions such as ‘how much’ or ‘how many’ and provides a strong basis for explaining phenomena. It is a research strategy that emphasizes quantification in the collection and analysis of data (Bryman, 2012). It also allows explanatory assertions and inferences to be made regarding the sample and population at large. Quantitative data on geotechnical investigation in construction projects in Rwanda was collected and analyzed, and the results used to synthesize a schematic model for enhancing performance of a construction project, with regard to geotechnical characteristics of the project site.

3.3 Research Design

This research adopted cross-sectional research design. As amplified in Bryman (2012), it involves the collection of data predominantly through questionnaires from more than one case at a single point in time, in order to gather a mass of quantitative data in connection with two or more variables. The variables under consideration are then examined so as to detect patterns of behaviour and association (Bryman, 2012). The researcher sought data on the applicability and usability of geotechnical data during the construction projects development in Rwanda, together with their effects on project performance. Particularly, the inquiry was on the significance of soil data and geological data and the extent to which they are required in the project development. Another query was how applicable the data were in mitigating the related cost, time, scope and stakeholder satisfaction impacts, especially during and after project execution.

3.4 Study Variables

3.4.1 Independent Variables

a) Geotechnical Investigation: This is the independent variable, representing the processes and methodologies used to assess soil and rock properties at construction sites.
b) Parameters of Geotechnical Nature: These are the specific factors identified through geotechnical investigations, such as soil type, moisture content, bearing capacity, shear strength, and consolidation properties.
c) Geotechnical Risks: These include potential issues like settlement, slope instability, foundation failure, and others that can arise due to poor geotechnical conditions or inadequate investigations.
d) Usage of Geotechnical Information: This examines how geotechnical data is applied throughout the project lifecycle, from planning and design to construction and maintenance.

3.4.2 Dependent Variables

a) Construction Project Performance: This is the dependent variable, influenced by the quality and utilization of geotechnical investigations. Performance is evaluated in terms of project quality, time, cost, and scope.
b) Mitigation Framework: This includes: risk assessment; best practices; training; monitoring and contingency planning.

3.5 Population and Sample

3.5.1 Study Population

The target population for this study consists of practicing engineers in Rwanda, as recorded by the Institution of Engineers Rwanda (IER), totaling 392 individuals. This population includes engineers who have expertise in construction processes and are likely to be familiar with the requirements for geotechnical studies on construction sites. The unit of analysis encompasses engineers with experience in building construction projects that involve significant geotechnical investigations. For this study, engineers are categorized as follows:

- **Civil Engineers**: Primarily involved in geotechnical investigations and construction management.
- **Structural Engineers**: Engaged in the design and analysis of structures influenced by geotechnical factors.
- **Geotechnical Engineers**: Specializing in soil and foundation analysis.
- **Project Engineers**: Overseeing construction projects and integrating geotechnical data into project planning and execution.

In addition to engineers, the study also targets:

- **Companies**: Firms involved in construction, including public and private sector entities.
- **Clients/Owners**: Individuals or organizations commissioning construction projects.
- **Testing Laboratories**: Institutions conducting geotechnical testing and analysis.
- **Design Companies**: Organizations responsible for project design, incorporating geotechnical information.
- **Contractors and Consultants**: Professionals involved in the execution and consultancy of construction projects.

Sample Size Determination

The sample size was estimated using the Fisher formula, as shown below:

$$n_f = \frac{\mathrm{n}}{1 + (\mathrm{n} - 1)/\mathrm{N}}$$

Where:

- n represents the sample size for an infinite population.
- Nf is the sample size adjusted for a finite population.
- N is the actual size of the population.

For this study, N is 392, which is the total number of practicing engineers in Rwanda. To determine n, the sample size for an infinite population, we use standard statistical tables or software.

The value of n=384 was derived using the following assumptions and steps:

1. **Confidence Level and Margin of Error**: For a 95% confidence level and a 5% margin of error, which are standard for such research, the required sample size for an infinite population is approximately 384. This value is derived from statistical sample size tables or online calculators used for determining sample sizes based on confidence levels and margins of error.
2. **Adjustment for Finite Population**: Since the actual population size N is 392, which is relatively small, we use the Fisher formula to adjust n for the finite population. The calculation is:

Accordingly, the sample size for the study, $n_f = \frac{384}{1+(384-1)/392}$ = 194 respondents.

This adjustment ensures that the sample size is proportionate to the actual population size, accounting for the reduced variability in a smaller population.

To account for potential attrition, the target sample size was set at 200 respondents.

A cluster sampling technique was employed to select participants from various organizations, including:

- **Public Institutions**: Government bodies involved in construction and infrastructure projects.
- **Private Companies**: Firms working on construction projects.
- **Contractors**: Entities executing construction work.
- **Consultants**: Professionals providing expertise and advice on construction projects.

This sampling approach ensures a diverse representation of professionals involved in the construction industry in Rwanda, capturing a broad spectrum of perspectives on the impacts of geotechnical investigations.

3.6 Data Collection Methods

A structured questionnaire was used in the data collection. Close ended questions were given in the questionnaire, shown in Appendix 1. These were used to derive opinions of the respondents, motivation as well as their professional backgrounds. The questions were formulated to include all parts under study, as captured in the research objectives. According to Bryman (2012), closed questions provide fixed alternatives for the respondents to choose the most appropriate. At first, a draft version of the questionnaire was made and distributed to a few respondents, then collected for pre-analysis and fine-tuning of the questionnaire, before the full data collection work. The data collection activity was carried out physically (self-administered questionnaire) and electronically - via email, using the Google Forms platform.

The questions were specifically designed to gauge the awareness and understanding of geotechnical investigations among all participants. These questions include both general and specific items to capture varying levels of knowledge and experience. The questionnaire incorporates a mix of general questions applicable to all respondents and more technical questions aimed at those with direct experience in geotechnical investigations. For clients/developers, responses to more general questions (e.g., their understanding of the purpose of geotechnical studies and their perceived importance in the project lifecycle) are compared to those from engineers to assess relative awareness levels.

3.7 Data Analysis

Data analysis can be described as organizing, providing structure and eliciting meaning from the data collected. Quantitative data analysis was performed using the Statistical Package for Social Scientists (SPSS for Windows, Version 25). Raw data from the questionnaire was fed into the software, and analyzed using frequencies and rankings of the scores. Finally, the data analysis results were used to formulate a model framework for enhancing integration of geotechnical data in a construction project in Rwanda. In developing an organizational framework, aimed at mitigating the adverse effects of geotechnical information, the Delphi method which is a structured communication technique that gathers insights from experts through multiple rounds of surveys to build consensus on the key components of the framework was applied. Additionally, root cause analysis was used to identify the underlying issues related to poor usage of geotechnical information and to develop targeted strategies within the framework. The framework will be formulated by integrating findings from the statistical analysis of the survey data, expert opinions, and best practices in the industry.

3.8 Validation and Reliability

Reliability is primarily concerned with issues of consistency of measures, whereas validity evaluates whether a measure of a concept really measures that concept (Bryman, 2012). To maintain validity in this study, the researcher first established face validity by consulting few experts involved in projects requiring deeper excavation of the soil and rock abrasion. Upon evaluating whether the questions were valid, a pilot survey was carried out on a sample of the target population. The responses derived from the pilot were then used to refine the research questions for the main survey. As for the reliability, the researcher re-administered the questions to the same group of respondents so as to ensure that the responses did not fluctuate.

3.9 Ethical Considerations

Ethics revolves around four main areas namely: whether there is harm to participants; whether there is lack of informed consent; whether there is invasion of privacy and whether deception is involved (Bryman, 2012). In order to ensure that there is ethical practice in carrying out this research, the researcher observed the following: (i) caution was taken not to interfere with the respondents' privacy during the interview; and (ii) the researcher obtained consent before digging into the particulars of the project, which might involve disclosing information that would seem rather confidential information.

Confidentiality was also treated with utmost regard. Caution was taken to ensure that the information obtained from each of the respondents was not to be disclosed to any other. To achieve this, the researcher avoided putting down any names on the questionnaire sheets. In addition, no respondent knew the identity of any other respondent.

CHAPTER FOUR

DATA ANALYSIS AND RESULTS

4.1 Introduction

This chapter presents the data analysis and the research findings. It starts with the response rate and background information of the respondents, followed by the data analysis results and their interpretation for each of the research objectives. The results form the basis of the recommendations covered in Chapter Five.

4.2 Response Rate and Profile of the Respondents

This regards the proportion of the completed questionnaires obtained and the background information on the respondents.

4.2.1 Response Rate

A total of 102 filled-in questionnaires were returned. Given that the target sample size was 200, the response rate was therefore 51%, as shown on Table 4.1 below.

Table 4.1: Response Rate

	Number of respondents targeted for the survey	**Actual number of respondents who participated in the survey**	**Response Rate; Percentage**
Number	200	102	51.00%

Source: Author (2022)

As explained earlier, in Section 1.8, a major limitation in this study was that the fieldwork was conducted during the COVID-19 pandemic which posed a challenge; accessing the respondents and convincing them to respond in those circumstances was not easy. Hence, the relatively low response rate. Despite this limitation, Mugenda & Mugenda (2003) explain that in questionnaire administration, a response rate of 50% is adequate for analysis and reporting; 60% is good response while 70% is very good, (Mugenda, 2003). In this study, the response rate of 51.0 % was considered good enough for data analysis and conclusions, because the quantitative analysis was mainly descriptive statistics – frequencies and percentages.

4.2.2 Demographic Profile of the Respondents

The demographic profile was evaluated in six dimensions namely: organization working for; section working for; project delivery methods; number of design and built projects in the last five years; period using Geotechnical Investigation Report and finally geotechnical parameters considered in the geotechnical analysis.

4.2.2.1 Respondents Institution

There are many parties that are involved in the construction industry. Majority of the respondents worked for an organization in the public sector, carrying 32% followed closely by the private sector at 27%, as shown in Figure 4.1.

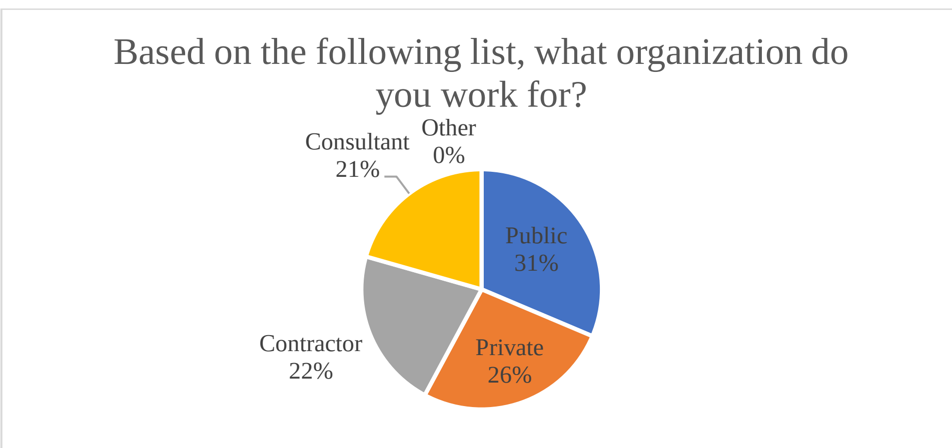

Figure 4.1: Respondents' Type of Organization

Source: (Researcher, 2022)

The focus of this research was construction projects mainly in building construction which required higher excavation of the soil and rock abrasion during the project. On average, most of such projects can fall under the public sector which explains why most of the engineers were falling under this category. Studies in construction management often show that public sector projects, particularly in developing countries like Rwanda, are more prevalent in infrastructure development and large-scale construction initiatives. This is because governments typically spearhead major building projects, such as schools, hospitals, and public offices, which require significant geotechnical investigations due to the complexity and scale of these developments. For instance, a study by *Ofori (2012)* on construction practices in Sub-Saharan Africa highlighted that public sector projects dominate the construction landscape due to governmental focus on infrastructure development, (Ofori, 2012).

Furthermore, the prominence of public sector projects in requiring rigorous geotechnical studies is echoed in research by Mwangi & Wamugo (2020), which analyzed construction trends in East Africa, (Mwangi & & Wamugo, 2020). They noted that public sector projects often have more stringent geotechnical requirements due to the need for long-term durability and safety, especially in critical infrastructure.

4.2.2.2 Respondent’s Work Section

As shown in table 4.2 below, the construction group (31%) emerged at the majority followed respectively by design group 26%), operations (19%), geotechnical (12%) and finally a permitting section (12%). The design group plays a critical role in the initial stages of a construction project, where geotechnical data is used to inform the design of foundations and other structural elements. Understanding their perspective helps in evaluating how well geotechnical investigations are integrated into the design process and their impact on the overall project performance. The construction group is involved in the actual building process. Their input is vital to assess how geotechnical issues identified during investigations are managed on-site, how they affect construction timelines, costs, and the quality of the work. The operations group handles the ongoing functioning of construction projects. Insights from this group can provide information on the long-term performance of structures and how initial geotechnical investigations impact maintenance and operational efficiency.

The geotechnical/foundations group specializes in geotechnical studies and foundation engineering. Their expertise is directly related to the research topic. They provide critical insights into the accuracy, thoroughness, and practical application of geotechnical investigations in construction projects. Finally the permitting section deals with regulatory compliance and obtaining necessary approvals for construction projects. Their input is essential to understand the regulatory requirements for geotechnical investigations and how these impact project approval and execution timelines.

Table 4.2: Respondent's Section

What section do you work in?	**Respondents**	**Percentage**
Design group	27	26%
Construction group	32	31%
Operations group	19	19%
Geotechnical/foundations group	12	12%
Permitting Section	12	12%
Total	**102**	**100**

Source: (Researcher, 2022)

The distribution of respondents across various sections provides a comprehensive understanding of the different roles and perspectives within the construction industry. By analyzing the responses from these diverse groups, the research can better assess the impacts of geotechnical investigations on construction project performance in Rwanda. This holistic approach ensures that recommendations for enhancing project performance are well-informed and applicable across different stages and facets of construction projects.

4.2.2.3 Organization Project Delivery Methods

Assessing respondents view on the project delivery method used by institution in construction industry, results indicates that majority applied construction manager at risk at 35% followed by design and built at 30%. Design and Build low bid have the lowest percentage. Under construction manager at risk, the construction manager commits to deliver within a guaranteed maximum price which is based on the construction documents and specifications. In part, this assumption of risk by the construction manager makes it more desirable to clients and owners.

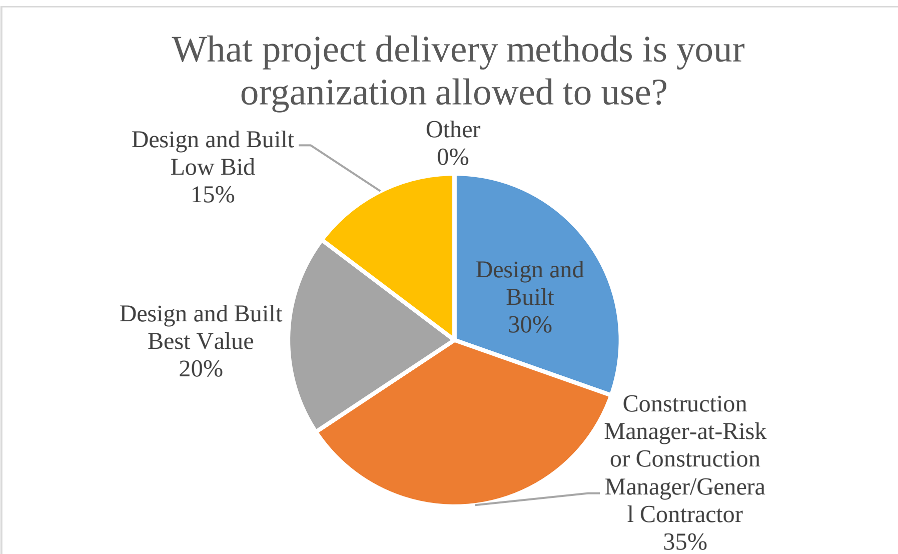

Figure 4.2: Project Delivery Method

Source: (Researcher, 2022)

The lower percentage of projects using the Low-Bid Design and Build approach in these findings reflects a broader industry trend where this method, while cost-effective, is less favored for complex projects due to concerns over quality and risk management. Molenaar & Gransberg (2001), discussed how the low-bid method can lead to cost overruns and disputes, making it less attractive for projects requiring high-quality outcomes and risk mitigation, (Molenaar K. R. & Gransberg, 2001).

4.2.2.4 Number of Design and Build Projects

As far as the respondent's experience in project delivery approach, results indicated that majority of the respondents who had delivered three to five design and build projects in the last 5 years as shown in Figure 4.3 below. In explaining this, the researcher opines that the kind projects in focus are capital intensive, as such take a long period to complete. The respondents thus are involved with such projects for over the project lifespan. In essence, they cannot take on more projects in a span of five years. Furthermore, the focus of the study was Kigali city.

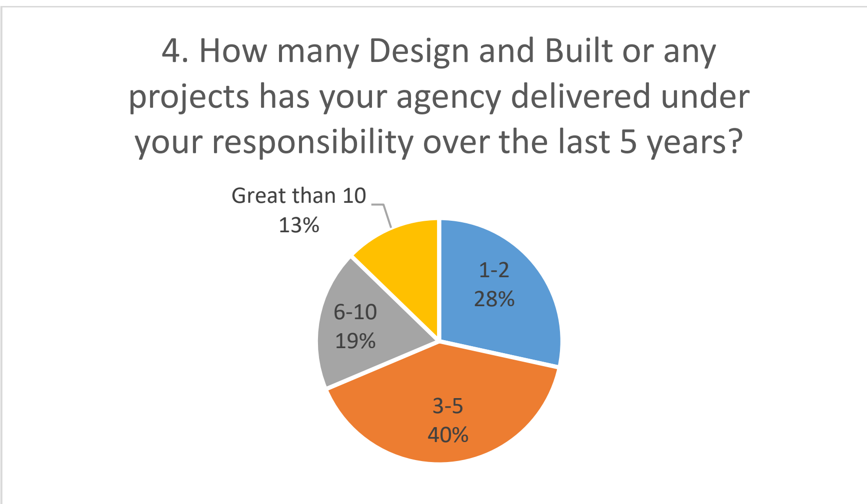

Figure 4.3: Design and Built Projects Undertaken in The Last Five Years

Source: (Researcher, 2022)

4.2.2.5 Period Using Geotechnical Investigation Reports in Project Delivery

The main focus of this study was in geotechnical report usage. As shown in Figure 4.4 below, majority of the respondents have used geotechnical investigation in project delivery for a period spanning 3-5 years and 6 -10 years respectively. This is sufficient period from which to make deductions on proper usage of the geotechnical investigations.

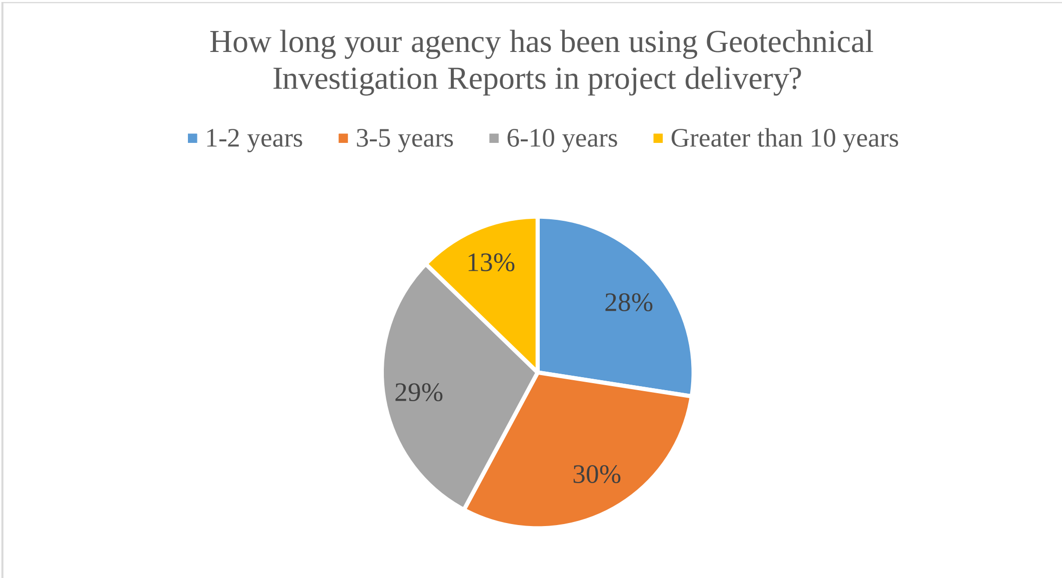

Figure 4.4: Period of Geotechnical Investigation reports in project delivery

Source: (Researcher, 2022)

4.2.2.6 Number of Geotechnical Parameters Focused on During Geotechnical Analysis

The study evaluated various geotechnical parameters including: compaction; geotechnical engineering; shear strength; soil particle distribution; soil permeability; soil bearing capacity anD SP & Borehole. Regarding the geotechnical content, while assessing the number of parameters mostly considered in geotechnical analysis and reporting, it has been observed that most of people consider parameters ranging between 3 to 5 which stands at 33%. In principle, the parameters go beyond; this is indicative that much still remains desired and that there is room for improvement.

Table 4.3: Geotechnical Parameters Focused on During Geotechnical Analysis

How many geotechnical parameters do you mostly focus on for geotechnical analysis?	N	Percent
1-2	27	26%
3-5	34	34%
6-10	27	26%
Greater than 10	14	14%
Total	**102**	**100**

Source: (Researcher, 2022)

Studies such as Coduto (2016), emphasize the importance of considering a broad range of geotechnical parameters to ensure the safety, stability, and performance of construction projects, (Coduto & Yeung, 2016). In many projects, particularly in developing countries, resource constraints often lead to a limited focus on critical parameters such as soil bearing capacity, shear strength, and compaction, similar to your findings. The fact that only 14% of respondents focus on more than 10 parameters suggests that there is significant room for improvement in geotechnical practices.

4.3 Data Analysis for the Study Objectives

4.3.1 Objective 1: Effect of Geotechnical Study on Project Performance

The impact of geotechnical studies on project performance is significant, as these studies provide essential information about subsurface conditions that directly influence the cost, quality, and timeline of construction projects. In this study, project performance was assessed through the availability and usage of geotechnical manuals and the extent to which geotechnical investigations were completed before making project execution decisions.

As shown in Figure 4.5, the majority of respondents (85%) indicated that their institutions do not have a dedicated manual or guide on geotechnical investigation. This lack of standardized procedures can lead to inconsistent practices, which negatively impacts project performance. Without a guide, critical geotechnical parameters such as soil bearing capacity, settlement potential, and soil permeability may be inadequately assessed, leading to poor foundation design, unexpected ground movements, and water infiltration issues. These issues can result in cost overruns, delays, and compromised structural quality.

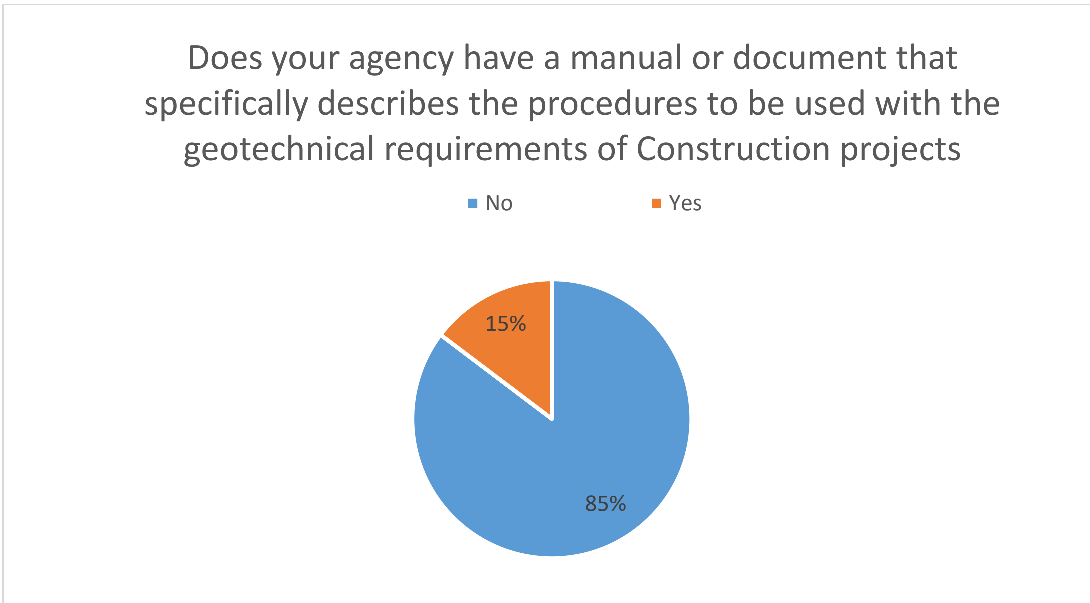

Figure 4.5: Results Showing the Availability of Manual/Document Describing Geotechnical Procedures for Use in a Construction Project

Source: (Researcher, 2022)

Figure 4.6 illustrates the extent to which different types of geotechnical reports are completed before decision-making on project execution. The analysis revealed that many organizations rely primarily on preliminary reports, such as the Reconnaissance Report or Data Report, which provide only a limited understanding of subsurface conditions. The absence of comprehensive reports, like the Geotechnical Baseline Report (GBR) or Geotechnical Design Report, can lead to inaccurate predictions regarding soil stability, bearing capacity, and other critical factors. This often results in miscalculations in project cost estimates and schedules, as unexpected ground conditions necessitate redesigns or additional construction work.

To better understand the impact of geotechnical studies on project performance, it is crucial to focus on specific geotechnical parameters that have a direct impact on the project. These include:

- **Bearing Capacity of Soil/Rock:** Determines the ability of the ground to support the loads imposed by the structure, affecting foundation design and construction costs.
- **Settlement:** Refers to the vertical movement of the ground due to load application, which can influence the structural integrity and require remediation measures if not adequately anticipated.
- **Soil Permeability:** Affects drainage and the risk of water-related damage, influencing both the quality of the structure and the time required to complete construction.

By quantitatively and qualitatively assessing these parameters, their direct impact on cost, quality, and the project schedule can be established, providing a more comprehensive understanding of how geotechnical studies influence overall project performance.

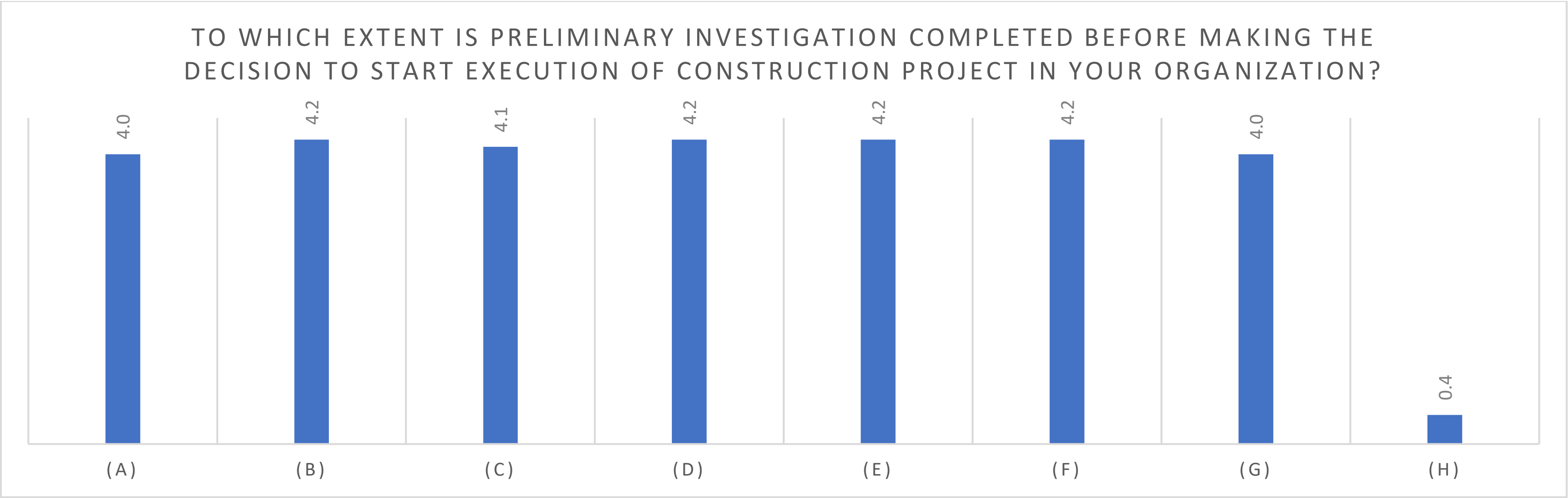

Figure 4.6: Results Showing Extent to which Geotechnical Investigation is Completed Before Decision Making on Project Execution Source: Researcher (2022)

This figure presents analysis of Question 8 in the research questionnaire.

Key:

(A): Reconnaissance Report - Review of Records & Observations from Site
(B): Data Report - Review of Records & Limited Investigation Data
(C): Summary Report - Review of Records & Geotechnical Investigation of Critical Areas
(D): Preliminary Geotechnical Design Report - Partial Geotechnical Investigation
F): Geotechnical Baseline Report (GBR) - A Report that Establishes the Contractual Understanding of Subsurface Site Conditions & Upon Which Risks Associated With Subsurface Conditions Can Be Allocated Between the Owner and the Design Builder
(E): Geotechnical Design Report - Full Subsurface Investigation for All Structures and Geotechnical Features
(G): Geotechnical Interpretation Report (GIR) - A Report that Interprets the Findings.
(H): None.

4.3.2 Objective 2: Geotechnical Parametes Affecting Project Performance

As already established in theory, there are various geotechnical parameters that affect project performance (quality, time, cost and scope). These include: soil shear, soil particle distribution, compaction, soil permeability, soil bearing capacity, organic matter, borehole and standard penetration test. As shown in Figure 4.7 below, soil shear, soil bearing capacity and the standard penetration test had highest ratings, implying that the respondents considered the factors to have substantial impact on project performance. Fundamentally, compressibility and shear strength are the principal geotechnical engineering properties of soils, which control the stability of soil mass under structural loads. Therefore, it is important that these are accurately measured before the design of the foundation of any structure. This emphasizes that thorough geotechnical investigation is fundamental to successful delivery of the construction project.

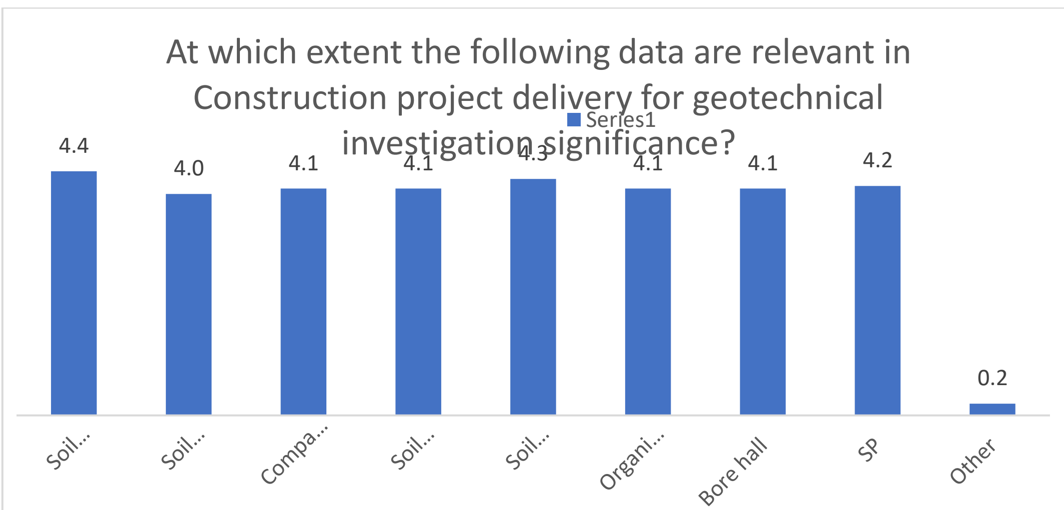

Figure 4.7: Results Showing Extent of Relevance of Various Geotechnical Parameters in Construction Project Delivery.

Source: (Researcher, 2022)

Similarly, analysis on the geotechnical parameters affecting construction project performance had the same results as shown on Table 4.4. Soil shear, soil bearing capacity and standard penetration test had the highest response rate.

Table 4.4: Geotechnical Parameters Affecting Construction Project Performance

At which extent the following data are relevant in construction project delivery for geotechnical investigation significance?							Frequency	Total Score	Aggregate Value	Ranking
a. Soil Shear	0	1	4	9	24	64	102	452	4.4	1
b. Soil Particle distribution	0	1	5	7	67	22	102	410	4.0	8
c. Compaction	0	0	5	15	45	37	102	420	4.1	4
d. Soil Permeability	0	0	5	7	61	29	102	420	4.1	4
e. Soil bearing capacity	0	0	4	5	50	43	102	438	4.3	2
f. Organic matters	2	1	2	12	46	39	102	420	4.1	4
g. Borehole	2	2	4	12	36	46	102	420	4.1	4
h. SP	2	1	3	7	48	41	102	425	4.2	3
i. Other	80	22	0	0	0	0	102	22	0.2	9

Source: Researcher (2022)

Nonetheless, all of the geotechnical parameters have an effect on the construction project performance. In essence, this also is indicative of the utility of carrying out geotechnical studies before commencement of any project.

Regarding project performance indicators, these are evaluated under the lens of cost, time, quality and scope. Fundamentally, client satisfaction with the product and service, profitability and productivity are to be achieved throughout the project life cycle. As shown in Figures 4.7, 4.8, 4.9, 4.10 and 4.11, all of the geotechnical parameters play a crucial role in the success of construction projects by providing essential information about the ground conditions at the site. According to the respondents, ways in which geotechnical studies would contribute to construction project success in Rwanda are:-

(a) *Site investigation and planning* – information on soil composition, groundwater conditions and other geotechnical parameters helps in planning the construction process, determining the type of foundation as well as assessing potential risks during construction.
(b) *Foundation design* – geotechnical studies provide valuable data for designing appropriate foundations that can safely support the proposed structure.
(c) *Risk mitigation* – geotechnical studies help identify potential risks such as landslides, slope instability or expansive soils. Understanding these risks in advance.
(d) *Construction methods and techniques* – geotechnical studies provide insights into the soil properties and behavior which influence construction methods and techniques. The study results help engineers determine the most suitable excavation and earthwork procedures, soil stabilization methods and dewatering techniques.
(e) *Construction schedule and cost estimation* – data obtained from geotechnical studies allows engineers to anticipate any ground-related challenges, potential delays or additional requirements that may arise during construction.
(f) *Environmental considerations* – geotechnical studies also evaluate the environmental impact of construction activities. By understanding the soil and

groundwater conditions, engineers can develop strategies to minimize disturbance to sensitive ecosystems, protect water resources and implement proper soil erosion and sediment control measures.

In a nutshell, geotechnical parameters provide essential information and insights that influence various aspects of construction projects.

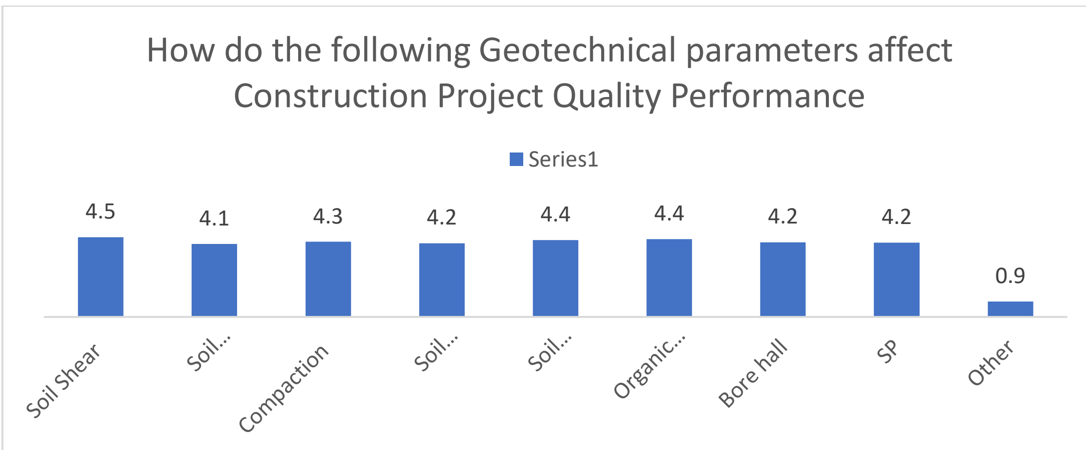

Figure 4.8: Results Showing Geotechnical Parameters Affecting Construction Project Quality Performance

Source: (Researcher, 2022)

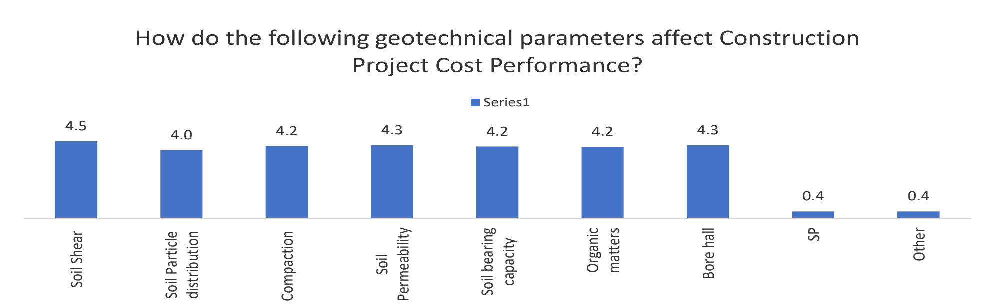

Figure 4.9: Results Showing Geotechnical Parameters Affecting Construction Cost Performance

Source: (Researcher, 2022)

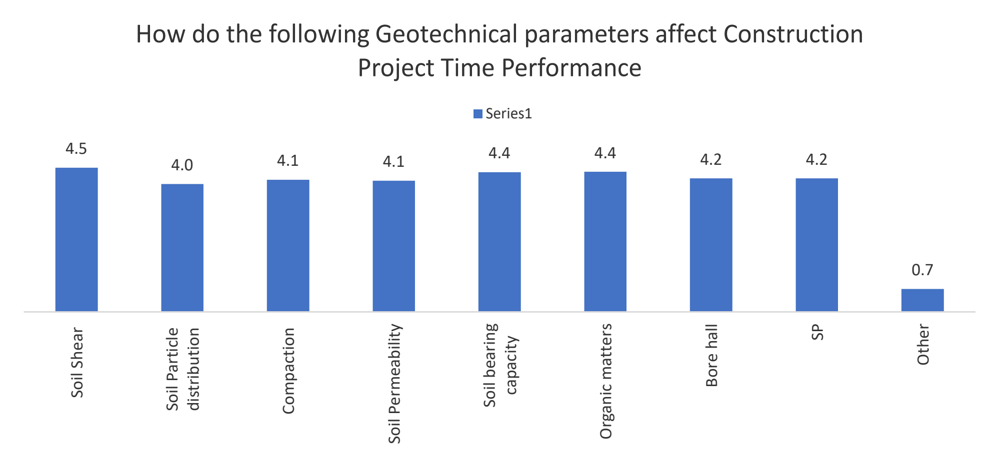

Figure 4.10: Results Showing Geotechnical Parameters Affecting Construction Project Time Performance

Source: (Researcher, 2022)

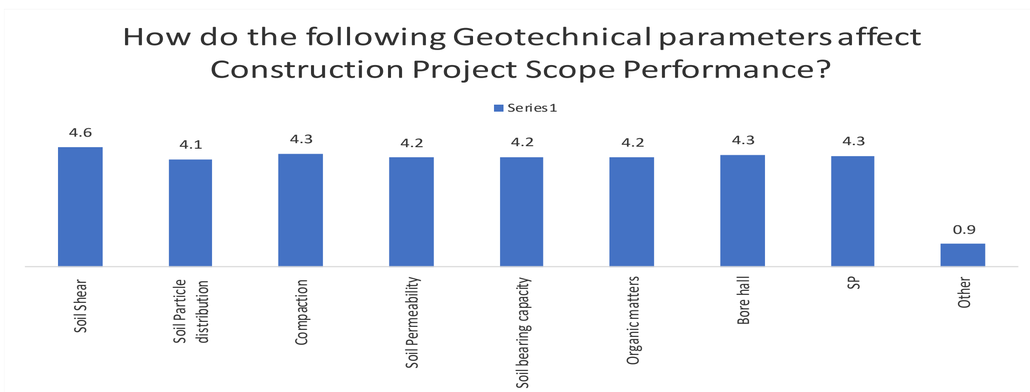

Figure 4.11: Results Showing Geotechnical Parameters Affecting Construction Project Scope Performance

Source: (Researcher, 2022)

Geotechnical parameters directly influence the design and execution of construction projects by providing essential information about ground conditions. Geotechnical parameters and project performance indicators include;

a) **Foundation Design:**

- **Shear Strength and Bearing Capacity:** These parameters are crucial for foundation design as they determine the soil's ability to support structural loads. Accurate measurement is essential to avoid foundation failures that could lead to project delays, cost overruns, and compromised quality.
- **Compaction:** Critical in road construction and pavement design, compaction ensures soil stability and load-bearing capacity, directly impacting the durability and performance of the infrastructure.

b. **Hydraulic Conductivity and Permeability:**

- These parameters are particularly important in the design of dams and water-retaining structures. Properly assessing permeability and hydraulic conductivity helps prevent seepage and ensures structural integrity, thus affecting both the cost and quality of such projects.

c. **Construction Methods and Risk Mitigation:**

- **Soil Particle Distribution and Organic Matter:** These factors influence the choice of construction techniques, such as soil stabilization and excavation methods. Poorly understood soil properties can lead to inefficient methods, delays, and increased costs.

d. **Project Scope and Schedule:**

- **California Bearing Ratio (CBR) and Unconfined Compressive Strength:** In road construction, these parameters are essential for evaluating the load-bearing capacity of subgrade soils, impacting the scope and scheduling of the project. Accurate CBR values help in the precise estimation of material quantities and construction timelines.

e. **Environmental Considerations:**

- **Soil Permeability and Groundwater Conditions:** These parameters also play a role in assessing the environmental impact of construction activities, such as erosion control and water resource protection. Addressing these early in the project lifecycle helps mitigate potential environmental risks.

By ensuring a thorough understanding of ground conditions, these studies contribute to the overall success of the construction process including foundation design, risk mitigation, efficient construction methods, accurate scheduling, cost estimation as well as environmental considerations.

When evaluating project performance in terms of geotechnical parameters, it is important to link these properties to specific performance indicators:

- **Cost:** The accuracy of geotechnical investigations influences the cost by determining the necessary construction methods, materials, and risk mitigation measures.
- **Time:** Properly conducted geotechnical studies reduce the likelihood of unexpected ground conditions, thereby minimizing delays.
- **Quality:** Ensuring that key geotechnical parameters like shear strength and permeability are within acceptable limits helps maintain the structural integrity and longevity of the project.
- **Scope:** Thorough geotechnical analysis ensures that the project scope remains consistent with the original design, avoiding costly variations.

4.3.3 Objective 3: Usage of Geotechnical Information in Project Lifecycle

The usage of geotechnical information throughout the project lifecycle is crucial for ensuring the successful delivery of construction projects. This involves incorporating geotechnical data at various stages, from preliminary design to construction and post-construction monitoring. The significance of this information becomes even more pronounced in projects with substantial geotechnical risks. Geotechnical information is not only valuable during the initial stages of a construction project but also throughout its entire lifecycle. As shown in Figure 4.12, geotechnical studies encompasses all the project parameters of scope, schedule, cost, quality as well as risk in its lifecycle.

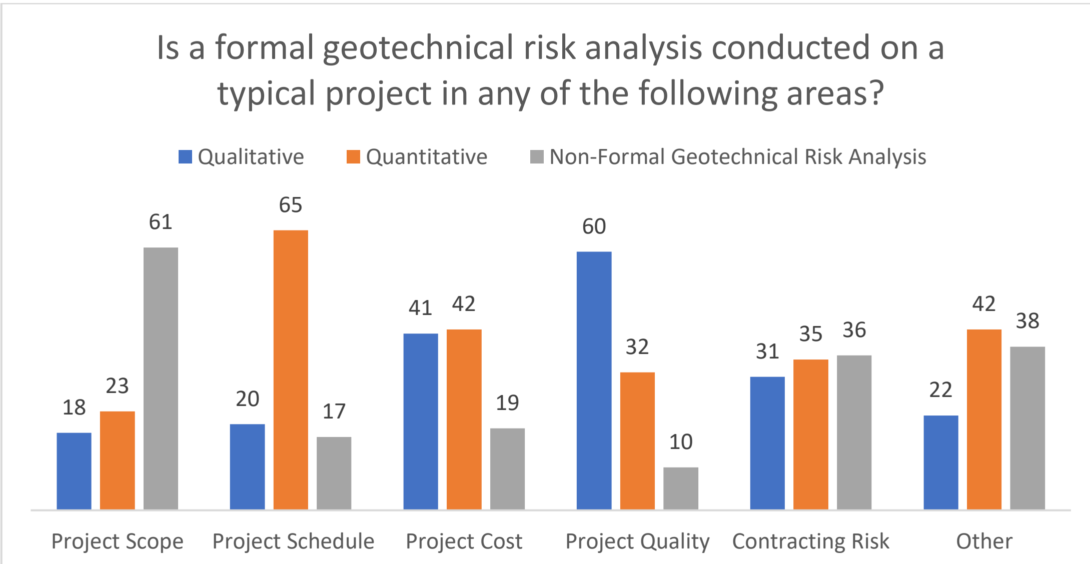

Figure 4.12: Results Showing Geotechnical Risk Analysis on a Typical Project throughout its Lifecycle

Source: (Researcher, 2022)

Throughout the lifecycle of a construction project, geotechnical information provides valuable insights that inform decision-making, design, construction, monitoring, maintenance, retrofitting as well as decommissing. It plays a critical role in ensuring the long term performance, safety as well as sustainability of the infrastructure. In a typical design-build project, geotechnical information is used primarily during the preliminary and detailed design stages. The focus is on ensuring that the soil and site conditions are adequate for the proposed structure, with standard geotechnical investigations providing sufficient data to guide design decisions and construction methods. Projects with significant geotechnical risks involve more complex site conditions, such as weak or highly variable soils, high water tables, or seismic activity. In these cases, geotechnical information plays a more critical role throughout the project lifecycle. Enhanced investigation techniques, such as deep borehole drilling, extensive soil testing, and continuous monitoring during construction, are necessary to mitigate risks. The design must account for potential issues such as foundation instability, excessive settlement, or soil liquefaction, and the project team must be prepared to implement adaptive construction methods and risk management strategies.

4.3.4 Objective 4: Geotechnical Risks

Several geotechnical risks can affect project performance in construction. These risks arise from the characteristics and behaviour of the soil, groundwater, and other geotechnical factors at the project site. As shown in Figure 4.12 below, increased geotechnical risk is carried out in projects with significant geotechnical issues. As established in theory, these projects are mainly construction projects requiring higher excavation of the soil and rock abrasion during the project. This is unlike the case for a typical design and built project.

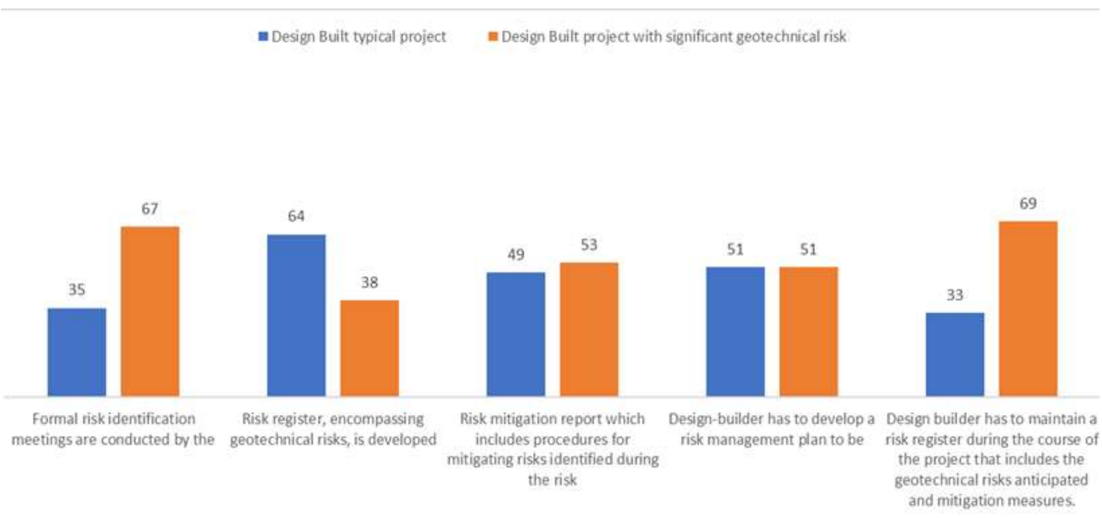

Figure 4.13: Results Showing Geotechnical Risk Management Process Conducted by an Agency or Required by the Design Builder

Source: (Researcher, 2022)

Furthermore, projects carrying out geotechnical risk assessment keep a register, which is used to identify, assess and manage gotechnical risks in a construction project. It helps project teams identify potential geotechnical risks, evaluate their likelihood and potential impact and develop appropriate mitigation measures. As shown in Figure 4.14 oveleaf, majority of the respondents held the opinion that the risk register developed by the agency determined the risk management mitigation strategies applicable to the geotechnical risk identified. In addition, the risk register developed usually contained geotechnical risks with estimated costs and schedule impact of the risk.

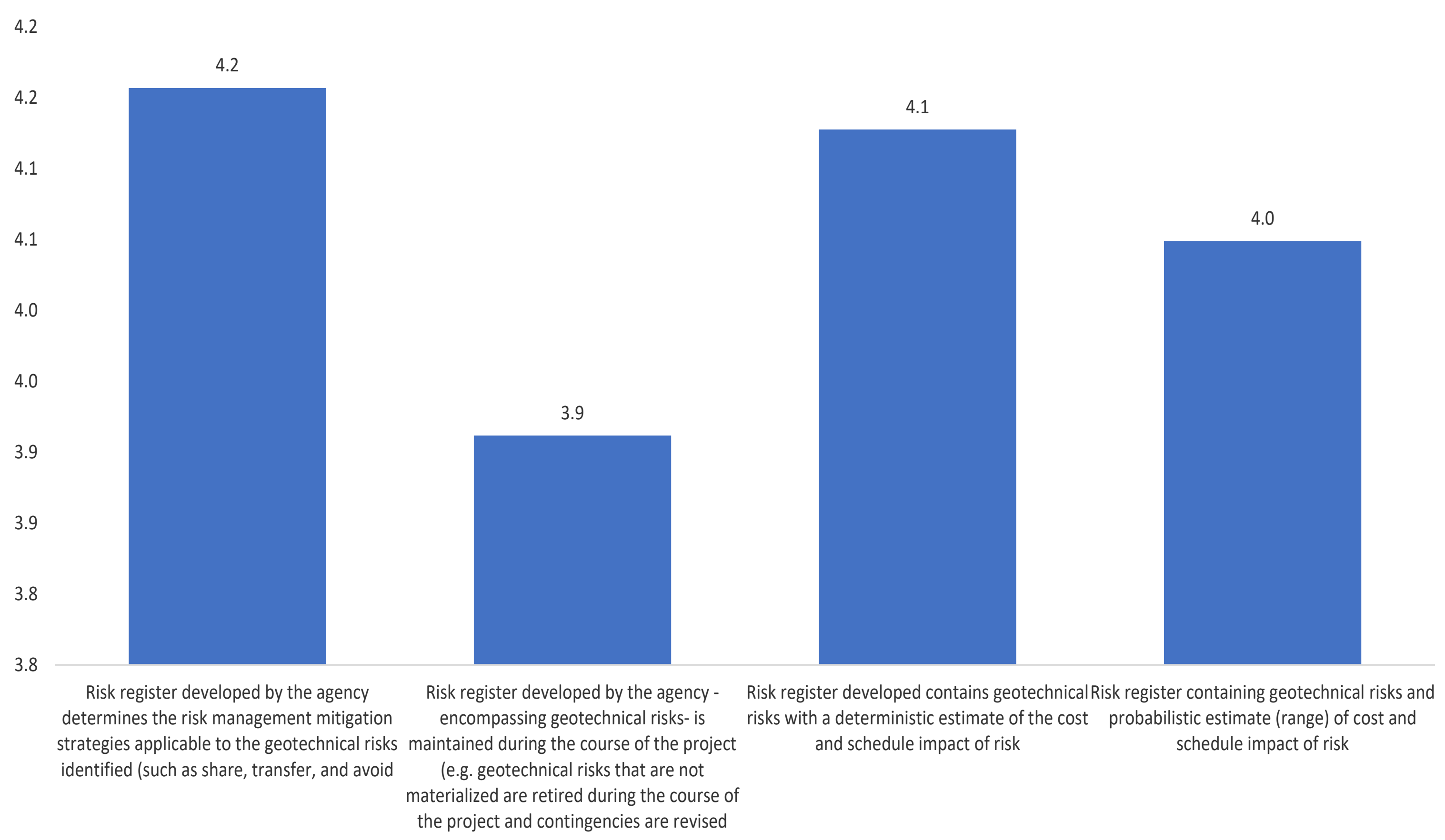

Figure 4.14: Results Showing the Contents of a Risk Register

Source: (Researcher, 2022)

By creating and maintaining a geotechnical risk register, project teams can systematically adress geotechnical risks, implement appropriate mitigation measures and reduce the likelihood of unexpected geotechnical problems. This helps ensure the overall success, safety, and performance of the construction project.

In creating a risk register, the first step is identifying potential geotechnical specific to the project. This involves considering various factors such as site conditions, geological features, soil properties and ground water conditions. Results on the geotechnical parameters typically encountered and the party assuming the related costs in shown in Figure 4.15. As observed, the allocation of costs for geotechnical risks can vary depending on the specific contractual agreements and arrangements between owner and contractor. In general, the responsibility for assuming the costs associated with geotechnical risks is often addressed through contractual agreeements, such as the construction contract or specific provisions within it. The specific terms and conditions regarding the assumption of costs can vary widely depending on factors such as project complexity, risk allocation preferences, local industry practives and applicable laws and regulations. Owners and contractors need to have a clear and comprehensive contractual agreements that address geotechnical risks explicitly.

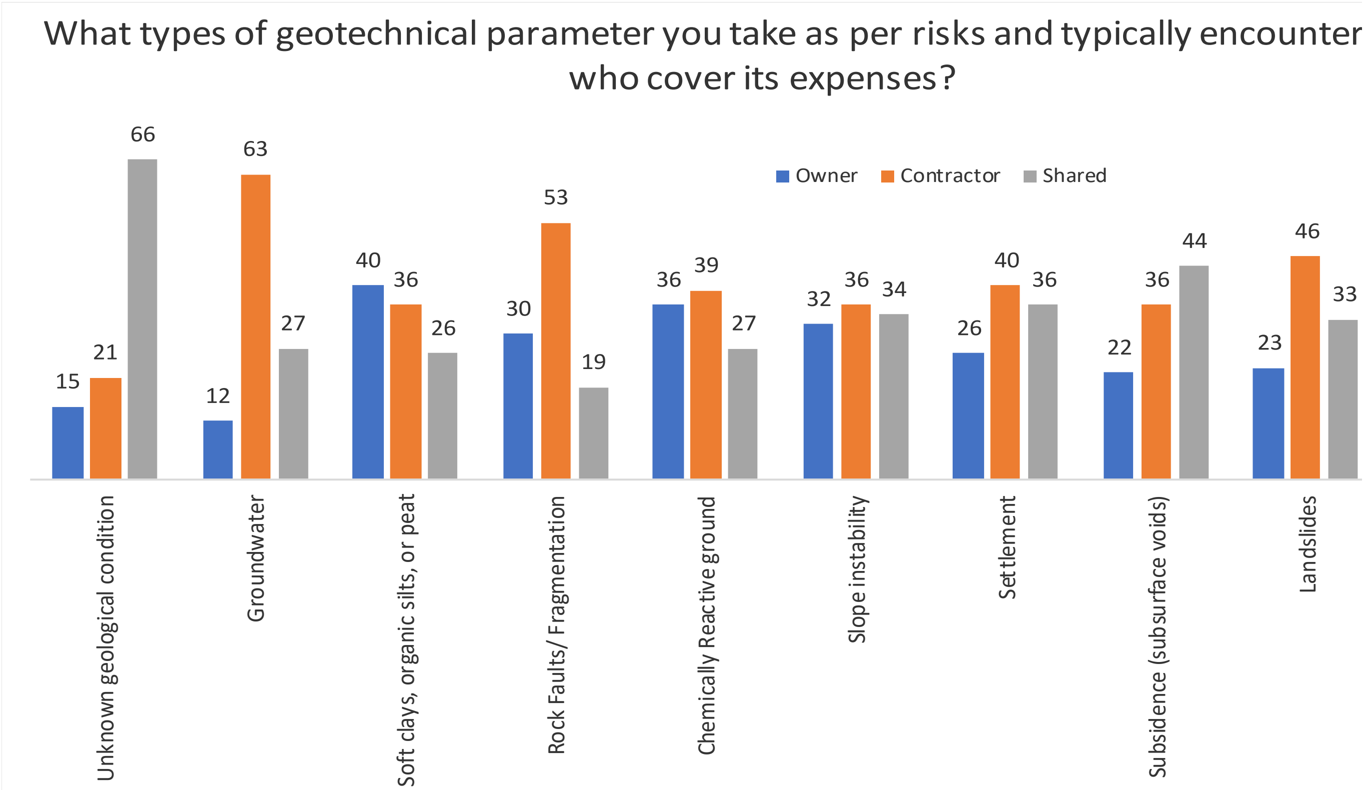

Figure 4.15: Results Showing Various Geotechnical Parameters and Responsible Party for the Related Costs

Source: Researcher (2022)

Figure 4.16 shows typical geotechnical risks encountered and who covers the risk. In some cases, the owner assumes the costs for geotechnical risks. This typically occurs when the owner retains the services of geotechnicl experts and conducts thorough geotechnical investigations before the construction phase. In other situations, the contractor may assume the costs for geotechnical risks. This can happen when the contract explicitly transfers the risk associated with subsurface conditions or unforeseen geotechnical challenges to the contractor. It is also possible for the costs of geotechnical risks to be shared between owner and the contractor. This may occur when both parties acknowledge the potential for geotechnical uncertainities and agree to share the associated costs and risks. Shared responsibility can be reflected in the contractual terms and may include provisiosn for cost sharing based on predefined criteria or percentages.

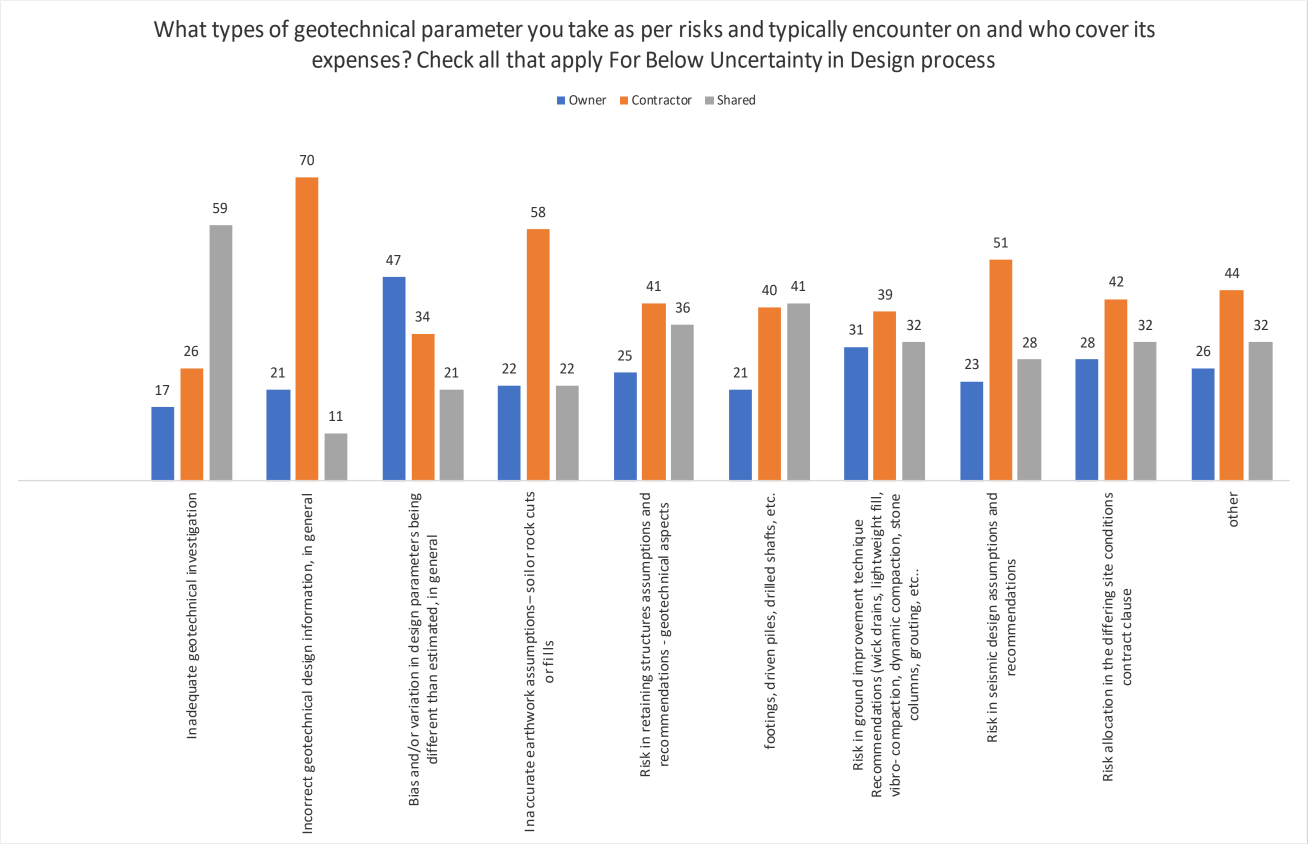

Figure 4.16: Results Showing Typical Geotechnical Risks Encountered and Parties Responsible for the Related Costs

Source: (Researcher, 2022)

Finally, planning and costing for geotechnical investigation in a construction projects should ensure that a thorough site assessment is carried out and that there is appropriate allocation of resources. As shown in Figure 4.17, majority of the respondents held the opinion that construction project cost estimates involve a quantitative analysis of the geotechnical uncertainty followed by item risk-based cost estimate of the geotechnical risks. In principle, geotechnical investigation costs can vary significantly depending on project complexity, site conditions and specific requirements. Regular communication and coordination between the project team and the geotechnical consultants/contractors is essential to ensure that the investigation plan, cots and deliverables align with the project needs.

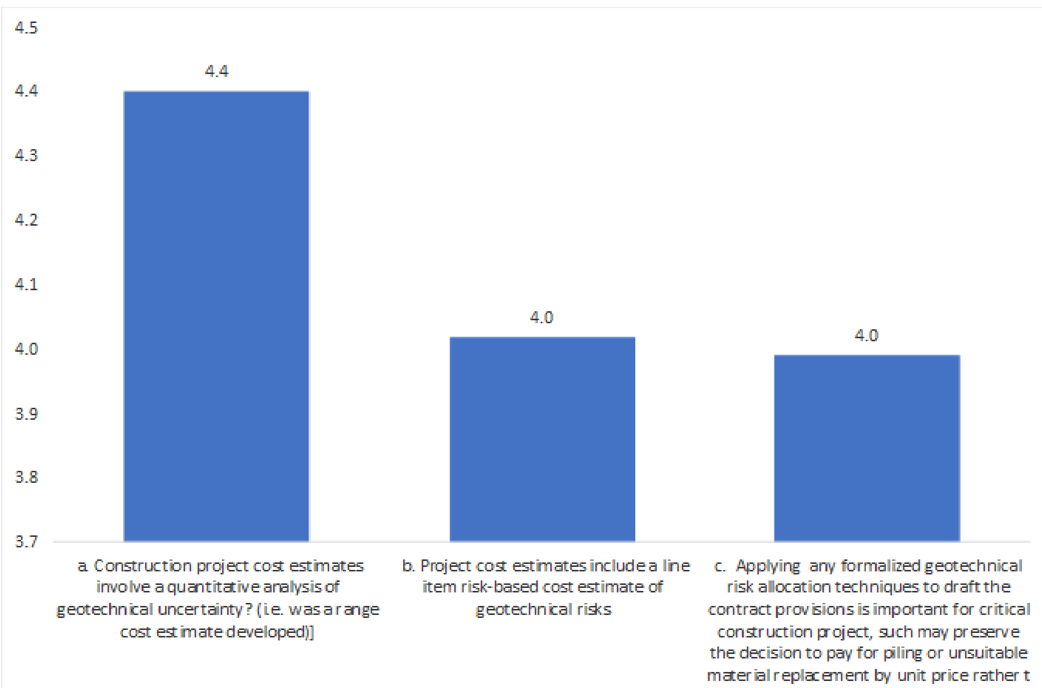

Figure 4.17: Results Showing Planning and Costing in Construction Project for Geotechnical Investigation for Risk Management

Source: (Researcher, 2022)

By following a well planned and cost-effective geotechnical investigation process, construction projects can obtain crucial geotechnical information necessary for design, risk assessment, and construction planning ultimately contributing to project success and minimizing unforeseen geotechnical challenges.

4.3.5 Objective 5: Framework for Enhancing Usage of Geotechnocal Information

Enhancing the usage of geotechnical information in Rwanda can significantly contribute to improved construction practices, infrastructure development, and overall project success. In the light of the data analysis results presented in Sections 4.3.1 to 4.3.4, a framework for this purpose can be conceptualized. Specific observations and insights from the findings, which guide the framework formulation are: (i) comprehensive geotechnical investigations; (ii) standardized use of geotechnical parameters; (iii) lifecycle integration of geotechnical data, (iv) Risk management and finally, (v) collaborative planning and cost management.

The first pillar of the proposed framework emphasizes the necessity of conducting thorough geotechnical investigations at every stage of a construction project. Often, projects suffer from delays, cost overruns, and structural failures due to incomplete or preliminary geotechnical assessments. By mandating full-spectrum geotechnical studies, including Geotechnical Baseline Reports (GBR) and Geotechnical Design Reports (GDR), the framework ensures that decisions are based on comprehensive data that accurately reflects subsurface conditions. This approach reduces the likelihood of encountering unexpected ground conditions during construction, thereby enhancing the predictability of project outcomes. Ensuring that these investigations are standard practice can prevent many of the common issues associated with inadequate geotechnical information.

The second component of the framework focuses on the consistent assessment and application of key geotechnical parameters throughout the project lifecycle. Soil shear strength, bearing capacity, and standard penetration tests are among the most critical parameters influencing the stability and safety of structures. By standardizing the assessment of these parameters before and during construction, the framework helps ensure that designs are grounded in accurate, site-specific data. This consistency is vital for maintaining structural integrity and avoiding costly post-construction modifications. The framework should also include guidelines for the periodic review of these parameters as the project progresses, allowing for adjustments to be made based on the latest data.

Integrating geotechnical information throughout the project lifecycle is the third key element of the framework. Geotechnical data should not only inform the initial design and planning stages but should also be continuously updated and utilized during construction, maintenance, and even decommissioning. This ongoing integration ensures that all project decisions—whether related to foundation design, material selection, or risk management—are based on the most current and accurate information. The framework advocates for the creation of a centralized data repository that is accessible to all stakeholders, facilitating real-time decision-making and fostering a more collaborative project environment. This approach also supports sustainability by enabling more informed decisions that account for long-term site conditions.

Effective risk management is critical to the success of construction projects, particularly when dealing with geotechnical uncertainties. The framework proposes the creation of a geotechnical risk register, a tool that systematically identifies, assesses, and mitigates geotechnical risks. This register would track potential risks such as landslides, soil liquefaction, or unexpected groundwater conditions, providing a structured approach to managing these challenges. Additionally, the framework emphasizes the importance of clear contractual agreements that delineate the responsibilities of the owner and contractor concerning geotechnical risks. By explicitly addressing these risks in contracts, the framework helps ensure that costs are allocated fairly and that all parties are prepared to manage potential issues proactively.

Finally, the framework advocates for a collaborative approach to planning and cost management in geotechnical investigations. Given the complex and variable nature of subsurface conditions, it is essential that project teams work closely with geotechnical consultants from the outset. This collaboration should extend to the development of detailed cost estimates that account for the full range of potential geotechnical challenges. By fostering regular communication between all parties, the framework ensures that geotechnical investigations are planned and executed efficiently, with resources allocated appropriately to address identified risks. This not only improves the accuracy of cost estimates but also enhances the overall reliability and success of the construction project.

The interrelationship of these factors is as shown in Figure 4.18 overleaf.

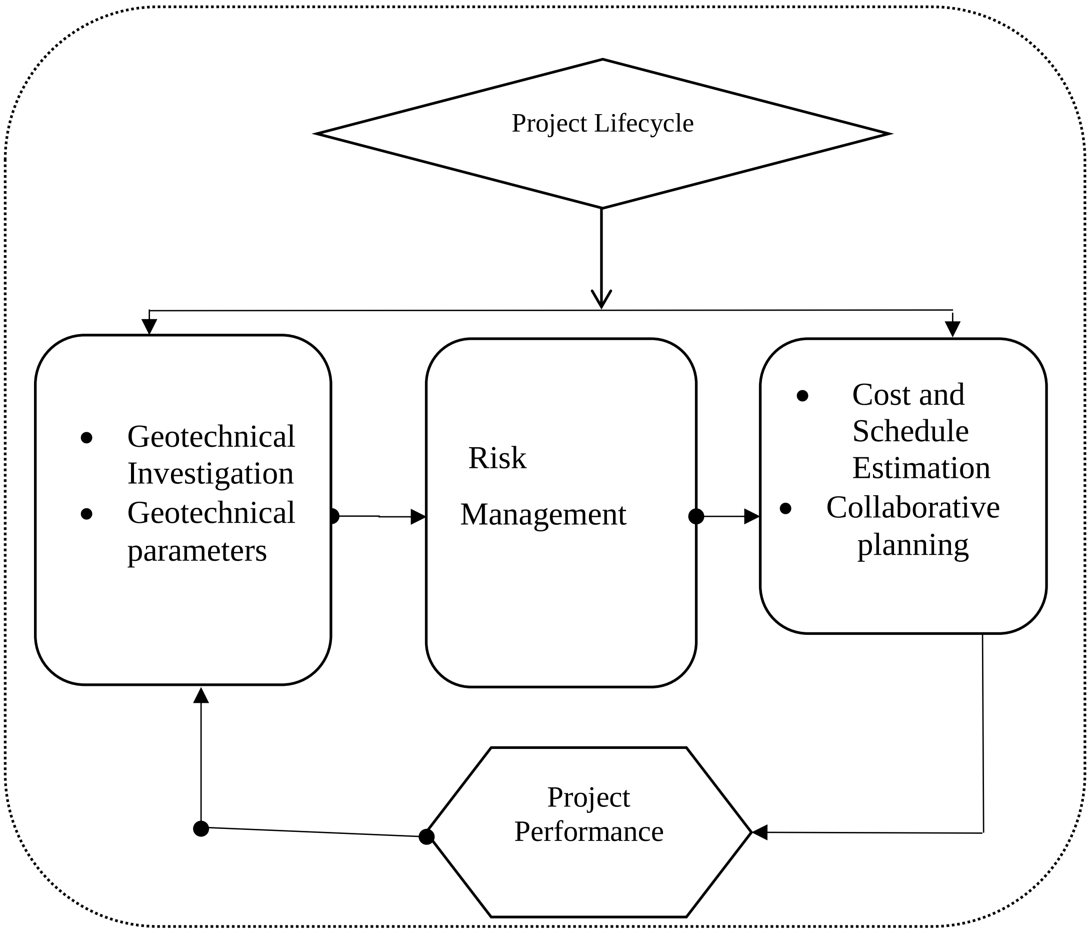

Figure 4.18: Framework for Enhancing Usage of Geotechnical Information for Improved Performance of Construction Projects in Rwanda

Source: (Researcher, 2022)

Key:

●——▶ Communication

As shown, the geotechnical study informs both project performance and risk management by providing critical data on site conditions. Geotechnical parameters such as soil shear and bearing capacity directly impact project performance and guide decisions throughout the project lifecycle, from plannig to decommission. Risk management integrates this information to identify, assess, and mitigate geotechnical risks, ensuring project safety, cost effectivenss, and successful delivery. The interconnections emphasize a holistic approach where each componet supports and enhances the others.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusions and recommendations of the study. It starts with presentation of a summary of the research findings, followed by the conclusions made in respect of each of the research objectives. Additionally, recommendations based on the research findings are given. Finally, areas for further study are suggested.

5.2 Summary of the Findings

5.2.1 Effect of Geotechnical Study on Project Performance

The analyzed data revealed that the extent and thoroughness of geotechnical studies conducted in a construction project significantly impact the project's performance, particularly in terms of cost, quality, time schedule, and scope. However, the study found that more than 85% of the surveyed institutions and companies in Rwanda do not have a formal manual or guide for conducting geotechnical investigations, which suggests that such studies are often not standardized or comprehensively utilized.

This lack of a standardized approach to geotechnical investigation directly affects the performance indicators as follows:

- **Cost:** Without a thorough geotechnical investigation, the actual ground conditions may be inadequately assessed, leading to unforeseen issues during construction. This often results in cost overruns due to additional work required to address unexpected soil conditions, such as increased excavation, stabilization efforts, or foundation redesign.
- **Quality:** Inadequate geotechnical data can lead to suboptimal design choices, such as improper foundation types or insufficient consideration of soil stability. This

compromises the structural integrity and overall quality of the construction, increasing the likelihood of defects or failures.

- **Time Schedule:** Projects are likely to face delays when geotechnical issues are encountered unexpectedly during construction. These delays arise from the need to perform additional investigations, redesigns, or remediation work, which could have been mitigated with a more comprehensive geotechnical study.
- **Scope and Variations:** Insufficient geotechnical information can lead to significant scope changes during construction, as adjustments are made to address unforeseen subsurface conditions. These scope variations are often costly and time-consuming, further impacting the project's overall performance.

5.2.2 Usage of Geotechnical Information throughout the Project Lifecycle

The survey revealed that the use of geotechnical investigation reports in project delivery has gained prominence in recent years. Specifically, 30% of respondents indicated that they had been using geotechnical reports for a period ranging between 3 to 5 years, 29% for a period of 6 to 10 years, and 27% for a period of 1 to 2 years. However, only 13% of respondents reported that geotechnical investigations had been consistently used over the last ten years. This trend suggests that geotechnical reports have only recently become a key consideration in project delivery.

The delayed adoption of geotechnical investigations has significant implications for project performance, particularly in the following areas:

- **Cost:** Projects that do not incorporate comprehensive geotechnical investigations from the outset are at risk of underestimating the financial requirements for managing subsurface conditions. This can lead to unexpected costs during construction, such as additional foundation work or soil stabilization measures, which could have been mitigated with earlier geotechnical input.
- **Quality:** The quality of construction is directly impacted by the adequacy of geotechnical data. Without proper geotechnical investigation, critical design

decisions may be based on incomplete or inaccurate information, leading to structural deficiencies or failures. Consistent use of geotechnical reports ensures that design and construction practices are based on reliable data, enhancing the overall quality of the project.

- **Time Schedule:** The lack of early geotechnical input can cause delays during construction as unexpected ground conditions necessitate redesigns or remedial actions. Projects that integrate geotechnical studies early in the lifecycle are better equipped to anticipate and manage these challenges, leading to more reliable scheduling and fewer delays.
- **Scope:** Without a clear understanding of the subsurface conditions, project scope can be subject to significant variations. These variations often arise due to the need for additional work to address unforeseen geotechnical challenges. By utilizing geotechnical reports consistently throughout the project lifecycle, the likelihood of scope changes is reduced, leading to more predictable project outcomes.

In conclusion, while the use of geotechnical investigation reports has increased in recent years, their integration into the project lifecycle remains critical to achieving optimal performance in terms of cost, quality, time, and scope. The findings highlight the importance of embedding geotechnical studies into the early stages of project planning and design to enhance overall project performance.

5.2.3 Geotechnical Parameters Affecting Project Performance

As for the size and content of the geotechnical investigation, most of people consider parameters in the range between 3 to 5, which was supported by 33% of the respondents. Only 14% of the respondents stood for beyond 10 parameters. Hence, geotechnical analysis relied on few parameters, which do not provide full information. This can be the reason for failure to deliver majority of the construction projects successively.

In assessing the effect of various geotechnical parameters on the project quality performance, analysis indicates that soil shear is ranked number one followed by organic matter, soil bearing capacity, compaction, borehole, SP, Soil permeability, soil particle distribution then others came last. Interestingly, organic matter is not considered in project delivery report as it affects more on the project quality dimension.

Looking at the findings related to effect of geotechnical parameters vis a vis cost performance. Soil shear has been ranked number one followed by both borehole and soil permeability followed by compaction and lastly SP. Hence, soil shear and borehole and soil permeability must be highly considered while targeting and regulating project cost performance.

Following the respondents' feedback on the surveying done, it is observed that soil shear, organic matter and soil bearing capacity as well as borehole and SP are highly ranked as parameters affecting much of the construction project performance. Following this, geotechnical investigation should not be taken for foundation or design consideration only but also to control the expenses related to unforeseen ground condition.

While assessing the respondents view vis a vis construction project scope performance, it has been found that soil shear, followed by compaction borehole and SP parameters affect highly construction project scope hence such parameters should well considered and deeply analyzed beforehand to control and monitor well the project scope.

5.2.4 Risks from Various Geotechnical Parameters

There are many risks to project performance, which are associated with geotechnical characteristics of the construction site. Geotechnical investigations should help to reveal those risks. Looking at how the risk register and risk management plan are done - in terms of the content of the risk register on geotechnical issues – it was observed that the risk register developed by the agency determined the risk management mitigation strategies applicable to the geotechnical risks identified, such as 'share risk' and/or 'transfer risk'. Anyway, the risk register contains geotechnical risk with a deterministic estimate of the cost and schedule impact of risk, which is rather unrealistic.

5.2.5 A Framework for Enhancing Usage of Geotechnical Information

In this study, a framework for mitigating the adverse effect of poor usage of geotechnical information in the construction project has been created. It is a schematic model integrating the relevant laws and regulations, institutions and stakeholder awareness creation, in a structured manner. Its adoption into the industry requires a more enabling policy environment in the construction industry of Rwanda.

5.3 Conclusions of the Study

From the data collected in this study, analysis of the impact of geotechnical investigations on construction projects in Rwanda was done. Expert views of the research respondents on the influence of the usage of geotechnical information on performance of construction projects in Rwanda were analyzed. Findings were gotten for each of the stated research objectives. Therefore, the research aim was achieved.

In brief, conclusions on the study can be made as follows: -

a. Impact on Construction Project Performance Indicators: All the indicators of construction project performance considered in this study—scope, cost, time, quality, and safety—are affected by geotechnical investigation parameters. Of the eight geotechnical parameters analyzed, at least six affect all performance indicators.
b. Key Geotechnical Parameters: Soil shear strength was found to have the highest impact, affecting all performance indicators—quality, cost, time, and scope. Soil bearing capacity significantly affects time, cost, and quality. Organic matter ranked second, influencing time and quality performance. Parameters such as soil plasticity (SP) and borehole characteristics are also important, impacting quality, time performance, and scope. These findings highlight the need for early attention to geotechnical parameters to ensure effective mitigation measures are implemented in a timely manner.

c. Usage of Geotechnical Information: It was observed that geotechnical investigations are often conducted as part of project documentation rather than being used as tools for quality, cost, schedule, and scope control. This limited usage explains why risks associated with geotechnical investigations remain significant.
d. Geotechnical Risks: Geotechnical parameters contribute to various risks; however, these risks are not adequately captured in the risk registers of project leaders. This results in unrealistic cost and schedule risk estimates, leading to poor risk management in construction projects.
e. Enhancing Project Performance through Geotechnical Information: To improve the use of geotechnical information and thereby enhance project performance, a structured approach is necessary. This involves establishing a framework of relevant laws, regulations, institutions, and stakeholders. A schematic model of this framework was formulated in this study.

In conclusion, the research demonstrates that geotechnical investigations have a significant impact on the performance of construction projects in Rwanda. Addressing geotechnical parameters early and using geotechnical information as a core component of project control can mitigate risks and enhance overall project performance.

5.4 Recommendations of the Study

Two recommendations can be made in this study, as follows: -

1. The organizational framework developed in this study should be adopted in the construction industry of Rwanda. This takes account of all the project performance and geotechnical variables considered in the study, because it is the observations made on the variables, which guided formulation of the framework. Therefore, by implementing the framework, Rwanda can strengthen its geotechnical practices in construction industry and boost project performance in the industry.

2. An enabling environment for the framework adoption should be created by the Government of Rwanda, through formulation of the necessary construction industry policies, prescription of the necessary changes in professional practices, and political support to the institutions required in the framework.

5.5 Areas for Further Study

In order to advance the concepts and ideas addressed in this study, three areas of further study are suggested as follows:

1. To carry out a stakeholder validation of the organizational framework developed in the study. For practical reasons, this exercise was outside the scope of this study.
2. To develop guiding tools and systems of geotechnical nature for the control of project quality at the initialization phase.
3. To evaluate the geotechnical behaviour of grounds under/around built structures to compare with the predictions made in the engineering design of the project.
4. To conduct a similar study - to investigate impact of geotechnical investigations on construction project performance in Rwanda – with a more representative sample, which is achievable in a post-COVID-19 context. With such data, more exhaustive statistical analysis of the variable relationships shown in the Conceptual Framework of this study can be done.

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APPENDICES

Appendix I: Questionnaire

ANALYSIS OF IMPACTS OF GEOTECHNICAL INVESTIGATION ON CONSTRUCTION PROJECTS PERFORMANCE: CASE STUDY OF KIGALI RWANDA

People argue that geotechnical investigation could be important or less important as per construction project size. However, it affects highly any construction project performance. This study through a set of questionnaires has been developed to come up with academic facts to support relevance, significance and definition of impacts of geotechnical investigation for any construction project Quality, cost, time and scope management as part award of Master of Construction, Project Management at Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.

We thank you for your participation while responding to the set of questionnaires related to this topic

PART A: General Information

1. Based on the following list, what organizations do you work for?
    - Public
    - Private
    - Contractor
    - Consultant
    - Other
2. What section do you work in?
    - Design group
    - Construction group
    - Operations group
    - Geotechnical/foundation group
    - Permitting section
    - Other
3. What project delivery methods is your organization allowed to use?
    - Design and Built
    - Construction Manager-at-Risk or Construction Manager/General Contractor
    - Design and Built Best Value
    - Design and Built Low Bid
    - Other

4. How many Design and Built or any projects has your agency delivered under your responsibility over the last 5 years?
   - 1-2
   - 3-5
   - 6-10
   - Over 10 years

5. How long has your agency been using Geotechnical Investigation Reports in Project Delivery?

   - 1-2 years
   - 3-5 years
   - 6-10 years
   - Over 10 years

6. How many geotechnical parameters do you mostly focus on for geotechnical analysis?

   - 1-2
   - 3-5
   - 6-10
   - Over 10

Part B: Geotechnical Risk Management Information Section

7. Does your agency have a manual or document that specifically describes the procedures to be used with the geotechnical requirements of construction projects.

   - No
   - Yes

8. To what extent Preliminary geotechnical investigation is completed before making the decision to start execution of construction project in your organization?

Ranking Scale: *0: Not Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important*

		Not Important	Somewhat Important	Important	Very Important	Strongly Important
a)	Reconnaissance Report (Review of records and observations from site)	◯	◯	◯	◯	◯
b)	Data Report (Review of records and limited investigation data)	◯	◯	◯	◯	◯
c)	Summary Report (Review of records and geotechnical investigation of critical areas)	◯	◯	◯	◯	◯
d)	Preliminary Geotechnical Design Report (Partial geotechnical investigation)	◯	◯	◯	◯	◯
e)	Geotechnical Design Report (Full subsurface investigation for all structures and geotechnical features)	◯	◯	◯	◯	◯
f)	Geotechnical Baseline Report (GBR). A report that establishes the contractual understanding of subsurface site conditions and upon which risks associated with subsurface conditions can be allocated between the owner and the design-builder)	◯	◯	◯	◯	◯
g)	Geotechnical Interpretation Report (GIR). A report that interprets the findings	◯	◯	◯	◯	◯

h) **None** ◯ ◯ ◯ ◯ ◯

9. To what extent is the following data relevant in Construction Project Delivery for geotechnical investigation significance?

Ranking Scale: 0: Not Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important

	Not Important	Somewhat Important	Important	Very Important	Strongly Important
a) Soil Shear	◯	◯	◯	◯	◯
b) Soil Particle Distribution	◯	◯	◯	◯	◯
c) Compaction	◯	◯	◯	◯	◯
d) Soil Permeability	◯	◯	◯	◯	◯
e) Soil Bearing Capacity	◯	◯	◯	◯	◯
f) Organic Matter	◯	◯	◯	◯	◯
g) Borehole	◯	◯	◯	◯	◯
h) SPT	◯	◯	◯	◯	◯
i) Other	◯	◯	◯	◯	◯

10. How do the following geotechnical parameters affect construction project performance?

Ranking Scale: 0: Not Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important

	Not Important	*Somewhat Important*	*Important*	*Very Important*	*Strongly Important*
a) Soil Shear	◯	◯	◯	◯	◯
b) Soil Particle Distribution	◯	◯	◯	◯	◯
c) Compaction	◯	◯	◯	◯	◯
d) Soil Permeability	◯	◯	◯	◯	◯
e) Soil Bearing Capacity	◯	◯	◯	◯	◯
f) Organic Matter	◯	◯	◯	◯	◯
g) Borehole	◯	◯	◯	◯	◯
h) SPT	◯	◯	◯	◯	◯
i) Other	◯	◯	◯	◯	◯

11. How do the following geotechnical parameters affect construction project quality performance?

Ranking Scale: 0: Not Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important

	Not Important	**Somewhat Important**	**Important**	**Very Important**	**Strongly Important**
a) Soil Shear	◯	◯	◯	◯	◯

b)	Soil Particle Distribution	◯	◯	◯	◯	◯
c)	Compaction	◯	◯	◯	◯	◯
d)	Soil Permeability	◯	◯	◯	◯	◯
e)	Soil Bearing Capacity	◯	◯	◯	◯	◯
f)	Organic Matter	◯	◯	◯	◯	◯
g)	Borehole	◯	◯	◯	◯	◯
h)	SPT	◯	◯	◯	◯	◯
i)	Other	◯	◯	◯	◯	◯

12. How do the following geotechnical parameters affect construction project Cost performance?

Ranking Scale: 0: Not Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important

		Not Important	Somewhat Important	Important	Very Important	Strongly Important
a)	Soil Shear	◯	◯	◯	◯	◯
b)	Soil Particle Distribution	◯	◯	◯	◯	◯
c)	Compaction	◯	◯	◯	◯	◯

d)	Soil Permeability	◯	◯	◯	◯	◯
e)	Soil Bearing Capacity	◯	◯	◯	◯	◯
f)	Organic Matter	◯	◯	◯	◯	◯
g)	Borehole	◯	◯	◯	◯	◯
h)	SPT	◯	◯	◯	◯	◯
i)	Other	◯	◯	◯	◯	◯

13. How do the following geotechnical parameters affect construction Time performance?

Ranking Scale: 0: Not Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important

		Not Important	Somewhat Important	Important	Very Important	Strongly Important
a)	Soil Shear	◯	◯	◯	◯	◯
b)	Soil Particle Distribution	◯	◯	◯	◯	◯
c)	Compaction	◯	◯	◯	◯	◯
d)	Soil Permeability	◯	◯	◯	◯	◯
e)	Soil Bearing Capacity	◯	◯	◯	◯	◯
f)	Organic Matter	◯	◯	◯	◯	◯
g)	Borehole	◯	◯	◯	◯	◯

h) **SPT**	◯	◯	◯	◯	◯
i) **Other**	◯	◯	◯	◯	◯

14. How do the following geotechnical parameters affect construction Scope performance?

Ranking Scale: 0: Not Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important

	Not Important	**Somewhat Important**	**Important**	**Very Important**	**Strongly Important**
a) **Soil Shear**	◯	◯	◯	◯	◯
b) **Soil Particle Distribution**	◯	◯	◯	◯	◯
c) **Compaction**	◯	◯	◯	◯	◯
d) **Soil Permeability**	◯	◯	◯	◯	◯
e) **Soil Bearing Capacity**	◯	◯	◯	◯	◯
f) **Organic Matter**	◯	◯	◯	◯	◯
g) **Borehole**	◯	◯	◯	◯	◯
h) **SPT**	◯	◯	◯	◯	◯

i) **Other**	◯	◯	◯	◯	◯

15. Is a formal geotechnical risk analysis conducted on a typical project in any of the following areas?

	Qualitative	***Quantitative***	***Non-Formal Geotechnical Risk Analysis***
a) **Project Scope**	◯	◯	◯
b) **Project Schedule**	◯	◯	◯
c) **Project Cost**	◯	◯	◯
d) **Project Quality**	◯	◯	◯
e) **Contracting Risk**	◯	◯	◯
f) **Other**	◯	◯	◯

16. Within the geotechnical risk management process that is conducted by the agency or required of the design builder, please select all that apply, whether on a DB typical or any other model of construction project with significant geotechnical issues

	Design Built typical project	**Design Built project with significant geotechnical risk**
a) **Formal risk identification meetings are conducted**	◯	◯

b)	**Project Schedule**	◯	◯
c)	**Project Cost**	◯	◯
d)	**Project Quality**	◯	◯
e)	**Contracting Risk**	◯	◯
f)	**Other**	◯	◯

17. Risk Register and Risk Management plan. Which of the following best describes the content of the risk register of geotechnical issues if not fully done?

		Not Register	Somewhat Register	Register	Very	Strongly Important
a)	**Risk register developed by the agency determines the risk management mitigation strategies applicable to the geotechnical risks identified (such as share, transfer and avoid)**	◯	◯	◯	◯	◯
b)	**Risk register developed by the agency - encompassing geotechnical risks is maintained during the course of the project (e.g. geotechnical risks that are not materialized**	◯	◯	◯	◯	◯

	are retired during the course of the project and contingencies are revised)					
c)	**Risk Register developed contains geotechnical risks with a deterministic estimate of the cost and schedule impact of risk**	○	○	○	○	○
d)	**Risk Register developed contains geotechnical risks with a deterministic estimate of the cost and schedule impact of risk**	○	○	○	○	○

18. What types of geotechnical parameter you take as per risks and typically encounter on and who covers its expenses? Check all that apply for below uncertainty in Ground conditions.

a) Unknown geological condition

- ○ Owner
- ○ Contractor
- ○ Shared

b) Groundwater

- ○ Owner
- ○ Contractor
- ○ Shared

c) Soft days, organic silts or peat

- Owner
- Contractor
- Shared

d) Rock Faults, Fragmentation

- Owner
- Contractor
- Shared

e) Chemically Reactive Ground

- Owner
- Contractor
- Shared

f) Slope Instability

- Owner
- Contractor
- Shared

g) Settlement

- Owner
- Contractor
- Shared

h) Subsidence (Subsurface voids)

- Owner
- Contractor
- Shared

i) Landslides

- Owner
- Contractor
- Shared

j) Karst Formations

- Owner
- Contractor
- Shared

k) Others

- Owner
- Contractor
- Shared

19. What types of geotechnical parameter you take as per risks and typically encounter on and who covers its expenses? Check all that apply for below uncertainty in design process

a) Inadequate geotechnical investigation

- Owner
- Contractor
- Shared

b) Incorrect geotechnical design information

- Owner
- Contractor
- Shared

c) Bias and/or variation in design parameters being different than estimated

- Owner
- Contractor
- Shared

d) Inaccurate earthwork assumptions - soil or rock cuts or fills

- Owner
- Contractor
- Shared

e) Risk in retaining structures assumptions and recommendations - geotechnical aspects

- Owner
- Contractor
- Shared

f) Risk in structure foundations assumptions and Recommendations (footings, driven piles, drilled shafts, etc.)

- Owner
- Contractor
- Shared

g) Risk in ground improvement technique recommendations (wick drains, lightweight fill, vibro-compaction, dynamic compaction, stone columns, grouting, etc.)

- Owner
- Contractor
- Shared

h) Risk in seismic design assumptions and recommendations

- Owner
- Contractor
- Shared

i) Risk allocation in the differing site conditions contract clause

- Owner
- Contractor
- Shared

j) Other

- Owner
- Contractor
- Shared

21. Planning and costing in construction project for geotechnical investigation for risk management

Ranking Scale: 0: Not Important, 1: Less Important, 2: Somewhat Important, 3: Important, 4: Very Important, 5: Strongly Important

	Not Important	Somewhat Important	Important	Very Important	Strongly Important
a) **Construction project cost estimates involve a quantitative analysis of geotechnical uncertainty (i.e. was a**	◯	◯	◯	◯	◯

	range cost estimate developed)					
b)	**b) Project cost estimates include a line item risk based cost estimate of geotechnical risks**	◯	◯	◯	◯	◯
c)	**c) Applying any formalized geotechnical risk allocation techniques to draft the contract provisions is important for critical construction project, such may preserve the decision to pay for piling or unsuitable material replacement by unit price rather than including it in the lump sum amount**	◯	◯	◯	◯	◯

Part C: Geotechnical Aspects of Design-Build or any Construction Procurement Process

21. If geotechnical parameters are included in the evaluation plan, how much weight do they carry with regard to all other evaluated factors?

Not Weight at all				**Heavy Weight**
◯	◯	◯	◯	◯

22. How much geotechnical information is provided in the construction project for proposals? Is a construction project with significant geotechnical investigation an issue?

		Not Important	Somewhat Important	Important	Very Important	Strongly Important
a)	**Reconnaissance Report (review of record observations from site)**	◯	◯	◯	◯	◯
b)	**Project cost estimates include a line item risk based cost estimate of geotechnical risks**	◯	◯	◯	◯	◯
c)	**Geotechnical summary report (review of records and geotechnical investigation of critical areas)**	◯	◯	◯	◯	◯
d)	**Preliminary Geotechnical design report (partial geotechnical investigation)**	◯	◯	◯	◯	◯
e)	**Geotechnical design report (full subsurface investigation for all structures and geotechnical features)**	◯	◯	◯	◯	◯
f)	**f) Geotechnical baseline report (GBR)**	◯	◯	◯	◯	◯
g)	**None**	◯	◯	◯	◯	◯

23. How do you rate the final quality of geotechnical work on construction projects and how does it influence construction project performance?

	Not Important	Somewhat Important	Important	Very Important	Strongly Important
a) **The final quality of geotechnical work does influence construction project performance**	◯	◯	◯	◯	◯