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Causes and Impacts of Geotechnical Problems on Bridge and Road Construction Projects

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CAUSES AND IMPACTS OF GEOTECHNICAL PROBLEMS ON BRIDGE AND ROAD CONSTRUCTION PROJECTS

by

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Bachelor of Engineering- Civil Engineering
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ABSTRACT

Causes and Impacts of Geotechnical Problems on Bridge and Road Construction Projects

By Krishna P. Neupane

Changes during the construction phase generate cost growth, schedule delays, and claims in any project. However, the impact of geotechnical problems on construction costs, schedules, and claims in bridge and road projects had not been investigated in depth. The major objectives of this study were to determine the geotechnical-related causes of cost and schedule growth and claims as well as their impacts on the bridge and pavement projects' performance. This study also identifies mitigation measures to avoid cost and schedule growth and claims in these projects.

A survey was conducted with 53 engineers from state Department of Transportations (DOTs) and 43 engineers from design consultant firms. It was found that the geotechnical-related causes that most impacted the costs, schedules, and claims of bridge projects were lack of boring locations and misclassified subgrade. The majority of the respondents stated that these geotechnical-related causes had negative impacts on cost and schedule growth and the number of claims for bridge projects during construction. When asked about pavement projects, the respondents stated that the significant problems to impact the cost and schedule growth and claims were misclassified subgrade and a level of groundwater table higher than expected. The results regarding the impact of these geotechnical-related causes on project performance were similar to those of bridge projects. The survey results also showed three major preventive measures to reduce these cost overruns, schedule growth, change orders, and claims were: the designer having detailed knowledge about the project site's geotechnical information, a detailed

site investigation with a well-experienced consultant, and the development and implementation of minimum standards for subsurface investigation and site characterization.

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LIST OF ABBREVIATIONS

Abbreviations	Stands For
AASHTO	American Association of State Highway and Transportation Officials
CPT	Cone Penetration Testing
CO	Change Orders
DOT	Department of Transportation
FHWA	Federal Highway Administration
LRFD	Load and Resistance Factor Design
NHI	National Highway Institute
RII	Relative Importance Index
SPT	Standard Penetration Test
UNLV	University of Nevada, Las Vegas
USA	United States of America

CHAPTER 1: INTRODUCTION

1.1 Background

Normally, construction projects are planned to be completed on schedule and within the estimated budget. In reality, the schedule and budget may change in transportation projects. These geotechnical reasons can generate claims, cost growth, and schedule growth in civil infrastructure construction projects. Cost growth due to change order is a common phenomenon in transportation projects (Flyvbjerg et al., 2004). Similarly, stated that a small alteration in the construction project could bring claims and disputes between owner and contractor (Alnuaimi et al., 2010). Therefore, this study is intended to explore the geotechnical issues that cause claims, change orders, and cost overruns.

Many publications discuss the causes and impact of claims, change orders and cost overruns in different civil construction projects such as buildings, highways, tunnels, hydropower, and water infrastructure projects. However, there are a limited number of research papers concerning claims, change orders, and cost overruns due to geotechnical reasons. This study compares the causes and effects of claims, change orders and overruns, and identifies remedies in bridge and road pavement construction projects.

1.1.1 Claims

A construction contract concerns an agreement between two parties: one party provides services or materials for construction, and another party pays for the services and materials. When one party perceives that the contract agreement has not been fulfilled, and they sense an authentic budgetary and/or time redress, they may put forward a claim.

Boeckmann & Loehr (2016) stated that a claim is a legal petition by a contractor for extra recompense or time when the contractor think he/she is allowed to it under the terms of the contract documents. Similarly, according to Kartam (1999), a claim is a legal contract approach used to evaluate contract arguments between the contracting parties, who also mentioned that claims might arise between owners and contractors or contractors and sub-contractors. If the parties fail to sort out the disputes through deliberation, then the claim case will go to court (p. 2). The basic sources of claims are the followings: (1) contract documents with errors, (2) unreasonable estimation of a project, (3) alteration of site conditions, and (4) involved stakeholders in a project (Kululanga et al., 2001)

1.1.2 Change Orders

Hanna et al. (2002) defined a change order as “any event that results in a modification of the original scope, execution time or cost of work, happens on the most projects due to the uniqueness of each project and the limited resources of time and money available for planning” (p. 1). According to Civitello (1987), a change order results in the following problems: (1) increases or decreases in the scope of the work, (2) changes in specifications of the character or quality of the material and (3) changes to the level, position, or dimension of any part in the original contract of the scope of the work.

Change orders may occur for various reasons in construction projects; they are: “unexpected and unpredictable site conditions, inadequate site investigation, design errors, weather conditions, increases in project scope, and other project changes” (Prezzi et al., 2011, p. 3). Depending upon the type of construction project, these factors directly affect the construction job in various ways. Among these causes, unpredictable site conditions and inadequate site investigation could be more vital causes for a change order in bridge and road pavement construction projects.

1.1.3 Cost Overruns

A cost overrun is an increased project cost above the original budgeted amount to complete the construction project (Avots, 1983). Lee (2008) found that changes in the project scope, delays in construction, unjustified estimation and adaptation of the project cost, and no practical use of the earned value management system are frequent causes of cost overrun in transportation construction projects. Similarly, Thomas et al. (1995) and Hanna et al. (1999) claimed that change orders are the common cause for cost overruns and schedule delay of projects.

1.1.4 Geotechnical Investigations

The geological condition of the subsurface cannot be known without detailed site investigations. In this unpredictable site condition, sufficient information from the geotechnical investigation is required to know about the geotechnical risk. A common cause of subsurface failure is a lack of knowledge about ground conditions. Unpredictable ground conditions can also lead to remarkable cost overruns and time delays for construction parties. By using the various methods of field and laboratory testing, site investigations reduce these ground uncertainties. However, cost and time limitations, as well as the acumen and insight of the geotechnical engineer and geologist who are directly involved in the project, have controlled the site investigations' scope (Goldsworthy et al., 2004).

Geotechnical investigations are the process of evaluating the geological, seismological, and soil conditions that affect the safety of the project, the effectiveness of the project's cost and design, and the completion time of a nominated construction project (Engineer Manual, 2001). The cost and completion time of civil constructions are interconnected to the subsurface conditions of the construction site. If geotechnical risks are present in the construction site during the construction period, it will increase the construction cost and completion time of the project. Experienced consultants affiliated with the project from the feasibility stage can consider the geotechnical risks in a proper way with the help of their previous experience, which helps to reduce the risks (Hoke and Palmieri, 1998).

1.2 Objectives of the Study

The objectives of this study are the following:

- To study the differences in the perceptions of clients (state Departments of Transportation) and consultants about use of geotechnical investigation methods and use of standard design guidelines in bridge and road pavement projects.
- To rank the geotechnical-related causes of cost and schedule growth, change orders, and claims in bridge and road pavement construction projects.
- To determine the range in percentage of the total project cost for geotechnical investigations during the design phase of bridge and road pavement projects.
- To determine the range of cost and schedule growth in bridge and road pavement projects.
- To identify recommended strategies by clients and consultants to mitigate such cost and schedule growth, change orders, and claims.

1.3 Research Hypotheses

Table 1 shows the six research hypotheses on the causes of change orders, overruns and claims due to geotechnical related problems, methods, and standards used for geotechnical investigation. The hypotheses formulated based on the impact of geotechnical changes on the change orders, overruns and claims in bridge and pavement construction are shown in Table 2.

Table 1. Research Hypotheses on Geotechnical-Related Causes of Cost and Schedule Growth, Change Orders, and Claims

No.	Research Hypotheses
I	Ha1: The rank of use of geotechnical investigation standards while designing bridge and road pavement construction by clients and consultants is significantly different
II	Ha2: The rank of methods of subsurface investigation while designing bridge and road pavement construction by clients and consultants is significantly different
III	Ha3: The rank of effect of the geotechnical-related problems during design on cost growth during bridge and road pavement construction by clients and consultants is significantly different
IV	Ha4: The rank of effect of the geotechnical-related problems during design on construction schedule growth during bridge road pavement construction by clients and consultants is significantly different
V	Ha5: The rank of effect of the geotechnical-related causes during design on bridge road pavements construction claims by clients and consultants is significantly different
VI	Ha6: The rank of recommendations for reducing the cost and schedule growth, change orders, and claims in bridge and road pavement construction due to geotechnical-related causes by clients and consultants is significantly different

Table 2. Research Hypotheses on the Impact of Geotechnical-Related Causes on Cost and Schedule Growth, Change Orders, and Claims in Bridge and Pavement Construction

No.	Research Hypotheses
I	Ha1: The proportion of respondents who stated that geotechnical-related causes had negative impact on cost growth during the construction of bridge and road pavement projects are not equal for these two groups
II	Ha2: The proportion of respondents who stated that geotechnical-related causes had negative impact on schedule growth during the construction of bridge and road pavement projects are not equal for these two groups
III	Ha3: The proportion of respondents who stated that geotechnical-related causes had negative impact on claims during the construction of bridge and road pavement projects are not equal for these two groups

1.4 Null Hypotheses

To perform statistical tests, the research hypotheses were converted to null hypotheses. The p-value must be less than or equal to 0.05 to reject the null hypothesis. Table 3 and Table 4 show the null hypotheses.

Table 3. Null Hypotheses on Geotechnical-Related Causes of Cost and Schedule Growth, Change Orders, and Claims

No.	Null Hypotheses
I	H01: There is not a significantly different between consultant's and client's rank for the use of geotechnical investigation standards while designing bridge and road pavement projects
II	H02: There is not a significantly different between client's and consultant's rank for the methods of subsurface investigation while designing bridge and road pavement construction
III	Ha3: There is not a significantly different between client's and consultant's rank of effect of the geotechnical-related problems during design on cost growth during bridge and road pavement construction
IV	H04: There is not a significantly different between client's and consultant's rank for the effect of the geotechnical-related problems during design on construction schedule growth during bridge road pavement construction
V	H05: There is not a significantly different between client's and consultant's rank for the effect of the geotechnical-related problems during design on bridge and road pavements construction claims
VI	H06: There is not a significantly different between client's and consultant's rank for the recommendations for reducing the cost and schedule overruns and claims in bridge and road pavement construction due to geotechnical-related causes

Table 4. Null Hypotheses on the Impact of Geotechnical-Related Causes on Cost and Schedule Growth, Change Orders, and Claims in Bridge and Pavement Construction

No.	Null Hypotheses
I	H01: The proportion of respondents who stated that geotechnical-related causes had negative impact on cost growth during the construction of bridge and road pavement projects are equal for these two groups
II	H02: The proportion of respondents who stated that geotechnical-related causes had negative impact on schedule growth during the construction of bridge and road pavement projects are equal for these two groups
III	H03: The proportion of respondents who stated that geotechnical-related causes had negative impact on claims during the construction of bridge and road pavement projects are equal for these two groups

1.5 Research Scope and Limitations

This study is limited to bridge and road pavement construction projects in the United States of America (USA). The survey was carried out from March 2016 to May 2016.

CHAPTER 2: LITERATURE REVIEW

The following literature review was conducted using various sources, including books, conference papers, the Internet, as well as construction management and civil engineering journals. The review of previous study is grouped into four sections. The first section covers the literature related to the claims. The second section explores the literature about the change orders. The third section includes the literature related to the cost overruns and schedule delay. And the last sections summarize the literature reviews related to the geotechnical reasons for claims, change orders, and cost overruns and schedule delay.

2.1 Claims

Semple et al. (1994) conducted research to learn the basic causes of claims in construction in order to minimize construction claims and disputes. Twenty-four projects in western Canada were analyzed for construction claims and the authors identified that increases in the extent of the work, weather, confined access, and escalation were the most common causes of those claims. Changes in design, extra work, and errors were also included in “increase in scope” (p. 793). The authors mentioned that most of the claims added significantly to project costs and project duration. Cost overruns of construction were in the range of 30%-100% of original contract cost and delays overreached the early contract period by over 100%. Delay in construction leads to cost overrun by extending site overhead and reducing output, including other direct and indirect costs. The following recommendations were provided to reduce construction claims: (1) adequately allocating time at the design stage of project, (2) following the Critical Path Method to control the cost, schedule, and analysis of productivity, (3) evaluating the change orders to develop the proper mechanism, and (4) applying value engineering and constructability throughout the life cycle of project.

Zaneldin (2006) studied 124 roads and building construction projects in the United Arab Emirates with the highest numbers of claims to learn the information about the causes of claims, their types, and the degree of their occurrence. For this study, the three parties of construction (client, contractor, and consultant) were requested to provide the information on claims related to their projects. Nine clients, thirty-three consultants, and twenty-nine contractors responded. Based on the collected data from the three parties, Zaneldin (2006) revealed the six main types of claims are: "(1) contract ambiguity claims, (2) delay claims, (3) acceleration claims, (4) changes claims, (5) extra-work claims, and (6) different site condition claims" (p. 3-4). The author also suggested some basic methods to reduce the number of construction claims based on his study. These include: (1) to assign a pragmatic time for the design team, which reduces disputes by providing clear and real contract documents, (2) to avoid ambiguity, contracts should be written clearly, (3) before signing, the contract should be read several times, (4) to establish a proper record-keeping system, and (5) to generate collaborative and problem-solving perspectives.

2.2 Change Orders

Moselhi (1991) conducted a study about correlations between change orders and labor productivity. The author used 90 cases from 57 different construction projects to identify this relation. The author found that there was a direct correlation between the loss of labor productivity and labor component change orders. This study supports the claim by Hanna et al. (1999). According to Hanna et al. (1999), change orders typically increase costs by extending the project duration or delaying the project process and often cause labor productivity losses. Similarly, according to Anastasopoulos et al. (2010), change orders also depend upon the size of the construction projects. They found that the frequency of change orders was directly correlated with the size of projects.

Serag (2010) studied how owner-created change orders influenced project cost in order to develop a model for the quantification of increased percentages due to the change orders. Sixteen large construction projects by Florida's DOT were analyzed; Serag (2010) concluded that the timing of change orders was one of the most remarkable factors that affected the amplification of contract price. To find out the cause of the increase in the percentage of the original contract price as a result of the change order, public owners were interviewed. According to Serag (2010), the range of increase in the original price was 0.01-15%. Based on that study, the author developed a model to quantify percentage expansions in early contract costs at different periods of time during the lifetime of the project and claimed that the model would be helpful to forecast the change order cost before the contract. To develop a model for the quantification of increased percentage, Serag (2010) conducted almost five interviews with resident engineers and consultants from nine districts of FDOT. In addition, two unstructured interviews were performed with five claims consultants who worked in the area of construction claims for both parties (clients and contractors).

Taylor et al. (2012) analyzed 610 Kentucky DOT projects with change orders completed between 2005 and 2008. The objective of this research was to investigate the leading risk produced by the change orders, the leading cause of the change orders, and the frequency and average percentage in change in cost for different types of change orders. Taylor et al. (2012) explored fuel & asphalt price adjustments, contract omissions, owner-induced enhancements, and contract item overruns as the major causes of the change orders in Kentucky's Transportation Cabinet projects. In this research, data was gathered through independent interviews with field engineers from four different districts in southern and central Kentucky and one interview with an administrator in the central Cabinet construction office. Based on these interviews, Taylor et al. (2012) claimed that, by project scoping and enhanced early planning, all the causes of change orders except fuel & asphalt price adjustments could be avoided. According to the authors, due to rapidly changing market trends, avoidance of fuel and asphalt price adjustments was more challenging than other change orders.

Halwatura and Ranasinghe (2013) conducted a study on causes of change orders in road construction projects in Sri Lanka to find out the degree of frequency and their effect. Based on a questionnaire survey with 50 respondents related to road constructions, the authors identified that poor estimations, unforeseen site conditions, political pressures during the construction stage, poor investigations, and client-initiated variations were the top five causes of the 55 causes of change orders listed by authors collected from the literature review.

2.3 Cost and Schedule Growth

Flyvbjerg et al. (2004) found that cost overrun (escalation) in transportation infrastructure development projects is a common, worldwide phenomenon. This conclusion was based on the study of three types (rails: 58, tunnels and bridges: 33, and roads: 167) of 258 projects covering twenty nations spanning five continents. The authors mentioned that the average cost overrun for rails was 45%, 34% for tunnels and bridges, and 20% for roads.

Hinze et al. (1991) studied 468 transportation projects completed for the Washington state Department of Transportation. They found that the percentage of cost overruns with respect to original contract amount was directly correlated with the size of projects.

Le-Hoai et al. (2008) carried out a questionnaire survey with 87 construction experts in Vietnam to find out the causes of delays in construction schedules and cost overruns. The research was mainly focused on the following areas: discovering the causes of delays and cost overruns and ranking these causes in terms of their frequency and severity of scale, testing the importance of these causes, and finding the strength of the relationships between the rating responses of different respondent groups. To garner responses, the survey questionnaire was randomly distributed to owners, consultants, and contractors. A total of 285 questionnaires were sent to construction professionals concerned with large projects. The following response rates were collected from three parties of construction: contractors - 43.7%, consultants - 23%, and owners - 33.3%. Similarly, different response rates from different types of projects were recorded, i.e., 75.9%- building and industrial projects, 17.2%- hydroelectric and irrigation projects, 4.6%- bridge and road projects, and 2.3%- others. From the questionnaire, 21 causes were collected and listed. Those causes divided into 6 different groups. The collected data was analyzed in terms of frequency index and ranking, severity index and ranking, importance index and ranking, and Spearman's rank correlation. Le-Hoai et al. (2008) concluded that the most frequent and severe causes of delays and cost overruns were: imperfect site management and supervision, deficient project management assistance, investment strains of the owner, monetary troubles of the contractor, design changes, and unforeseen site conditions.

Lee (2008) found that the main causes of cost overruns in construction projects were: changes in the scope of the project, delays in construction, unrealistic estimations or modifications of the project cost, and no practical use of the earned value management system. The outcomes of his study were based on a total of 161 completed projects, including 138 roads, 16 rails, 2 airports, and 5 port projects during the period between 1985 and 2005 in Korea. The analyzed data was collected from two different sources. They were the "Ministry of construction and Transportation (MOCT), and the Ministry of Maritime Affairs and Fisheries (MOMF)" (p. 59). The author also mentioned that, in the case of roads, 95% of projects have a maximum cost overrun of 50%, whereas 100% of rail projects have a maximum cost overrun of 50 %. It was not viable to generalize the cost overruns related to airport and port projects because of their very small sample sizes.

Kaliba et al. (2009) conducted research on the cost increases and timeline delays in road construction projects in Zambia. This study identified eight major causes of cost escalation: bad weather due to heavy rains and resulting floods, scope changes, environmental protection and mitigation costs, schedule delays, strikes, local government pressures, technical challenges, and inflation were found to be major contributors to cost escalation. The data of this study was collected using structured interviews, questionnaires and case studies of road construction projects in Zambia.

Alnuaimi et al. (2010) performed a case study on four types of construction projects: (1) water transmission projects, (2) building projects, (3) road projects, and (4) port projects. Based on these case studies, the authors made the conclusion that change orders in construction projects are the main factors in cost and time overruns. After these studies, the researchers conducted a field survey among 30 clients, 25 contractors, and 20 consultants who all worked on analogous types and sizes of projects presented in the above case studies to find out the causes, effects, benefits, and remedies of change orders on public construction projects in the context of Oman. They found that the owner requesting additional work is the number one cause of change orders. The delayed completion date of projects is the most important effect of variation and the first party that benefits from alteration is the contractor.

According to Alinaitwe (2013), changes in the scope of the work, excessive inflation and interest rates, fuel shortages, improper monitoring and control, and delayed payments to contractors were the five factors ranked the highest based on their impact on cost overruns and delays in Uganda's Public Sector Construction Projects. The authors also conducted a case study on 30 projects of the Civil Aviation Authority to confirm the results from questionnaire responses. Fifty-three percent of the projects had cost overruns and changes in the scope of work were the most recurrent cause (46%). These results indicate that similar results were found in the case study and the most highly rated cause in the survey questionnaire.

The reasons for cost overrun are unique for different construction project locations as well as different types of projects. However, with the reference of the above literature, we can say that change orders are the main reason for cost overruns.

2.4 Geotechnical Causes for Cost and Schedule Growth, Change Orders, and Claims

The engineering properties of soil and rock are significantly variable from one location to another. This is why, in civil engineering projects, ground engineering risks play a significant role in contributing to financial as well as technical hazards (Institution of Civil Engineers, 1991). So, to reduce the risk associated with contributing to subsurface conditions, Jaska (2000) has given the following recommendations: two stages of site investigation, preliminary and detailed, and the involvement of a geotechnical consultant and/or engineer in any construction project should be from site investigation to after construction monitoring.

Gould (1995) studied how subsurface investigation acted as a troublesome feature in geotechnical construction. During his study, he differentiated two types of site condition claims, Type I and Type II, which are not interconnected. In Type I, there are huge changes between construction site conditions and the site conditions described in legally binding documentation. Similarly, Type II refers to not only this divergence, but also the revelation of unexpected and atypical physical conditions. Gould (1995) experienced that there is less risk factor in Type II regarding supplementary subsurface examination, but Type I can be vulnerable by "offering a larger target to an aggrieved contractor" (p. 523). During examination, Gould (1995) observed four causes of change which occurred during subsurface investigation:

1. Challenges due to insufficient skills in dealing with local geology/construction assignments create surprise claims.
2. Basic investigation methods which are unable to fully define ground conditions can lead to issues.
3. Misapprehensions or misconceptions of the ground’s properties leads to claims as a consequence of “limitation in the state of the art” (p. 526).
4. On some occasions, issues can be caused by features too small to be found by even precise subsurface investigations.

To control such claims, Gould (1995) encompassed 11 particular suggestions in his detailed guidance for subsurface investigation. The process of subsurface investigation is a major risk factor for geotechnical construction.

According to Whyte (1995), low levels of investigation lead to potentially high construction costs due to less information about the properties of soils and rock resulting in large uncertainties. Adopting the appropriate method as well as adequate quality and time for site investigation can reduce ground uncertainty. The National Research Council (1984) recommended that site investigation cost should be at least 3% of total project cost.

However, Kim et.al (2009) conducted the study “North Carolina Department of Transportation’s (NCDOT) practice and experience with design build contracts geotechnical perspective.” According to the authors, subsurface investigation and design build were performed separately. Subsurface investigation was conducted by the NCDOT and their geotechnical report was given to the design build team. The study compared nine NCDOT design build projects with traditional construction methods in terms of surface investigation and found that Pre-Let subsurface investigation costs were varied from 0.18% to 1.15% of the total contract prices, whereas traditionally this percentage is considered 3% to 5% of total project costs.

Mott MacDonald and Soil Mechanics, Ltd. (1994) gathered information on 58 transportation projects in the United Kingdom to find the impact of subsurface examination on construction cost overruns. The authors claimed that cost overruns with more than 10% of original contract price were found in 75% of total projects and geotechnical causes contributed 50% of total cost overruns. According to their research, problems from seepage and groundwater, encountering materials different in classification from those predicted, and withdrawal and replacement of supplementary inappropriate materials were the most common geotechnical causes of cost overruns. The authors also claimed that indirect costs resulting from delays and disruptions associated with subsurface conditions claims, change orders and cost overruns were 5 %, which was greater than the site investigation cost, which is generally 3% of total project cost.

Hoke and Palmieri (1998), explored the hypothesis that the main factor of geotechnical risk in large civil engineering construction is unexpected site conditions, which cause cost and schedule overruns, and the best way to reduce these risks is detailed site investigation in the beginning stages of projects with well-experienced consultants. The objective of this research was to investigate the geotechnical hazards of large civil engineering projects and to give suggestions for decreasing these risks by defining the geological conditions in the early stages of the design period of the projects. The authors suggested some methods of avoiding unexpected geotechnical conditions; use of locally available geological knowledge is one of them. In this research article, data was collected, which gives information about modifications in cost versus the ratio of inspection borehole length to tunnel length. The first source of data was 84 tunnel projects by the U.S. National Committee on Tunnel Technology, and the second source of data was 64 thermal and 71 hydroelectric plants of World Bank's Energy Department, which were performed in 35 developing countries. This data was collected by interviewing the owners, engineers and contractors. Results show that construction costs for hydropower projects were on average 27% more than estimated and construction time was on average 28% longer than estimated.

Goldsworthy et al. (2004) explored the hypothesis that consultants and clients can save large amounts of money by extending the scope of the site exploration, which significantly reduces the risk of foundation failure. The risk of foundation failure is heavily dependent on the quantity and quality of information obtained from a geotechnical site investigation aimed at characterizing the underlying soil conditions. By developing and implementing a model of quantification for risk factors due to the scope of site investigation, the authors claimed that a small enlargement of investment at the site exploration stage may result in probable savings of up to four times the outlay amount.

Prezzi et al. (2011) studied 300 projects (including bridge, pavement, and resurfacing) conducted by the INDOT's geotechnical office between 2003 and 2007. The study was focused on finding the causes and numbers of change orders related to geotechnical work at INDOT and to give suggestions for decreasing the number of change orders. The authors found that 84 projects were affected by geotechnical change orders and average geotechnical change orders cost was 1.3% of the total estimated project cost and 10 % of the total change orders cost. The authors gathered the following causes of geotechnical change order based on interviews with the projects' engineers and external consulting engineers: "failure to identify poor sub-grade, Pile overruns and underruns, erosion control material quantity errors, often associated with underestimating riprap and geotextile quantities as a result of mischaracterizing the 'soil drainage conditions,' and Mechanically Stabilized Earth (MSE) wall construction, though the changes were mostly related to non-geotechnical aspects such as wall geometry conflicting with surface drainage lines" (p. 67-68). Based on the interviews, the authors summarized the following recommendations for minimizing geotechnical change orders: additional boreholes as well as extra pliability in organizing subsurface exploration pondering geology, previous site and region understanding, and a design checklist addressing issues commonly encountered throughout the construction period. These are beneficial decisions when construction problems are encountered.

Boeckmann and Loehr (2016) found that 'pile overruns, groundwater table higher than expected, misclassified or mischaracterized sub-grade, unpredicted rock confronted at the time of foundation construction, and mischaracterized rock for drilled shaft construction were the most common causes of geotechnical investigation and subsurface conditions on claims, change orders and overruns' (p. 1-2). The outcomes of their research are based on a survey with geotechnical engineers of 51 US transportation agencies. The study indicated that about $10 million per agency was the annual cost of change orders attributed to subsurface conditions, 5% of the number and 7% of the cost of all claims, change orders, and cost overruns were those induced by subsurface conditions. The authors claimed that the cost of change orders due to subsurface conditions was near to 1% of the agencies' total budgets for new construction, and subsurface conditions that cause claims, change orders, and cost overruns are significant to projects on a macro level. The authors also mentioned that the following standards are generally followed by transportation agencies for subsurface investigation:

1. AASHTO manual on subsurface investigations and LFRD bridge design specifications
2. National Highway Institute manual on subsurface investigations
3. FHWA geotechnical engineering circular no. 5
4. Agencies' own geotechnical investigation guidelines

2.5 Summary of Literature Review

A significant amount of literature can be found on claims, change orders, cost, and schedule performance in different types of construction projects. However, these papers mainly cover the causes and impacts of claims, change orders, cost overruns, and schedule delays in construction projects. These sources have mainly focused on gathering information on geotechnical issues (see Table 5), their strategies for mitigation, and design standards practiced by transportation agencies in transportation construction projects. There is no separate study focusing on bridge and road pavement as discrete entities.

Some of the findings from previous studies disclose that the causes for claims, change orders, cost overruns and schedule delays in construction projects are changes in design, extra work, escalation, weather, unforeseen site conditions, imperfect site management, pile overruns, groundwater table higher than expected, misclassified subgrade, and mischaracterized rock for drill shaft construction. Further, an increase of at least 1% of total project cost was reported due to geotechnical issues. Recommendations for reducing geotechnical issues, as suggested in the reviewed literature, are: a detailed site investigation with a well-experienced consultant, more boreholes and more flexibility in planning subsurface investigations, prior site knowledge, a design checklist, and expedient decisions.

This study, however, covers the different perceptions of clients and consultants on geotechnical claims, change orders, cost overruns, and schedule delays in bridge and road pavement projects respectively, covering almost all the US states. This study ranks the causes of geotechnical-related problems in regards to their impact on cost and schedule performance and claims. This study also discusses possible mitigation strategies for these problems. This study also posits a suggestion for a standard design guideline which, according to the national survey conducted, is highly recommended. Also, it suggests the best method of subsurface investigation for bridge and road pavement projects respectively based on the rated responses in the national survey. This study can assist in helping to reduce geotechnical problems in bridge and road pavement projects by adopting the recommended design standard, subsurface investigation methods, and subsurface investigation cost.

Table 5. Geotechnical-Related Causes of Cost Overruns, Schedule Delays, and Claims

Geotechnical Related Causes	Authors
• Lack of sufficient boring locations	Hoke and Palmieri (1998)
• Design Change	Le-Hoai et al. (2008)
• Lack of detail specifications in problematic areas, such as subgrade treatment and piling • Erosion and sediment control • The prescribed soil treatment method was not suitable for a particular site condition • Mismatch in pile quantities • Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	Prezzi et al. (2011)
• Level of groundwater table higher than expected • Misclassified or mischaracterized subgrade • Seepage problems	Boeckmann and Loehr (2016)

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Outline of Research Methodology

For successful completion of this research, the following five activities were executed in sequential order: define the scope and objectives of the study, review the literature, conduct a national survey with state DOTs and consultants, analyze the data, and finally, draw a conclusion. A sequential breakdown of these activities is shown in Figure 1.

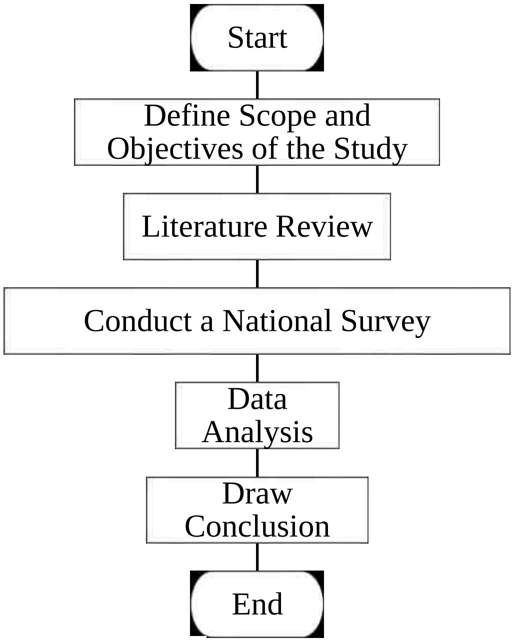


Figure 1. Flowchart of research methodology.

Among these activities, the study's objectives and the literature review are presented in Chapters 1 and 2, respectively. The methodology and data analysis are summarized in Chapters 3 and 4, and the conclusion is presented in Chapter 5.

In the literature review chapter (Chapter 2), references related to the objectives' topics were examined and summarized. In the beginning of this literature review, a summary of claims was presented. In addition, references on change orders, and references on cost overruns were documented. The literature review concluded with references related to geotechnical investigations.

3.2 Data Collection

3.2.1 Population and Sample

To conduct the national survey, a questionnaire was designed in the Qualtrics survey tools. The survey sample consists of about 360 personnel of two types of target groups: (1) 50 state DOTs' geotechnical engineers, and (2) consultants' geotechnical engineers. For contact with target personnel, email addresses and phone numbers of 110 geotechnical engineers who worked in 50 DOTs and contact information for about 250 consultants' geotechnical engineers were collected through their websites. First, invitations were sent to the target samples via emails describing the research objectives and participants' involvement with research. Once the perspective survey participants show their interest, a survey questionnaire was distributed to the selected personnel for this study by sending the web link via email.

3.2.2 The Questionnaire

The questionnaire was divided into three parts. The first part consisted of the personal information of respondents, including respondent's name, the name of respondent's agency, respondent's address, education level, and experience with the design and construction of bridge and road pavement projects. The second part of the questionnaire contained questions related to bridge projects. In this section, questions were based on qualitative information about causes and preventive measures against claims and change orders, as well as cost and schedule performance in bridge construction. Similarly, in the third part, questions related to road pavement projects were designed like the questions related to bridge projects. The survey also included questions related to methods of subsurface investigation and guidelines for investigation. Participants were requested to rate the geotechnical-related causes of cost and schedule growth, cost overruns (CO), and claims, as well as a preventive measure against cost and schedule growth, and claims on a one-to-five scale based on their occurrences for both types of construction projects: bridge and road pavement. On the Likert scale, five represented the most common occurrences to rare occurrences.

3.3 Data Analysis

To better understand and summarize the data collected from the survey, a descriptive data analysis was conducted. Initially, rating and comparing the geotechnical causes of claims, change orders, and cost and schedule performance in bridge and pavement construction were done. The rated reasons responsible for the claims and change orders, as well as the severity scale of cost performances and schedule performances, were documented after obtaining survey responses. Then, a comparison table between the two different responder groups and a compression table between pavement construction and bridge construction were presented.

The Relative Importance Index (RII) method is used to rank the causes of claims, CO, cost and schedule performance, and a preventive measure against claims, CO and cost overruns. The equation (a) given below was used to find out the RII value. The RII value indicate the rank of the variables. This method is similar to the one implemented by Gunduz et al. (2013) to determine the relative importance of the causes of delay in construction projects in Turkey.

$$RII = \frac{\sum_{i=1}^{N} W_i}{(A*N)} \text{ ………….. (a)}$$

Where,

Wi = Rank assigned by ith responder,

A = Highest rank,

N = Total number of respondents, and

RII = Relative importance index

3.4 Statistical Analysis

After this descriptive analysis, the collected responses were further analyzed by the three different types of statistical analyses to test the hypothesis. The statistical analyses were done with the help of IBM SPSS Statistics (version 22).

3.4.1 Kruskal-Wallis Test

The Kruskal-Wallis Test is used when the assumptions of ANOVA are not met, so it is also called the alternative to the one-way ANOVA test (Laerd statistic). It is a rank-based nonparametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. It is an extension of the Mann-Whitney U Test to allow the comparison of more than two independent groups. The Kruskal-Wallis test was conducted to determine whether the ratings provided by the clients and consultants on the use of geotechnical design standards are significantly different.

3.4.2 Mann-Whitney U Test

Mann-Whitney U Test is a nonparametric statistics test used to compare differences between two independent groups (Laerd statistic). For the data analysis, the two independent samples of responders were clients and contractors.

3.4.3 Pearson Chi-Square Test

Pearson Chi-Square Test is the type of test used to find the linear relationship between two categorical variables (Practical cryptography, 2015). In the survey, the Pearson Chi-Square Test was conducted to test the association between client participants and consultant participants who had the same type of impact on cost performance, schedule performance, and requested claims. For this Pearson Chi-Square Test, the two independent samples of responders were clients and contractors.

These statistical tests are significant at alpha level 0.05

CHAPTER 4: DATA ANALYSIS

Among the 360 perspective participants, 162 experts responded to the invitation (88 clients' engineers and 74 consultants' engineers). Later, the questionnaires were distributed to these 162 experts who responded to the invitation using the Qualtrics survey tool on March 21st, 2016. The respondents were given two months to respond. The collected rating responses obtained from the survey were ranked using the RII method. After finding the rankings, the Mann-Whitney U, Kruskal-Wallis, and Pearson Chi-Square Tests were performed to test the research hypotheses.

4.1 Demographic Information of Respondents

4.1.1 Respondent Percentage

The survey questionnaires were sent to 88 clients and 74 consultants. Fifty-three out of 88 clients' participants and 43 out of 74 consultants' participants completed the survey. Figures 2 and 3 show the respondent rates of the participants.

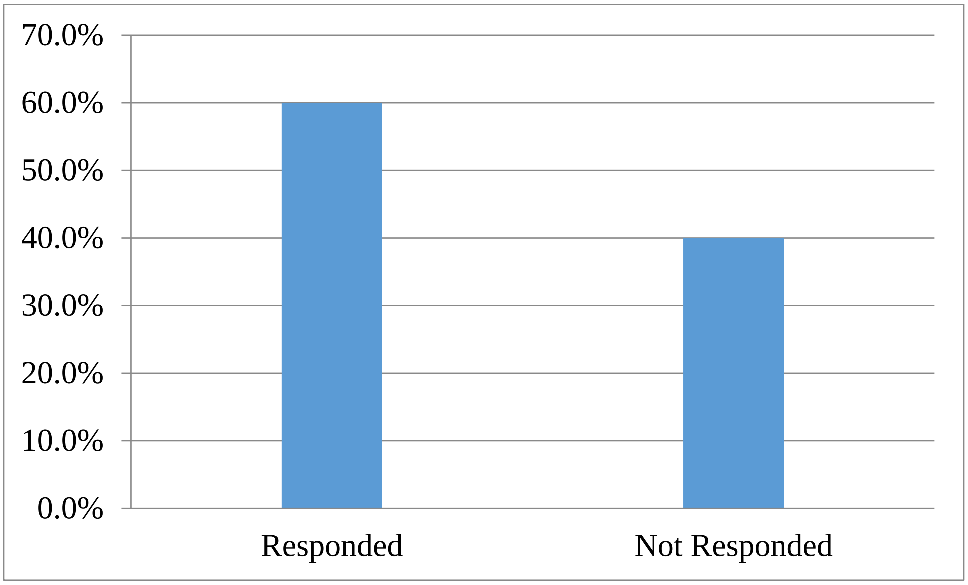


Figure 2. The response rate of clients.

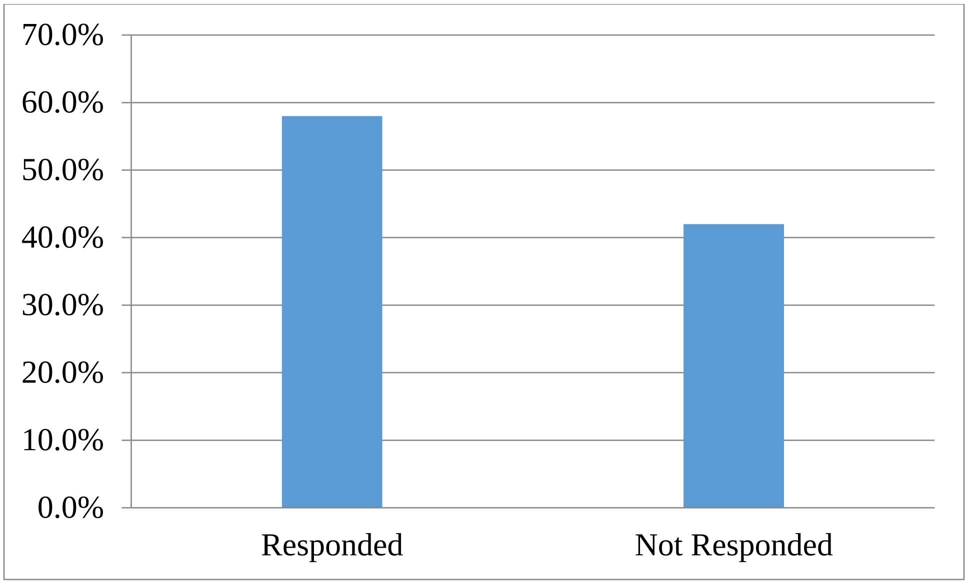


Figure 3. The response rate of consultants.

4.1.2 Representative States

The survey questionnaires were distributed to both groups of respondents covering all fifty US states. Out of fifty, the survey participants cover 42 states. The remaining, unrepresented eight states are as follows: Alabama, Hawaii, Indiana, Kentucky, Mississippi, South Carolina, West Virginia, and Washington.

4.1.3 Education Level

A maximum number of participants with Master's degrees in civil engineering from consultants and a maximum number of participants with Bachelor's degrees from clients were involved in the survey. Table 6 and Figure 4 show the education levels of respondents.

Table 6. Education Levels of Respondents

S.N.	Education Level	Clients	Consultants	Total	Percentage
1.	Bachelor's Degree	29	16	45	46.9 %
2.	Master's Degree	18	22	40	41.7 %
3.	Ph. D.	0	3	3	3.1 %
4.	No response	6	2	8	8.3%
5.	Total	53	43	96	100%

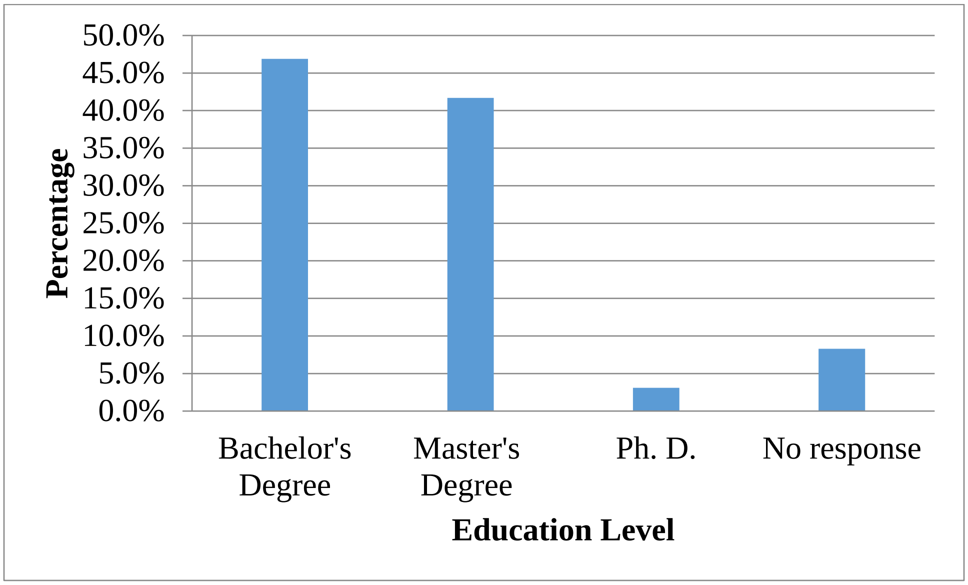


Figure 4. The education levels of respondents.

4.1.4 Bridge Design Experience

In this survey, almost half of the participants (39.6%) indicated that they have less than six years of experience in bridge design. More than 20 years of experience was a distant second in highest number of respondents with 16.7 percent, and the 11 to 15 years' experience category was last with 6.2 percent. The bridge design experience of respondents is shown in Table 7 and Figure 5.

Table 7. Bridge Design Experience of Respondents

S.N.	Bridge Design Experience	Clients	Consultants	Total	Percentage
1.	Below 6 years	20	18	38	39.6%
2.	6 to 10 years	6	4	10	10.4%
3.	11 to 15 years	5	4	9	9.4%
4.	16 to 20 years	3	3	6	6.2%
5.	More than 20 years	6	10	16	16.7%
6.	No response	13	4	17	17.7%
7.	Total	53	43	96	100.0%

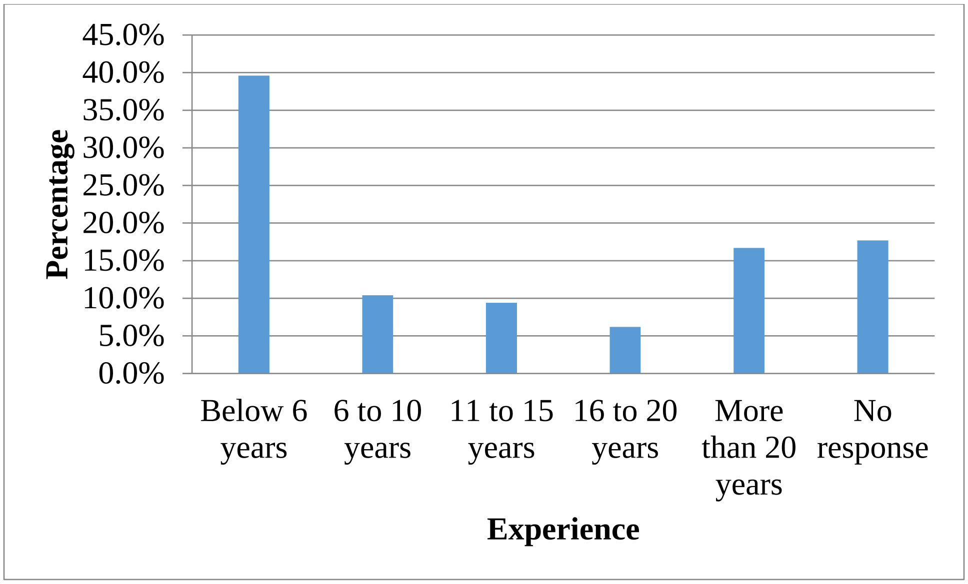


Figure 5. Bridge design experience of respondents.

4.1.5 Bridge Construction Experience

The below table illustrates that participants with less than six years of experience in bridge construction were the majority in the survey. Similarly, as with bridge design experience, participants with more than 20 years of experience were second most common. The 16 to 20 years' experience category was the least common in the survey. Table 8 and Figure 6 show the bridge construction experience of respondents.

Table 8. Bridge Construction Experience of Respondents

S.N.	Bridge Construction Experience	Clients	Consultants	Total	Percentage
1.	Below 6 years	13	18	31	32.3%
2.	6 to 10 years	7	4	11	11.5%
3.	11 to 15 years	8	4	12	12.5%
4.	16 to 20 years	4	1	5	5.2%
5.	More than 20 years	9	11	20	20.8%
6.	No response	12	5	17	17.7%
7.	Total	53	43	96	100%

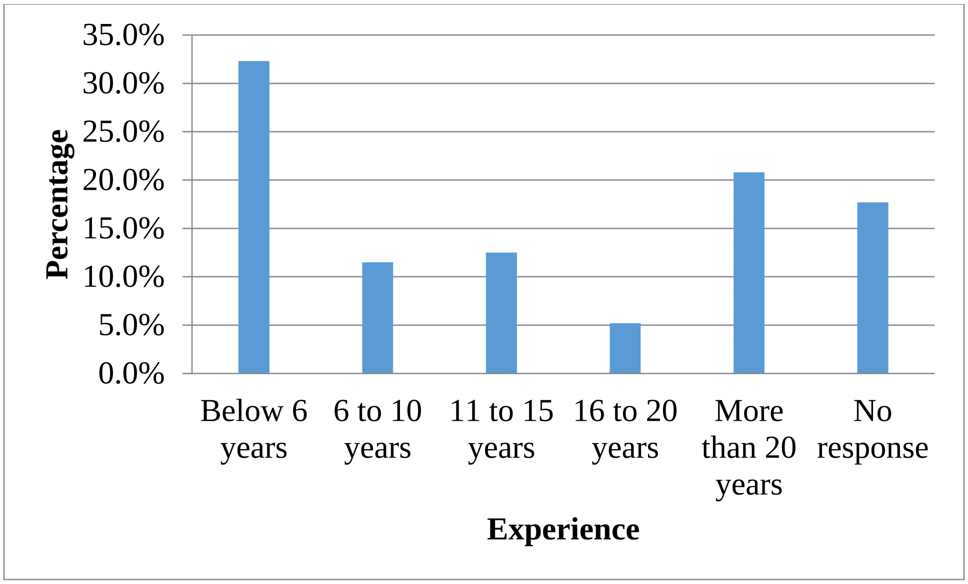


Figure 6. Bridge construction experience of respondents.

4.1.6 Pavement Design Experience

In this survey, almost half of the participants indicated that they have less than six years of experience in pavement design. More than 20 years of experience was a distant second in highest number of respondents with 12.5 percent, and the 11 to 15 years' experience category was last with 8.3 percent. The pavement design experience of respondents is shown in Table 9 and Figure 7.

Table 9. Pavement Design Experience of Respondents

S.N.	Pavement Design Experience	Clients	Consultants	Total	Percentage
1.	Below 6 years	25	18	43	44.8%
2.	6 to 10 years	5	4	9	9.4%
3.	11 to 15 years	5	3	8	8.3%
4.	16 to 20 years	5	4	9	9.4%
5.	More than 20 years	3	9	12	12.5%
6.	No response	10	5	15	15.6%
7.	Total	53	43	96	100.0%

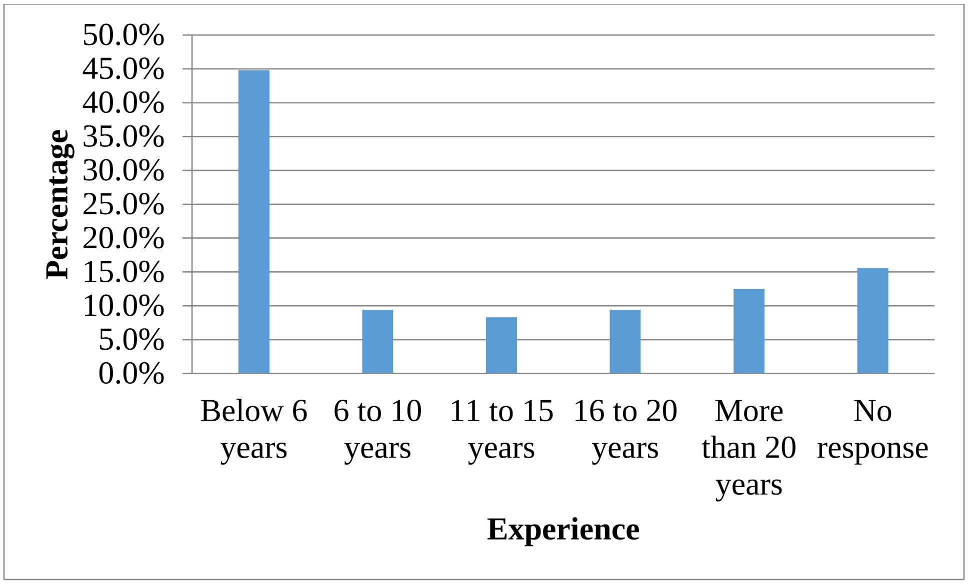


Figure 7. Pavement design experience of respondents.

4.1.7 Pavement Construction Experience

Of the 96 participants in this survey, 40 indicated having less than six years of experience. Sixteen noted having more than 20 years of experience. However, there are only seven out of 96 participants in both the 6-10 years and 16-20 years of experience categories. Table 10 and Figure 8 show the pavement construction experience of respondents.

Table 10. Pavement Construction Experience of Respondents

S.N.	Pavement Construction Experience	Clients	Consultants	Total	Percentage
1.	Below 6 years	21	19	40	41.7%
2.	6 to 10 years	6	1	7	7.3%
3.	11 to 15 years	5	4	9	9.4%
4.	16 to 20 years	5	2	7	7.3%
5.	More than 20 years	5	11	16	16.6%
6.	No response	11	6	17	17.7%
7.	Total	53	43	96	100.0%

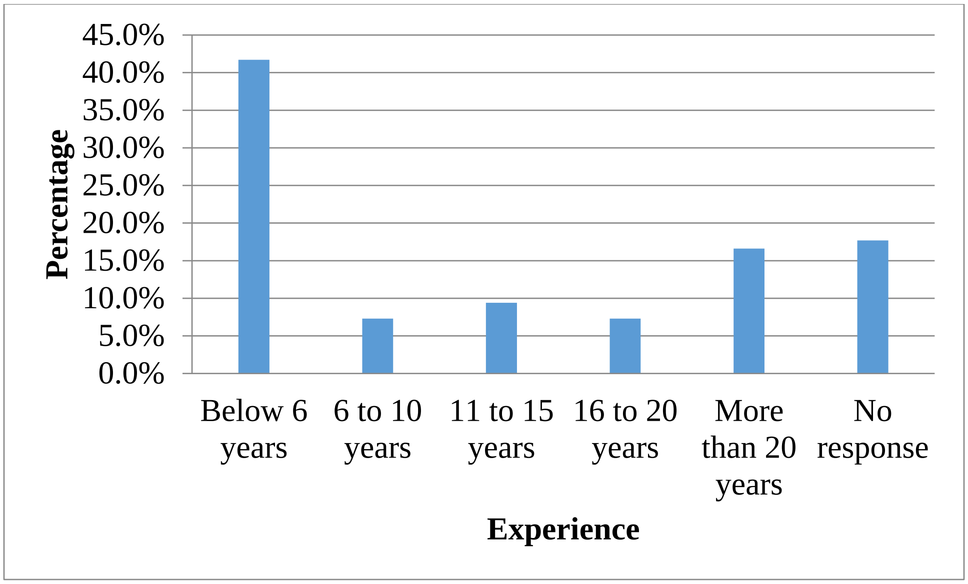


Figure 8. Pavement construction experience of respondents.

4.2 Data Analysis Results Regarding Bridge Projects

4.2.1 Descriptive Statistics on Bridge Projects

In the survey questionnaire, a total of ten questions were asked to the survey participants regarding bridge projects. These questions encompassed the use of geotechnical design standards, methods of subsurface investigations, impacts on cost overruns, schedule overruns, and claims and their ranges due to geotechnical concerns, and recommendations for reducing these impacts. In this section, descriptive information identified from the RII analysis is presented.

4.2.1.1. Use of Geotechnical Design Standards for Bridge Design

The results of the RII analysis for the use of geotechnical design standards for bridge projects showed that both clients' and consultants' first preference was the ASSHTO Manual on Subsurface Investigation, followed by FHWA Geotechnical Engineering Circular No. 5, and the National Highway Institute (NHI) Manual on Subsurface Investigation (see Table 11). Based on the RII values, the clients' importance rating for these standards were very close, whereas the consultants rated the AASHTO Manual as highly important compared to the FHWA and NHI Manuals. When the ratings of both groups are combined, it is evident that the respondents gave higher preference to the AASHTO Manual compared to the FHWA and NHI Manuals.

Table 11. Rating of the Use of Geotechnical Design Standards for Bridge Projects

S. No.	Standards Used	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	AASHTO Manual on Subsurface Investigation	42	77%	37	72%	75%
2.	FHWA Geotechnical Engineering Circular No. 5	41	73%	37	56%	65%
3.	NHI Manual on Subsurface Investigation	40	72%	36	51%	62%

4.2.1.2. Use of Subsurface Investigation Methods for Bridge Design

The results of the RII analysis for the use of subsurface investigation methods for bridge design showed that both clients' and consultants' first preference was the Standard Penetration Test (SPT), followed by Cone Penetration Testing (CPT) and the Geophysical Method (see Table 12). Based on the RII values, the clients' importance rating, the consultants' importance rating, and the rating of both groups were combined; the results declared that the respondents gave highest preference to the Standard Penetration Test (SPT) compared to other subsurface investigation methods for bridge design.

Table 12. Ratings of Subsurface Investigation Methods for Bridge Design

S. No.	Methods Used	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Standard Penetration Test (SPT)	48	90%	37	84%	88%
2.	Cone Penetration Testing (CPT)	45	46%	37	45%	46%
3.	Geophysical Method	44	47%	35	40%	44%
4.	Vane Share Test (VST)	43	38%	36	33%	35%
5.	Falling Weight Deflectometer Method	42	36%	36	29%	33%
6.	Hydraulic Conductivity Testing Method	44	33%	36	32%	33%
7.	Pressure Meter Testing	44	28%	35	36%	31%
8.	Remote Sensing	42	30%	35	31%	30%
9.	Flat plate Dilatometer Testing	43	30%	36	31%	30%

4.2.1.3 Geotechnical-Related Causes of Cost Growth for Bridge Projects

The results of the RII analysis for the geotechnical-related causes of cost growth for bridge projects showed that both clients' and consultants' first rank was a lack of sufficient boring locations, followed by misclassified or mischaracterized subgrade, and level of groundwater table higher than expected (see Table 13). Based on the RII values, both clients' and consultants' ranks for these causes were close. When the rating of both groups was combined, it was revealed that the respondents gave first rank to lack of sufficient boring locations and last to erosion and sediment control.

Table 13. Ratings of Geotechnical-Related Causes of Cost Growth for Bridge Projects

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Lack of sufficient boring locations	47	62%	37	70%	65%
2.	Misclassified or mischaracterized sub-grade	44	56%	36	64%	60%
3.	Level of ground water table higher than expected	45	57%	36	57%	57%
4.	De-watering due to seepage problems	44	54%	37	60%	56%
5.	Design change in super structure	44	51%	36	62%	56%
6.	The prescribed soil treatment method was not suitable for a particular site condition	44	52%	37	58%	55%
7.	Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	44	50%	37	61%	55%
8.	Mismatch in pile quantities	44	53%	37	56%	54%
9.	Erosion and sediment control	42	47%	37	48%	48%

4.2.1.4 Geotechnical-Related Causes of Schedule Growth for Bridge Projects

The results of the RII analysis for the geotechnical-related causes of schedule growth for bridge projects showed that both clients' and consultants' first rank was a lack of sufficient boring locations, followed by misclassified or mischaracterized subgrade, a design change in the superstructure, and de-watering due to seepage problems (see Table 14). Based on the RII values, both clients' and consultants' importance rating for these causes were close. When the ratings of both groups were combined, it was revealed that respondents gave first rank to lack of sufficient boring locations and last to erosion and sediment control.

Table 14. Ratings of Geotechnical-Related Causes of Schedule Growth for Bridge Projects

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Lack of sufficient boring locations	44	59%	35	69%	63%
2.	Misclassified or mischaracterized subgrade	42	54%	35	64%	59%
3.	Design change in the superstructure	43	51%	35	69%	59%
4.	De-watering due to seepage problems	41	55%	35	59%	57%
5.	Level of groundwater table higher than expected	42	54%	35	59%	57%
6.	Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	42	51%	35	65%	57%
7.	The prescribed soil treatment method was not suitable for a particular site condition	42	51%	35	63%	56%
8.	Mismatch in pile	43	47%	35	57%	52%

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
	quantities					
9.	Erosion and sediment control	42	42%	35	47%	44%

4.2.1.5 Geotechnical-Related Causes of Claims for Bridge Projects

The results of the RII analysis for geotechnical-related causes of claims for bridge projects showed that both clients' and consultants' first rank was a lack of sufficient boring locations, followed by misclassified or mischaracterized subgrade, and lack of detailed specifications in problematic areas, such as subgrade treatment and piling (see Table 15). Erosion and sediment control were the least preferred impact by both groups. Based on the RII values, both clients' and consultants' importance rating for these impacts were close. When the ratings of both groups were combined, it was revealed that the respondents gave first rank to lack of sufficient boring locations, and ratings for these causes were also close.

Table 15. Ratings of Geotechnical-Related Causes of Claims for Bridge Projects

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Lack of sufficient boring locations	42	63%	35	71%	67%
2.	Misclassified or mischaracterized subgrade	41	57%	35	67%	62%
3.	Lack of detail specifications in	41	56%	35	68%	61%

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
	problematic areas, such as subgrade treatment and piling					
4.	Level of groundwater table higher than expected	41	55%	35	61%	58%
5.	Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	41	53%	35	63%	58%
6.	The prescribed soil treatment method was not suitable for a particular site condition	40	51%	35	65%	58%
7.	Design change in the superstructure	42	50%	35	67%	58%
8.	De-watering due to seepage problems	40	54%	35	59%	57%
9.	Mismatch in pile quantities	42	47%	35	58%	52%
10.	Erosion and sediment control	41	40%	35	50%	44%

4.2.1.6 The Impact of Geotechnical-Related Causes on Cost Growth of Bridge Projects

Out of 96 total respondents, 15 respondents (15.6%) did not respond to this question. A majority of the respondents (52%) indicated that geotechnical-related causes increased cost growth by more than 5 percent in bridge projects (Table 16). Only one client's participants indicated that these causes had a positive impact on cost growth. Similarly, 38.3 percent of total responsive participants indicated that there was no impact on cost growth.

Table 16. The Impact of Geotechnical-Related Causes on Cost Growth of Bridge Projects

S.N.	Range of cost performance	Clients	Consultants	Total	Percentage
1.	Overrun budget by over 25%	0	1	1	1.2%
2.	Overrun budget by 16- 25%	3	6	9	11.1%
3.	Overrun budget by 5-15%	13	19	32	39.5%
4.	Overrun budget by below 5%	5	2	7	8.6%
5.	On budget	22	9	31	38.3%
6.	Under budget by below 1%	1	0	1	1.2%
7.	Under budget by 1-5%	0	0	0	0.0%
8.	Under budget by 6-10%	0	0	0	0.0%
9.	Under budget by over 10%	0	0	0	0.0%
	Total	44	37	81	100.0%

4.2.1.7 The Impact of Geotechnical-Related Causes on Schedule Growth of Bridge Projects

Out of 96 total respondents, 79 respondents (82.3%) responded to this question. About 37 percent of participants stated that there was no impact on schedule growth from geotechnical-related causes (Table 17). Only one client’s participants indicated that these causes had a positive impact on schedule growth. Similarly, 47 percent of participants indicated that these causes increased schedule growth by more than 5 percent.

Table 17. The Impact of Geotechnical-Related Causes on Schedule Growth of Bridge Projects

S.N.	Range of schedule performance	Clients	Consultants	Total	Percentage
1.	Behind schedule by over 25%	1	3	4	5.1%
2.	Behind schedule by 16- 25%	5	5	10	12.7%
3.	Behind schedule by 5-15%	7	16	23	29.1%
4.	Behind schedule by below 5%	7	4	11	13.9%
5.	On schedule	21	8	29	36.7%
6.	Ahead of schedule by below 1%	1	0	1	1.3%
7.	Ahead of schedule by 1-5%	0	0	0	0.0%
8.	Ahead of schedule by 6-10%	0	0	0	0.0%
9.	Ahead of schedule by over 10%	1	0	1	1.3%
	Total	33	36	79	100.0%

4.2.1.8 The Impact of Geotechnical-Related Causes on Claims of Bridge Projects

When asked about the impact of geotechnical causes on claims of bridge projects, about 84 percent of respondents answered this question. Out of these, about 25 percent stated that there were no claims due to geotechnical-related causes in bridge projects (Table 18). However, a majority of respondents (75%) stated that geotechnical-related causes increased construction claims by more than 5 percent.

Table 18. The Impact of Geotechnical-Related Causes on Claims of Bridge Projects

S.N.	Cost claims	Clients	Consultants	Total	Percentage
1.	Extra cost requested over 25%	3	0	3	3.7%
2.	Extra cost requested 16-25%	4	11	15	18.5%
3.	Extra cost requested 5-15%	20	19	39	48.1%
4.	Extra cost requested below 5%	3	1	4	4.9%
5.	No claims	14	6	20	24.7%
	Total	44	37	81	100.0%

4.2.1.9 The Percentage of Total Project Cost for Geotechnical Investigations during the Design Phase of Bridge Projects

Clients' and consultants' participants were asked to recommend a percentage of the total cost for geotechnical investigation during the design phase of bridge projects. Only 52 participants responded this question. The results showed that the mean and median cost percentage recommended for geotechnical investigations in bridge projects were about 6.79 percent and 4 percent, respectively. A box plot was made to determine the outlier in the data set and it can be seen that two data sets were the outliers (Figure 9).

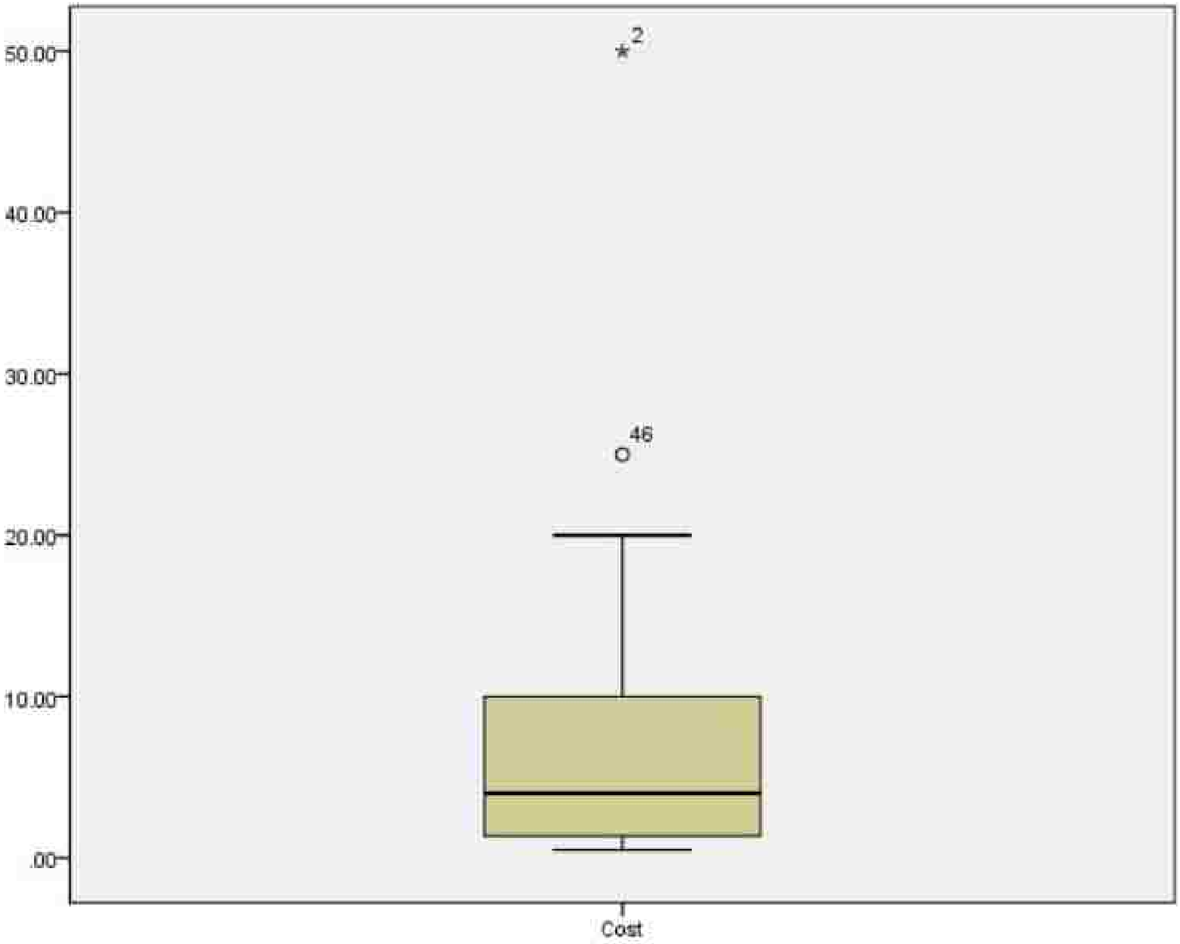


Figure 9. Box plot of geotechnical investigation costs

4.2.1.10 Mitigation Strategies for Reducing the Cost and Schedule Growth and Number of Claims in Bridge Construction Due to Geotechnical-Related Causes

The results of the RII analysis for participants’ recommendations for reducing the cost and schedule growth and claims in bridge construction due to geotechnical-related causes showed that both clients' and consultants’ first preference was that the designer have detailed knowledge about the project site’s geotechnical information, followed by detailed site investigation with a well-experienced consultant, and development and implementation of minimum standards for subsurface investigation and site characterization (see Table 19). Based on the RII values, both clients’ and consultants’ importance rating for these recommendations were close. When the ratings of both groups were combined, it was revealed that the respondents gave first preference to the designer having detailed knowledge about the project's geotechnical information and least preference to specification needing to be more solid in problematic areas such as subgrade treatment and piling.

Table 19. Ratings of Mitigation Strategies for Reducing the Cost and Schedule Growth and Number of Claims in Bridge Construction Due to Geotechnical-Related Causes

S. No.	Recommendations	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Designer should have detail knowledge about geotechnical information of project site	45	87%	38	92%	89%
2.	Detail site investigation with well-experienced consultant	44	81%	38	91%	86%
3.	Development and implementation of minimum standards for subsurface investigation and site characterization	45	87%	38	80%	84%
4.	Choose the appropriate pile type for a particular soil type, with more accurately predicted pile lengths	45	79%	38	81%	80%
5.	Accuracy of boring locations	45	80%	38	76%	78%
6.	Causes of geotechnical change order should be routed through the geotechnical office, which helps to designer for reducing that type of	45	79%	38	77%	78%

S. No.	Recommendations	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
	change order in design period					
7.	Intra-agency training and communication to improve the implementation of surface information	45	76%	38	79%	78%
8.	Specification needs to be more solid in the problematic areas such as subgrade treatment and piling	44	74%	38	79%	76%

4.2.2 Statistical Test Results on Bridge Projects

Statistical tests were conducted to determine whether the rankings provided by the respondents were significantly different from each other. Kruskal-Wallis, Mann-Whitney, and Chi-Square Tests were conducted, and the significant level selected for these tests was 0.05. The results of these tests are described below.

4.2.2.1. Statistical Test on Use of Geotechnical Design Standards for Bridge Projects

The Kruskal-Wallis test was conducted to determine whether the ratings provided by the clients and consultants on the use of geotechnical design standards for bridge projects were significantly different. The test results showed that the ratings provided by the clients for three types of manuals used were not significantly different. However, in the case of consultants' data, the ratings were significantly different (Table 20). Therefore, it is necessary to conduct the Mann-Whitney U test to determine which ratings were significantly different.

Table 20. Results of the Kruskal-Wallis Test for Geotechnical Design Standards Used for Bridge Projects

S. No.	Standards	Clients' Ranking		Consultants' Ranking	
		Mean Rank	p-value	Mean Rank	p-value
1.	AASHTO Manual on Subsurface Investigation	66.9	0.52	37.3	0.01*
2.	NHI Manual on Subsurface Investigation	59.7		30.0	
3.	FHWA Geotechnical Engineering Circular No. 5	59.3		32.0	

*significant at alpha level 0.05

The Mann-Whitney U test results showed that the rating provided by consultants for the ASSHTO manual was significantly higher than that provided for the FHWA and NHI Manuals (Table 21). The results showed that consultants significantly preferred the AASHTO Manual for the geotechnical design of bridge projects compared to the FHWA engineering Circular 5 and NHI Manual. However, the preference of clients among these three manuals for the geotechnical design of bridge projects was not significantly different.

Table 21. Results of the Mann-Whitney U Test for Consultants' Ranking of Use of Design Standards for Bridge Projects

S. No.	Standards Used	Mean Rank	U-value	Z-value	p-value
1.	AASHTO Manual FHWA Eng. Circular 5	45.0 28.8	371	-3.3	<0.01*
2.	AASHTO Manual NHI Manual	44.0 31.0	446	-2.6	<0.01*
3.	FHWA Eng. Circular 5 NHI Manual	35.2 38.7	603	-0.7	0.48

*significant at alpha level 0.05

The Mann-Whitney U test was conducted to determine whether the ratings provided regarding the use of these three manuals for bridge design by clients and consultants were significantly different. The test results showed that the clients' and consultants' ratings were significantly different for the FHWA and NHI Manuals, whereas both groups rated the AASHTO

Manual similarly (see Table 22). Therefore, the results showed that clients significantly preferred the FHWA and NHI Manuals to conduct geotechnical design compared to consultants.

Table 22. Mann-Whitney U Test Results for Ranking of Use of Geotechnical Design Standards for Bridge Projects

S. No.	Standards used	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	AASHTO Manual	42.4	37.3	677	-1.0	0.30
2	FHWA Eng. Circular 5	46.3	32.0	480	-2.9	<0.01*
3	NHI Manual	46.1	30.1	417	-3.2	<0.01*

* significant at alpha level 0.05

4.2.2.2. Statistical Test for the Use of Subsurface Investigation Methods for Bridge Projects

The Kruskal-Wallis test was conducted to determine whether the ratings provided by the clients and consultants on the use of subsurface investigation methods for bridge projects were significantly different. The test results showed that the ratings provided by both clients and consultants for the top three methods used were significantly different (see Table 23). Therefore, it is necessary to conduct the Mann-Whitney test to determine which ratings were significantly different.

Table 23. Results of the Kruskal-Wallis Test for the Use of Subsurface Investigation Methods for Bridge Projects

S. No.	Methods Used	Clients' Ranking		Consultants' Ranking	
		Mean Rank	p-value	Mean Rank	p-value
1.	Standard Penetration Test	106.1	0.01*	82.2	0.01*
2.	Geophysical Method	49.8		37.2	
3.	Cone Penetration Testing	48.2		44.6	

* significant at alpha level 0.05

The Mann-Whitney U test results showed that the rating provided by both respondents, clients, and consultants for the Standard Penetration Test was significantly higher than that provided for Cone Penetration Testing and the Geophysical Method (see Tables 24 and 25). The results showed that respondents significantly preferred the use of the Standard Penetration Test for the geotechnical design of bridge projects compared to Cone Penetration Testing and the Geophysical Method.

Table 24. Results of the Mann-Whitney U Test for Clients' Ranking of the Use of Subsurface Investigation Methods for Bridge Projects

S. No.	Methods Used	Mean Rank	U-value	Z-value	p-value
1.	Standard Penetration Test Geophysical Method	64.6 26.8	189	-7.1	<0.01*
2.	Standard Penetration Test Cone Penetration Testing	66.0 26.7	167	-7.4	<0.01*
3.	Geophysical Method Cone Penetration Testing	45.5 44.5	968	-0.2	0.84

Table 25. Results of the Mann-Whitney U Test for Consultants' Ranking of the Use of Subsurface Investigation Methods for Bridge Projects

S. No.	Methods Used	Mean Rank	U-value	Z-value	p-value
1.	Standard Penetration Test Cone Penetration Testing	51.1 23.9	183	-5.6	<0.01*
2.	Standard Penetration Test Geophysical Method	50.2 22.1	143	-5.8	<0.01*
3.	Cone Penetration Testing Geophysical Method	39.7 33.1	528	-1.4	0.15

The Mann-Whitney U test was conducted to determine whether the ratings provided for the use of subsurface investigation methods for bridge projects by clients and consultants were significantly different from each other. The test results showed that the clients and consultants did not rate any investigation method significantly differently (see Table 26). Therefore, the results showed that the preference of both clients and consultants among these three methods for subsurface investigation for bridge projects was not significantly different.

Table 26. The Mann-Whitney U Test Results for Ranking of the Use of Subsurface Investigation Methods for Bridge Projects

S. No.	Methods Used	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Standard Penetration Test	46.0	39.1	743	-1.5	0.13
2	Cone Penetration Testing	41.9	41.0	813	-1.8	0.84
3	Geophysical Method	43.9	35.1	597	-0.2	0.07

4.2.2.3 Statistical Test on Geotechnical-Related Causes of Cost Growth for Bridge Projects

The Kruskal-Wallis test was conducted between the top three causes to determine whether the ratings provided by clients and consultants on the geotechnical-related causes of cost growth for bridge projects were significantly different. The test results showed that the ratings provided by both the clients and consultants for the top three causes on cost growth were not significantly different (see Tables 27 and 28).

Table 27. Results of Clients' Kruskal-Wallis Test for Causes on Cost Overruns for Bridge Projects

S. No	Causes	Mean Rank	P-value
1.	Lack of sufficient boring location	75.2	0.32
2.	Level of groundwater table higher than expected	65.0	
3.	Misclassified or mischaracterized subgrade	65.0	

Table 28. Results of Consultants' Kruskal-Wallis Test for Causes on Cost Overruns for Bridge Projects

S. No	Causes	Mean Rank	P-value
1.	Lack of sufficient boring location	61.3	0.28
2.	Level of groundwater table higher than expected	53.2	
3.	Design change in the superstructure	50.3	

The Mann-Whitney U test was conducted to determine whether the ratings provided for the causes of geotechnical-related cost growth for bridge projects by clients and consultants were significantly different. The test results showed that the clients and consultants rated similarly (see

Table 29). Therefore, the results showed that the preference of both groups among these three impacts on cost growth was not significantly different.

Table 29. The Mann-Whitney U Test Results for Ranking of Geotechnical-Related Causes of Cost Growth for Bridge Projects

S. No.	Causes	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Lack of sufficient boring location	38.4	47.7	677	-1.8	0.07
2	Misclassified or mischaracterized subgrade	36.2	45.7	604	-1.9	0.06
3	Level of groundwater table higher than expected	40.2	42.0	773	-0.4	0.7

4.2.2.4 Statistical Test on Geotechnical-Related Causes of Schedule Growth for Bridge Projects

The Kruskal-Wallis test was conducted between the top three causes to determine whether the ratings provided by the clients and consultants on the causes of geotechnical-related schedule growth for bridge projects were significantly different. The test results showed that the ratings provided by both the clients and consultants for the top three causes of schedule growth were not significantly different (see Tables 30 and 31).

Table 30. Results of Clients' Kruskal-Wallis Test for Geotechnical-Related Causes of Schedule Growth for Bridge Projects

S. No	Causes	Mean Rank	P-value
1.	Lack of sufficient boring location	67.8	0.67
2.	De-watering due to seepage problems	62.3	
3.	Misclassified or mischaracterized subgrade	61.7	

Table 31. Results of Consultants' Kruskal-Wallis Test for Geotechnical-Related Causes of Schedule Growth for Bridge Projects

S. No	Causes	Mean Rank	P-value
1.	Lack of sufficient boring location	54.9	0.65
2.	Design change in the superstructure	54.9	

S. No	Causes	Mean Rank	P-value
3.	Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	49.2	

The Mann-Whitney U test was conducted to determine whether the ratings provided for the top three causes on schedule growth for bridge projects by clients and consultants were significantly different from each other. The test results showed that the clients and consultants rated significantly differently for lack of sufficient boring locations, a design change in the superstructure, and misclassified or mischaracterized subgrade (see Table 32). Therefore, the results showed that the consultants significantly preferred these three causes of schedule growth compared to clients.

Table 32. Mann-Whitney U Test Results for Ranking of Geotechnical-Related Causes of Schedule Growth for Bridge Projects

S. No.	Causes	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Lack of sufficient boring location	35.4	45.8	565	-2.1	0.04*
2	Design change in the superstructure	31.9	48.8	426	-3.4	<0.01*
3	Misclassified or mischaracterized sub-grade	34.1	44.9	528	-2.2	0.03*

*significant at alpha level 0.05

4.2.2.5 Statistical Test on Geotechnical-Related Causes of Claims for Bridge Projects

The Kruskal-Wallis test was conducted between the top three causes to determine whether the ratings provided by the clients and consultants on geotechnical-related causes of claims for bridge projects were significantly different. The test results showed that the ratings provided by both the clients and consultants for the top three causes of claims were not significantly different (see Table 33).

Table 33. Results of the Kruskal-Wallis Test for Geotechnical-Related Causes of Claims for Bridge Projects

S. No.	Causes	Clients' Ranking		Consultants' Ranking	
		Mean Rank	p-value	Mean Rank	p-value
1.	Lack of Sufficient Boring Location	69.0	0.3	56.2	0.73
2.	Misclassified or mischaracterized subgrade	60.1		50.9	
3.	Lack of detail specifications in problematic areas, such as subgrade treatment and piling	57.7		51.9	

The Mann-Whitney U test was conducted to determine whether the ratings provided for the top three geotechnical-related causes of claims for bridge projects by clients and consultants were significantly different from each other. The test results showed that the clients and consultants rated significantly differently for misclassified or characterized subgrade and lack of detailed specifications in problematic areas, such as subgrade treatment and piling, whereas both groups rated lack of sufficient boring location similarly (see Table 34). Therefore, the results showed that consultants significantly rated higher importance for misclassified or characterized subgrade and lack of detailed specifications in problematic areas, such as subgrade treatment and piling, compared to clients.

Table 34. Mann-Whitney U Test Results for Ranking of Geotechnical-Related Causes of Claims for Bridge Projects

S. No.	Impacts on Claims	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Lack of Sufficient Boring location	35.2	43.5	576	-1.0	0.09
2	Misclassified or mischaracterized subgrade	33.8	44.1	523	-2.9	0.04*
3	Lack of detail specifications in	43.3	44.6	505	-3.2	0.02*

S. No.	Impacts on Claims	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
	problematic areas, such as subgrade treatment and piling					

* significant at alpha level 0.05

4.2.3.6 Statistical Test for the Impact of Geotechnical-Related Causes on Cost Performance of Bridge Projects

The Chi-Square test was conducted to determine whether the proportion of respondents in these two groups (clients and consultants) responded significantly differently regarding the impact of geotechnical-related causes on cost growth during the construction of bridge projects. The test results showed that there was a significantly higher number of consultants who responded that geotechnical-related causes had a negative impact on cost growth than number of clients (see Table 35).

Table 35. Chi-Square Test Results for the Impact of Geotechnical-Related Causes on Cost Performance of Bridge Projects

S. No.	Impacts	Clients' Rating		Consultants' Rating		P- value
		Sample size	Percentage	Sample size	Percentage	
1.	Negative Impact	21	48.8%	28	75.7%	0.014*
2.	No Impact	22	51.2%	9	24.3%	
3.	Total	43	100%	37	100%	

*significant at alpha level 0.05

4.2.3.7 Statistical Test for the Impact of Geotechnical-Related Problems on Schedule Growth of Bridge Projects

The Chi-Square test was conducted to determine whether the proportion of respondents in these two groups (clients and consultants) responded significantly differently regarding the impact of geotechnical-related causes on schedule growth during the construction of bridge projects. The test results showed that there was a significantly higher number of consultants who responded that geotechnical-related causes had a negative impact on schedule growth than number of clients (see Table 36).

Table 36. Chi-Square Test Results for the Impact of Geotechnical-Related Causes on Schedule Growth of Bridge Projects

S. No.	Impacts	Clients' Rating		Consultants' Rating		P- value
		Sample size	Percentage	Sample size	Percentage	
1.	Negative Impact	20	48.8%	28	77.8%	0.009*
2.	No Impact	21	51.2%	8	22.2%	
3.	Total	41	100%	36	100%	

*significant at alpha level 0.05

4.2.3.8 Statistical Test for the Impact of Geotechnical-Related Causes on Claims of Bridge Projects

The Chi-Square test was conducted to determine whether the proportion of respondents in these two groups (clients and consultants) responded significantly differently regarding the impact of geotechnical-related causes on claims during the construction of bridge projects. The test results showed that there was not a significantly different number of consultants who responded that geotechnical-related causes had a negative impact on claims compared to the number of clients (see Table 37).

Table 37. Chi-Square Test Results for the Impact Geotechnical-Related Causes on Claims of Bridge Projects

S. No.	Impacts	Clients' Rating		Consultants' Rating		P- value
		Sample size	Percentage	Sample size	Percentage	
1.	Negative Impact	30	68.2%	31	83.8%	0.105
2.	No Impact	14	31.8%	6	16.2%	
3.	Total	44	100%	37	100%	

4.2.2.9 Statistical Test on Mitigation Strategies for Reducing Cost Overruns, Schedule Delays, and Number of Claims in Bridge Construction Due to Geotechnical Problems

The Kruskal-Wallis test was conducted to determine whether the ratings provided by the clients and consultants for the top three recommendations for reducing cost and schedule growth and claims for bridge projects were significantly different. The test results showed that the ratings provided by the clients for the top three recommendations were not significantly different. However, in the case of consultants' data, the ratings were significantly different (see Tables 38 and 39). Therefore, it is necessary to conduct the Mann-Whitney U test to determine which ratings were significantly different.

Table 38. Results of Clients' Kruskal-Wallis Test for Mitigation Strategies for Bridge Projects

S. No	Recommendations	Mean Rank	P-value
1.	Designer should have detail knowledge about geotechnical information of project site	70.3	0.46
2.	Development and implementation of minimum standards for subsurface investigation and site characterization	70.0	
3.	Detail site investigation with well-experienced consultant	62.0	

Table 39. Results of Consultants' Kruskal-Wallis Test for Mitigation Strategies for Bridge Projects

S. No	Recommendations	Mean Rank	P-value
1.	Designer should have detail knowledge about geotechnical information of project site	65.2	<0.01*
2.	Detail site investigation with well-experienced consultant	62.5	
3.	Choose the appropriate pile type for a particular soil type, with more accurately predicted pile length	44.8	

*significant at alpha level 0.05

The Mann-Whitney U test results showed that the rating provided by consultants for choosing the appropriate pile type for a particular soil type, with more accurately predicted pile length, was significantly lower than what was provided for the designer having detailed knowledge about the project site's geotechnical information and detailed site investigation with a well-experienced consultant (see Table 40). However, the preference of clients among these top three recommendations for reducing cost growth and schedule growth and claims for bridge projects was not significantly different.

Table 40. Results of the Mann-Whitney U Test of Consultants' Ranking of Mitigation Strategies for Bridge Projects

S. No.	Recommendations	Mean Rank	U-value	Z-value	p-value
1.	Designer should have detail knowledge about geotechnical information of project site	39.5	685	-0.45	0.66
	Detail site investigation with well-experienced consultant	37.5			
2.	Designer should have detail knowledge about geo-technical information of project site	45.3	465	-2.9	<0.01*
	Choose the appropriate pile type for a particular soil type, with more accurately predicted pile length	31.7			
3.	Detail site investigation with well experienced consultant	44.5	495	-2.6	0.01*
	Choose the appropriate pile type for a particular soil type, with more accurately predicted pile length	32.5			

* significant at alpha level 0.05

The Mann-Whitney U test was conducted to determine whether the ratings provided for recommendations for reducing cost and schedule growth and claims for bridge projects by clients and consultants were significantly different from each other. The test results showed that clients and consultants rated significantly differently for the development and implementation of minimum standards for subsurface investigation and site characterization, whereas both groups rated the designer having detailed knowledge of the project site's geotechnical information and a detailed site investigation with a well-experienced consultant similarly (see Table 41). Therefore, the results showed that clients significantly preferred the development and implementation of minimum standards for subsurface investigation and site characterization as a recommendation for reducing cost and schedule growth and claims when compared to consultants.

Table 41. Mann-Whitney U Test Results for Ranking of Mitigation Strategies for Bridge Projects

S. No.	Recommendations	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Designer should have detail knowledge about geotechnical information of project site	40.1	44.3	769	-0.9	0.37
2	Detail site investigation with well experienced consultant	38.0	45.6	682	-1.6	0.12
3	Development and implementation of minimum standards for subsurface investigation and site characterization	46.8	36.2	639	-2.1	0.03*

*significant at alpha level 0.05

4.3 Data Analysis Results Regarding Road Pavement Projects

4.3.1 Descriptive Statistics on Road Pavement Projects

In total, ten questions related to the use of geotechnical design standards, use of methods of subsurface investigation, impact on cost overruns, schedule overruns, claims and their ranges due to geotechnical-related problems, and recommendations for reducing these impacts in road pavement projects were asked to participants. In this section, descriptive information based on the experience of participants gathered from the survey and the RII analysis are presented.

4.3.1.1 Use of Geotechnical Design Standards for Road Pavement Design

The results of the RII analysis for the use of geotechnical design standards for road pavement showed that both clients' and consultants' first preference was the ASSHTO Manual on Subsurface Investigation, followed by the FHWA Geotechnical Engineering Circular No. 5, and the National Highway Institute (NHI) Manual on Subsurface Investigation (see Table 42). Based on the RII values, the clients' importance rating for these standards was very close, whereas the consultants rated the AASHTO Manual highly important compared to the FHWA and NHI Manuals. When the ratings of both groups were combined, it was revealed that the respondents gave high importance to the AASHTO Manual when compared to FHWA and NHI Manuals.

Table 42. Ratings of the Use of Geotechnical Design Standards for Road Pavement Projects

S. No.	Standards Used	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	AASHTO Manual on Subsurface Investigation	34	68%	35	74%	71%
2.	FHWA Geotechnical Engineering Circular No. 5	34	62%	34	55%	59%
3.	NHI Manual on Subsurface Investigation	32	63%	34	51%	56%

4.3.1.2 Use of Subsurface Investigation Methods for Road Pavement Design

The results of the RII analysis for the use of subsurface investigation methods for road pavement design showed that both clients' and consultants' first preference was the Standard Penetration Test (SPT), followed by the Falling Weight Deflectometer Method for clients and Cone Penetration Testing (CPT) for consultants (see Table 43). Based on the RII values, the clients' importance ratings for these methods were very close, whereas the consultants rated the Standard Penetration Test highly important as compared to other methods. When the ratings of both groups were combined, it was revealed that the respondents gave the highest preference to the Standard Penetration Test (SPT) to other subsurface investigation methods for road pavement design.

Table 43. Ratings of Subsurface Investigation Methods for Road Pavement Design

S. No.	Method Used	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Standard Penetration Test (SPT)	37	66%	34	77%	72%
2.	Falling weight Deflectometer Method	39	62%	33	41%	52%
3.	Geophysical Method	36	41%	33	38%	39%
4.	Cone Penetration Testing (CPT)	36	32%	34	44%	38%
5.	Hydraulic Conductivity Testing Method	36	32%	33	35%	33%
6.	Vane Share Test (VST)	37	30%	33	34%	32%
7.	Flat Plate Dilatometer Testing	37	29%	33	32%	30%
8.	Remote Sensing	37	26%	34	32%	29%
9.	Pressure Meter Testing	37	25%	33	28%	27%

4.3.1.3 Geotechnical-Related Causes of Cost Growth for Road Pavement Projects

The results of the RII analysis for geotechnical-related causes of cost growth for road pavement projects showed that both clients' and consultants' first rank was misclassified or mischaracterized subgrade, followed by a level of groundwater table higher than expected, and design in road pavement (see Table 44). A mismatch in pile quantities was the least significant cause according to both groups. Based on the RII values, the clients' importance ratings for these causes were close, whereas the consultants rated misclassified or mischaracterized subgrade more highly as compared to other causes. When the ratings of both groups were combined, it was revealed that the respondents gave first rank to misclassified or mischaracterized subgrade and ratings for these causes were also close.

Table 44. Geotechnical-Related Causes of Cost Growth for Road Pavement Projects

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Misclassified or mischaracterized subgrade	40	63%	33	76%	68%
2.	Level of groundwater table higher than expected	41	62%	33	65%	63%
3.	Design change in the road pavement	41	57%	33	67%	61%
4.	Lack of sufficient boring locations	41	55%	33	67%	61%
5.	The prescribed soil treatment method was not suitable for a particular site condition	40	58%	32	63%	60%
6.	De-watering due to seepage problems	39	55%	33	57%	56%
7.	Erosion and sediment control	40	44%	33	47%	45%
8.	Variation of piling quantities due to the selection of the wrong pile type for a particular	37	24%	32	31%	27%

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
	soil type					
9.	Mismatch in pile quantities	37	23%	33	30%	26%

4.3.1.4 Geotechnical-Related Causes of Schedule Growth for Road Pavement Projects

The results of the RII analysis for geotechnical-related causes of schedule growth for road pavement projects showed that both clients' and consultants' first rank was misclassified or mischaracterized subgrade, followed by a level of groundwater table higher than expected, and prescribed soil treatment method unsuitable for a particular soil type (see Table 45). Based on the RII values, the clients' importance ratings for these causes were close, whereas the consultants rated misclassified or mischaracterized subgrade more highly than other causes. When the ratings of both groups were combined, it was revealed that the respondents gave first rank to misclassified or mischaracterized subgrade, and ratings for these causes were close. The least preferred cause rated by the combined respondents was a mismatch in pile quantities.

Table 45. Geotechnical-Related Causes of Schedule Growth for Road Pavement Projects

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Misclassified or mischaracterized subgrade	40	58%	31	72%	64%
2.	Level of groundwater table higher than	40	61%	31	60%	61%

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
	expected					
3.	The prescribed soil treatment method was not suitable for a particular site condition	39	59%	31	63%	61%
4.	De-watering due to seepage problems	39	57%	31	61%	59%
5.	Design change in the road pavement	39	53%	31	63%	58%
6.	Lack of sufficient boring locations	39	49%	31	62%	55%
7.	Erosion and sediment control	40	41%	31	48%	44%
8.	Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	37	26%	31	30%	28%
9.	Mismatch in pile quantities	37	23%	32	33%	28%

4.3.1.5 Geotechnical-Related Causes of Claims for Road Pavement Projects

The results of the RII analysis for geotechnical-related causes of claims for road pavement projects showed that both clients' and consultants' first rank was misclassified or mischaracterized subgrade, followed by a level of groundwater table higher than expected, and prescribed soil treatment method unsuitable for a particular soil type (see Table 46). A mismatch in pile quantities was the least ranked cause by both groups. Based on the RII values, the clients' importance ratings for these causes were close, whereas the consultants rated misclassified or mischaracterized subgrade more highly than other causes. When the ratings of both groups were combined, it was revealed that the respondents gave highest rank to misclassified or mischaracterized subgrade compared to other causes.

Table 46. The Rating of Geotechnical-Related Causes of Claims for Road Pavement Projects

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Misclassified or mischaracterized subgrade	41	62%	31	74%	68%
2.	Level of groundwater table higher than expected	41	60%	31	63%	61%
3.	The prescribed soil treatment method was not suitable for a particular site condition	39	58%	31	65%	61%
4.	Lack of detail specifications in problematic areas, such as subgrade treatment and piling	39	56%	31	62%	59%
5.	Lack of sufficient boring locations	41	55%	31	64%	59%
6.	De-watering due to seepage problems	40	53%	31	59%	56%
7.	Design change in the road pavement	41	48%	30	64%	55%
8.	Erosion and sediment control	41	39%	31	50%	43%

S. No.	Causes	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
9.	Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	38	26%	31	31%	28%
10.	Mismatch in pile quantities	38	24%	31	30%	26%

4.3.1.6 The Impact of Geotechnical-Related Causes on Cost Growth for Road Pavement Projects

When the respondents were asked about the impact of geotechnical-related causes on cost growth, about 73 respondents answered the question. Out of these respondents, 25 percent stated that there was no impact on cost growth due to geotechnical-related causes on pavement projects (Table 47). About 43 percent of the respondents answered that these causes increased construction cost growth by more than 5 percent. Two participants stated these geotechnical reasons could have a positive impact on the cost growth of pavement projects.

Table 47. The Impact of Geotechnical-Related Causes on Cost Growth for Road Pavement Projects

S.N.	Range of cost performance	Clients	Consultants	Total	Percentage
1.	Overrun budget by over 25%	1	0	1	1.0%
2.	Overrun budget by 16- 25%	1	3	4	4.2%
3.	Overrun budget by 5-15%	16	20	36	37.5%
4.	Overrun budget by below 5%	5	1	6	6.3%
5.	On budget	17	7	24	25.0%
6.	Under budget by below 1%	1	0	1	1.0%
7.	Under budget by 1-5%	0	1	1	1.0%
8.	Under budget by 6-10%	0	0	0	0.0%
9.	Under budget by over 10%	0	0	0	0.0%
	Total	41	32	73	100.0%

4.3.1.7 The Impact of Geotechnical-Related Causes on Schedule Growth for Road Pavement Projects

A similar question was asked about the impact on schedule growth, and 73 out of 96 respondents answered the question. Out of these respondents, about 49 percent said that these causes will increase a project's schedule growth by more than 5 percent (Table 48). However, 32 percent of the respondents stated that there was no impact on schedule growth due to geotechnical-related reasons. One participant mentioned that these causes had a positive impact on schedule growth of pavement projects.

Table 48. The Impact of Geotechnical-Related Causes on Schedule Growth for Road Pavement Projects

S.N.	Range of schedule performance	Clients	Consultants	Total	Percentage
1.	Behind schedule by over 25%	0	0	0	0.0%
2.	Behind schedule by 16- 25%	3	6	9	12.3%
3.	Behind schedule by 5-15%	12	15	27	37.0%
4.	Behind schedule by below 5%	7	4	11	15.1%
5.	On schedule	16	7	23	31.5%
6.	Ahead of schedule by below 1%	2	0	2	2.7%
7.	Ahead of schedule by 1-5%	0	0	0	0.0%
8.	Ahead of schedule by 6-10%	0	0	0	0.0%
9.	Ahead of schedule by over 10%	1	0	1	1.4%
	Total	41	32	73	100.0%

4.3.1.8 Geotechnical-Related Causes on Claims for Road Pavement Construction

When asked about the impact of geotechnical-related causes on claims for pavement projects, about 75 percent of respondents answered question. Of these respondents, a majority of (61%) stated that these causes had increased claims by more than 5 percent (Table 49). About 36 percent of respondents said that these causes did not have any impact on construction claims for pavement projects.

Table 49. The Impact of Geotechnical-Related Causes on Claims for Road Pavement Projects

S.N.	Cost claims	Clients	Consultants	Total	Percentage
1.	Extra cost requested over 25%	1	0	1	1.4%
2.	Extra cost requested 16-25%	7	7	14	19.4%
3.	Extra cost requested 5-15%	13	16	29	40.3%
4.	Extra cost requested below 5%	1	1	2	2.8%
5.	No claims	19	7	26	36.1%
	Total	41	31	72	100.0%

4.3.1.9 The Percentage of Total Project Cost for Geotechnical Investigations during the Design Phase of Road Pavement Projects

The respondents were asked what percentage of pavement projects' cost was recommended for geotechnical investigations. Out of 96, only 43 responded to this question. The mean and median cost percentages recommended by the respondents were 7.03 percent and 3.0 percent, respectively. A box plot was made to identify the outlier data point in the dataset (Figure 10). The box plot showed there are four outlier data points.

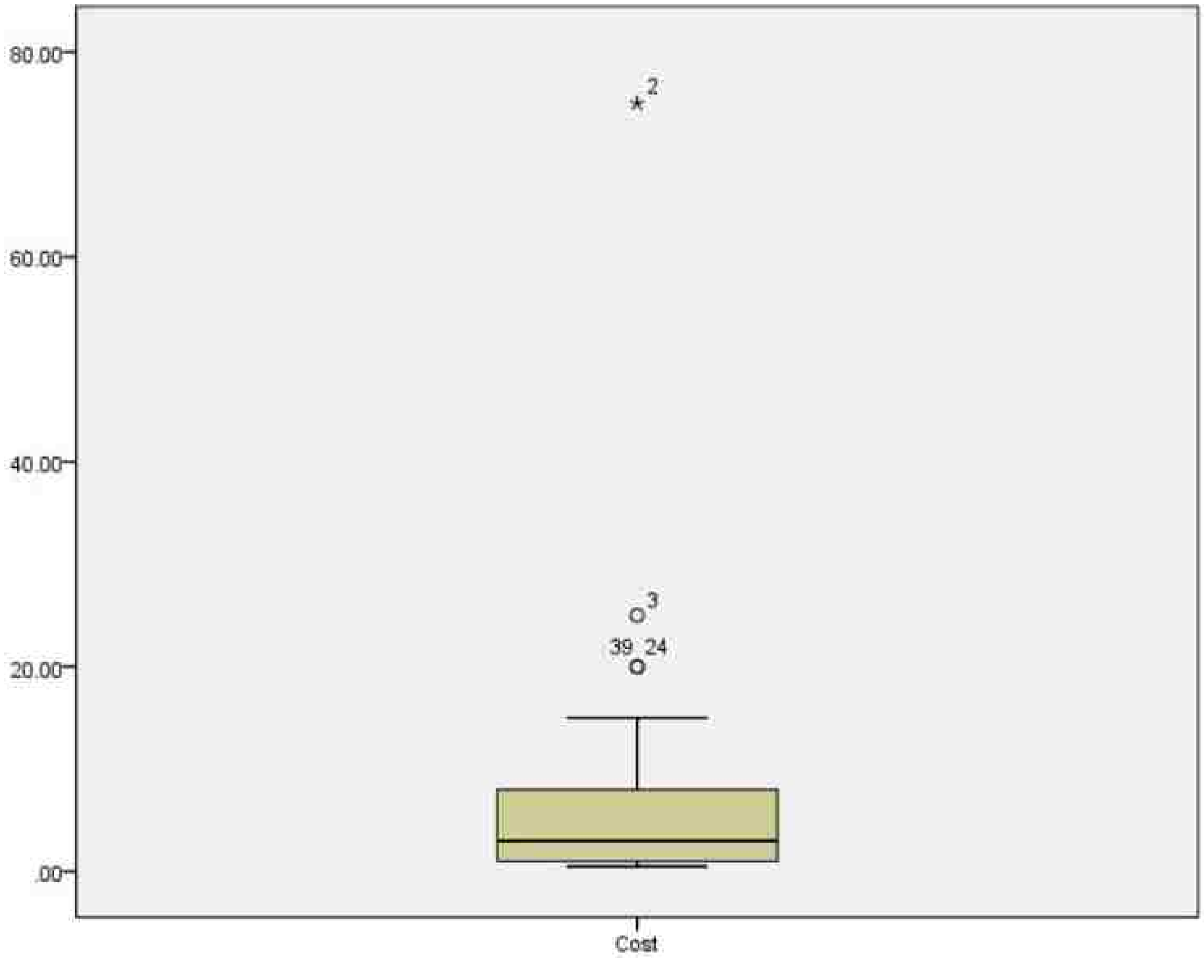


Figure 10. Box plot of recommended cost percentage for road pavement projects

4.3.1.10 Mitigation Strategies for Reducing Cost and Schedule Growth, and Number of Claims in Road Pavement Construction Due to Geotechnical-Related Causes.

The results of the RII analysis for recommendations for reducing cost and schedule growth and claims in road pavement construction due to geotechnical-related causes showed that both clients' and consultants' first rank was designer having detailed knowledge about the project site's geotechnical information, followed by a detailed site investigation with a well-experienced consultant, and the development and implementation of minimum standards for subsurface investigation and site characterization (see Table 50). Choosing the appropriate pile type for a particular soil type, with more accurately predicted pile lengths, was the least important recommendation rated by both groups. Based on the RII values, both clients' and consultants' importance ratings for these impacts were close. When the ratings of both groups were combined, it was revealed that the respondents gave first preference to misclassified or mischaracterized subgrade, and the rating for these recommendations were close.

Table 50. Ratings of Mitigation Strategies for Reducing Cost Overruns, Schedule Delays, and Number of Claims for Road Pavement Projects Due to Geotechnical Problems

S. No.	Recommendations	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
1.	Designer should have detail knowledge about geotechnical information of project site	40	87%	34	88%	87%
2.	Development and implementation of minimum standards for subsurface investigation and site characterization	40	85%	34	79%	82%
3.	Detail site investigation with well-experienced consultant	39	78%	34	86%	82%
4.	Intra-agency training and communication to improve the implementation of surface information	39	77%	34	75%	76%
5.	Specification needs to be more solid in problematic area such as subgrade treatment and piling	39	76%	34	76%	76%
6.	Causes of geotechnical change order should be routed through the	40	75%	34	77%	76%

S. No.	Recommendations	Clients' Rating		Consultants' Rating		Combined Rating
		Sample size	Relative Importance Index (RII)	Sample size	Relative Importance Index (RII)	
	goetechnical office, which helps to designer for reducing that type of change order in design period					
7.	Accuracy of boring locations	40	74%	34	65%	70%
8.	Choose the appropriate pile type for a particular soil type, with more accurately predicted pile lengths	38	42%	34	43%	43%

4.3.2 Statistical Test Results for Road Pavement Projects

The Statistical test was conducted to determine whether the rankings provided by the respondents were significantly different from each other. Also, the rankings provided by these two groups were tested to determine whether they were significantly different. Kruskal-Wallis, Mann-Whitney U, and Chi-Square tests were conducted, and the significant level selected for these tests was 0.05. The results of these tests are described below.

4.3.2.1. Statistical Test on Use of Geotechnical Design Standards for Road Pavement Projects

The Kruskal-Wallis test was conducted to determine whether the ratings provided by the client and consultants on the use of geotechnical design standards for road pavement projects were significantly different. The test results showed that the ratings provided by the clients for the three types of manuals used were not significantly different. However, in the case of consultants' data, the ratings were significantly different (see Table 51). Therefore, it is necessary to conduct the Mann-Whitney U test to determine which ratings were significantly different.

Table 51. Results of Kruskal-Wallis Test of Geotechnical Design Standards Used for Road Pavement Projects

S. No.	Standards Used	Clients' Ranking		Consultants' Ranking	
		Mean Rank	p-value	Mean Rank	p-value
1.	AASHTO Manual on Subsurface Investigation	53.7	0.72	66.8	0.01*
2.	NHI Manual on Subsurface Investigation	48.8		42.3	
3.	FHWA Geotechnical Engineering Circular No. 5	48.9		46.5	

* significant at alpha level 0.05

The Mann-Whitney U test results showed that the rating provided by consultants for the ASSHTO Manual was significantly higher than that provided for the FHWA and NHI Manuals (see Table 52). This showed that consultants significantly preferred the AASHTO Manual for the geotechnical design of road pavement projects compared to the FHWA engineering Circular 5 and NHI Manual. However, the preference of clients among these three Manuals for the geotechnical design of bridge projects was not significantly different.

Table 52. Results of the Mann-Whitney U Test on Consultants' Ranking of Use of Design Standards for Road Pavement Projects

S. No.	Standards Used	Mean Rank	U-value	Z-value	p-value
1.	AASHTO Manual FHWA Eng. Circular 5	41.8 28.0	357	-2.9	<0.01*
2.	AASHTO Manual NHI Manual	43.0 26.8	315	-3.4	<0.01*
3.	FHWA Eng. Circular 5 NHI Manual	36.0 33.0	526	-0.65	0.51

* significant at alpha level 0.05

The Mann-Whitney U test was conducted to determine whether the ratings provided for the use of these three manuals by clients and consultants were significantly different from each other. The test results showed that the clients and consultants both rated these design manuals similarly (see Table 53).

Table 53. Mann-Whitney U Test Results on Ranking of Use of Geotechnical Design Standards for Road Pavement Projects

S. No.	Standards used	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	AASHTO Manual	32.9	37.0	524	-0.88	0.38
2	FHWA Eng. Circular 5	37.1	31.9	489	-1.7	0.09
3	NHI Manual	37.6	29.7	414	-1.1	0.27

4.3.2.2. Statistical Test on Use of Subsurface Investigation Methods for Road Pavement Projects

The Kruskal-Wallis test was conducted to determine whether the ratings provided by the clients and consultants on the use of subsurface investigation methods for road pavement projects were significantly different. The test results showed that the ratings provided by both the clients and consultants for the top three ratings of methods used were significantly different. (see Tables 54 and 55). Therefore, it is necessary to conduct the Mann-Whitney U test to determine which ratings were significantly different.

Table 54. Results of Clients' Kruskal-Wallis Test for the Use of Subsurface Investigation Methods for Road Pavement Projects

S. No.	Methods Used	Mean Rank	P-value
1.	Standard Penetration Test	67.3	0.01*
2.	Falling Weight Deflectometer Method	61.9	
3.	Geophysical Method	39.6	

*significant at alpha level 0.05

Table 55. Results of Consultants' Kruskal-Wallis Test for the Use of Subsurface Investigation Methods for Road Pavement Projects

S. No.	Methods Used	Mean Rank	P-value
1.	Standard Penetration Test	73.3	0.01*
2.	Cone Penetration Testing	41.7	
3.	Falling Weight Deflectometer Method	37.7	

*significant at alpha level 0.05

The Mann-Whitney U test results showed that the rating provided by both clients' and consultants' respondents for the Standard Penetration Test was significantly higher than that provided for Cone Penetration Testing and the Geophysical Method (see Tables 56 and 57). This showed that consultants significantly preferred the Standard Penetration Test for the geotechnical design of road pavement projects compared to Cone Penetration Testing and the Falling Weight Deflectometer Method. However, the preference of clients among these top three methods for subsurface investigation methods of road pavement projects was the Geophysical Method, significantly different than the other two.

Table 56. Results of the Mann-Whitney U Test on Clients' Ranking of the Use of Subsurface Investigation Methods for Road Pavement Projects

S. No.	Methods Used	Mean Rank	U-value	Z-value	p-value
1.	Standard Penetration Test	40.7	639	-0.87	0.38
	Falling Weight Deflectometer	36.4			
2.	Standard Penetration Test	45.6	348	-3.6	<0.01*
	Geophysical Method	28.2			
3.	Falling Weight Deflectometer	45.5	410	-3.2	<0.01*
	Geophysical Method	29.9			

*significant at alpha level 0.05

Table 57. Results of the Mann-Whitney U Test on Consultants' Ranking of the Use of Subsurface Investigation Methods for Road Pavement Projects

S. No.	Methods Used	Mean Rank	U-value	Z-value	p-value
1.	Standard Penetration Test	45.8	195	-4.8	<0.01*
	Cone Penetration Testing	23.2			
2.	Standard Penetration Test	45.0	187	-4.8	<0.01*
	Falling Weight Deflectometer	22.7			
3.	Cone Penetration Testing	36.0	494	-0.9	0.37
	Falling Weight Deflectometer	32.0			

*significant at alpha level 0.05

The Mann-Whitney U test was conducted to determine whether the ratings provided for the use of subsurface investigation methods for road pavement projects by clients and consultants were significantly different from each other. The test results showed that the clients and consultants rated significantly differently for the Falling Weight Deflectometer Method, whereas both groups rated SPT and CPT similarly (Table 58). Therefore, the results showed that clients significantly preferred the Weight Deflectometer Method to conduct subsurface investigations as compared to consultants.

Table 58. Mann-Whitney U Test Results on Ranking of the Use of Subsurface Investigation Methods for Road Pavement Projects

S. No.	Methods Used	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Standard Penetration Test	33.1	39.2	520	-1.3	0.20
2	Falling Weight Deflectometer Method	43.3	28.5	380	-3.1	<0.01*
3	Geophysical Method	36.6	33.3	536	-0.7	0.46

* significant at alpha level 0.05

4.3.2.3 Statistical Test on Geotechnical-Related Causes of Cost Growth for Road Pavement Projects

The Kruskal-Wallis test was conducted between the top three geotechnical-related causes to determine whether the ratings provided by the clients and consultants on geotechnical-related causes of cost growth for road pavement projects were significantly different. The test results showed that the ratings provided by both the clients and consultants for the top three causes of cost growth were not significantly different (see Tables 59 and 60).

Table 59. Results of Clients' Kruskal-Wallis Test for Geotechnical-Related Causes of Cost Growth for Road Pavement Projects

S. No.	Causes	Mean Rank	P-value
1.	Misclassified or mischaracterized sub-grade	63.3	0.49
2.	Level of groundwater table higher than expected	63.8	
3.	The prescribed soil treatment method was not suitable for a particular site condition	55.8	

Table 60. Results of Consultants' Kruskal-Wallis Test for Geotechnical-Related Causes of Cost Growth for Road Pavement Projects

S. No.	Causes	Mean Rank	P-value
1.	Misclassified or mischaracterized subgrade	57.7	0.15
2.	Lack of sufficient boring locations	46.3	
3.	Design change in the road pavement	45.9	

The Mann-Whitney U test was conducted to determine whether the ratings provided for the geotechnical-related causes of cost growth for road pavement projects by clients and consultants were significantly different. The test results showed that clients and consultants rated significantly differently for misclassified or mischaracterized subgrade, whereas both groups rated a level of groundwater table higher than expected and a design change in road pavement similarly (see Table 61). Therefore, the results showed that the consultants significantly rated higher importance to misclassified or mischaracterized subgrade when compared to clients.

Table 61. Mann-Whitney U Test Results on Ranking of Geotechnical-Related Causes of Cost Growth for Road Pavement Projects

S. No.	Causes	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Misclassified or mischaracterized subgrade	31.2	44.0	429	-2.6	<0.01*
2	Level of groundwater table higher than expected	37.2	37.9	662	-0.16	0.88
3	Design change in the road pavement	33.5	42.5	512	-1.85	0.06

* significant at alpha level 0.05

4.3.2.4 Statistical Test on Geotechnical-Related Causes of Schedule Growth for Road Pavement Projects

The Kruskal-Wallis test was conducted between the top three causes to determine whether the ratings provided by the clients and consultants on geotechnical-related causes of schedule growth for road pavement projects were significantly different. The test results showed that the ratings provided by both clients and consultants for the top three causes of schedule growth were not significantly different (see Tables 62 and 63).

Table 62. Results of Clients' Kruskal-Wallis Test on Geotechnical-Related Causes of Schedule Growth for Road Pavement Projects

S. No.	Causes	Mean Rank	P-value
1.	Level of groundwater table higher than expected	62.2	0.86
2.	The prescribed soil treatment method was not suitable for a particular site condition	59.4	
3.	Misclassified or mischaracterized subgrade	58.4	

Table 63. Results of Consultants' Kruskal-Wallis Test on Geotechnical-Related Causes of Schedule Growth for Road Pavement Projects

S. No.	Causes	Mean Rank	P-value
1.	Misclassified or mischaracterized subgrade	53.4	0.25
2.	Design change in the road pavement	43.9	
3.	The prescribed soil treatment method was not suitable for a particular site condition	43.7	

The Mann-Whitney U test was conducted to determine whether the ratings provided for the top three causes on schedule growth by clients and consultants were significantly different. The test results showed that the clients and consultants rated significantly differently for misclassified or mischaracterized subgrade, whereas both groups rated a level of groundwater table higher than expected and prescribed soil treatment method unsuitable for a particular site condition similarly (see Table 64). Therefore, the results showed that the consultants significantly ranked higher importance to misclassified or mischaracterized subgrade as compared to clients.

Table 64. Mann-Whitney U Test Results on Ranking of Geotechnical-Related Causes of Schedule Growth for Road Pavement Projects

S. No.	Causes	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Misclassified or mischaracterized subgrade	30.9	42.5	417	-2.4	0.02*
2	Level of groundwater table higher than expected	36.5	35.4	601	-0.22	0.83
3	The prescribed soil treatment method was not suitable for a particular site condition	33.9	37.6	540	-0.79	0.43

* significant at alpha level 0.05

4.3.2.5 Statistical Test on Geotechnical-Related Causes of Claims for Road Pavement Projects

The Kruskal-Wallis test was conducted between the top three causes to determine whether the ratings provided by the clients and consultants on geotechnical-related causes of claims for road pavement projects were significantly different. The test results showed that the ratings provided by both the clients and consultants for the top three causes of claims were not significantly different (see Tables 65 and 66).

Table 65. Results of Clients' Kruskal-Wallis Test on Geotechnical-Related Causes of Claims for Road Pavement Projects

S. No.	Causes	Mean Rank	P-value
1.	Misclassified or mischaracterized subgrade	64.8	
2.	Level of groundwater table higher than expected	60.6	0.62
3.	The prescribed soil treatment method was not suitable for a particular site condition	57.5	

Table 66. Results of Consultants' Kruskal-Wallis Test on Geotechnical-Related Causes of Claims for Road Pavement Projects

S. No	Causes	Mean Rank	P-value
1.	Misclassified or mischaracterized subgrade	53.8	
2.	The prescribed soil treatment method was not suitable for a particular site condition	42.9	0.15

S. No	Causes	Mean Rank	P-value
3.	Design change in the road pavement	42.6	

The Mann-Whitney U test was conducted to determine whether the ratings provided for the top three geotechnical-related causes of claims by clients and consultants were significantly different from each other. The test results showed that clients and consultants rated significantly differently for misclassified or mischaracterized subgrade, whereas both groups rated a level of groundwater table higher than expected and the prescribed soil treatment method unsuitable for a particular site condition similarly (see Table 67). Therefore, the results showed that the consultants rated significantly higher importance to misclassified or mischaracterized subgrade's impact on claims as compared to clients.

Table 67. Mann-Whitney U Test Results on Ranking of Geotechnical-Related Causes of Claims for Road Pavement Projects

S. No.	Causes	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Misclassified or mischaracterized subgrade	31.7	42.8	440	-2.3	0.02*
2	Level of groundwater table higher than expected	35.1	38.3	579	-0.67	0.51
3	The prescribed soil treatment method was not suitable for a particular site condition	32.9	38.8	502	-1.3	0.21

* significant at alpha level 0.05

4.3.3.6 Statistical Test on the Impact of Geotechnical-Related Causes of Cost Growth for Road Pavement Projects

The Chi-Square test was conducted to determine whether the proportion of respondents in these two groups (clients and consultants) responded significantly differently regarding the impact of geotechnical-related causes on cost growth during the construction of road pavement projects. The test results showed that there was not a significant difference in opinion between clients and consultant regarding the impact of geotechnical-related causes on cost growth during the construction of road pavement projects (see Table 68).

Table 68. Chi-Square Test Results on the Impact of Geotechnical-Related Causes on Cost Growth for Road Pavement Projects

S. No.	Impacts	Clients' Rating		Consultants' Rating		P- value
		Sample size	Percentage	Sample size	Percentage	
1.	Negative Impact	23	57.5%	24	77.4%	0.078
2.	No Impact	17	42.5%	7	22.6%	
3.	Total	40	100%	31	100%	

4.3.3.7 Statistical Test of the Impact of Geotechnical-Related Causes on Schedule Growth for Road Pavement Projects

The Chi-Square test was conducted to determine whether the proportion of respondents in these two groups (clients and consultants) responded significantly differently regarding the impact of geotechnical-related causes on schedule growth during the construction of road pavement projects. The test results showed that there was not a significant difference in opinion between clients and consultant regarding the impact of geotechnical-related causes on schedule growth during the construction of road pavement projects (see Table 69).

Table 69. Chi-Square Test Results on the Impact on Schedule Growth for Road Pavement Projects

S. No.	Impacts	Clients' Rating		Consultants' Rating		P- value
		Sample size	Percentage	Sample size	Percentage	
1.	Negative Impact	22	57.9%	25	78.1%	

S. No.	Impacts	Clients' Rating		Consultants' Rating		P- value
		Sample size	Percentage	Sample size	Percentage	
2.	No Impact	16	42.1%	7	21.9%	0.073
3.	Total	38	100%	32	100%	

4.3.3.8 Statistical Test on the Impact of Geotechnical-Related Causes on Claims for Road Pavement Projects

The Chi-Square test was conducted to determine whether the proportion of respondents in these two groups (clients and consultants) responded significantly differently regarding the impact of geotechnical-related causes on claims during the construction of road pavement projects. The test results showed that there was a significantly higher number of consultants who responded that geotechnical-related causes had a negative impact on claims than clients (see Table 70).

Table 70. Chi-Square Test Results on the Impact of Geotechnical-Related Causes on Claims for Road Pavement Projects

S. No.	Impacts	Clients' Rating		Consultants' Rating		P- value
		Sample size	Percentage	Sample size	Percentage	
1.	Negative Impact	22	53.7%	24	77.4%	0.038*
2.	No Impact	19	46.3%	7	22.6%	
3.	Total	41	100%	31	100%	

*significant at alpha level 0.05

4.3.2.9 Statistical Test on Mitigation Strategies for Reducing Cost Overruns, Schedule Delays, and Number of Claims for Road Pavement Projects

The Kruskal-Wallis test was conducted to determine whether the ratings provided by the clients and consultants on the top three recommendations for reducing cost and schedule growth and claims for road pavement projects were significantly different. The test results showed that the ratings provided by the clients and consultants for the top three recommendations used were not significantly different (see Table 71).

Table 71. Results of the Kruskal-Wallis Test on Mitigation Strategies for Road Pavement Projects

S. No.	Recommendations	Client's Ranking		Consultants' Ranking	
		Mean Rank	p-value	Mean Rank	p-value
1.	Designer should have detail knowledge about geo-technical information of project site	63.6	0.3	57.2	0.09
2.	Development and implementation of minimum standards for subsurface investigation and site characterization	62.8		43.2	
3.	Detail site investigation with well experienced consultant	53.5		54.0	

The Mann-Whitney U test was conducted to determine whether the ratings provided for recommendations for reducing cost overruns, schedule delays, and claims for road pavement projects by clients and consultants were significantly different. The test results showed that clients and consultants rated similarly (see Table 72). Therefore, the results showed that the preference of both groups among these three recommendations for reducing cost and schedule growth and claims was not significantly different.

Table 72. Mann-Whitney U Test Results on Ranking of Mitigation Strategies for Road Pavement Projects

S. No.	Recommendations	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
1	Designer should have detail knowledge about geotechnical information of project site	36.1	39.2	622	-0.7	0.49

S. No.	Recommendations	Clients' Mean Rank	Consultants' Mean Rank	U-value	Z-value	p-value
2	Development and implementation of minimum standards for subsurface investigation and site characterization	40.6	33.9	557	-1.4	0.16
3	Detail site investigation with well experienced consultant	34.0	40.4	546	-1.4	0.17

4.4 Miscellaneous Findings

Some of the clients' and consultants' participants also provided the minimum standards used by their agencies in the "if any other" section of the questionnaire. They were: the NYSDOT Standard, the SCDOT Geotechnical Design Manual, the NCDOT Internal Manual, the ITD (Idaho) Materials Manual, the Arizona DOT Internal Manual, the Ohio DOT Standards, the FDOT Soils and Foundation Manual/ Handbook, the MNDOT Standards, the CT Guidelines, which basically follow the AASTO and FHWA, the VDOT Materials Division Manual of Instructions, the CalTrans Manuals, the PennDOT Pub 222, the MTDOT Geotechnical Manual, the FHWA-NHI-05-037 Geotechnical Aspects of Pavement, the NMDOT Internal Policy and Guidelines, the AK Geotechnical Proc Manual, the MDSHA Pavement and Geotechnical Design Guide, the AZ Guidelines, and the Oregon Department of Transportation (ODOT) Pavement Design Guide.

Two of the respondents from the consultant group noted that their companies also formerly used the rock coring method for subsurface investigation while designing bridge projects.

Dynamic Cone Penetrometer and Undisturbed and Disturbed sample testing were also other methods of subsurface investigation for road pavement projects used by clients in their agencies. Likewise, muck probing, coring, test pits, hand borings, Dynamic Cone Penetrometer

Tests, field CBR testing, and coring and DCP testing using the dual mass DCP on existing pavements were other extra methods of subsurface investigation for road pavement projects used by consultants.

According to one of the consultants' participants, insufficient protection of pavement subgrade from wet weather was also the effect of geotechnical-related problems during design on cost overruns, schedule overruns, and claims during road pavement construction.

Other recommendations for reducing cost and schedule overruns and claims in bridge construction due to geotechnical problems recommended by participants were: budget control by technical staff, geotechnical training to non-geotechnical personnel, minimum tip elevations for piling not just bearing capacity, involvement of geotechnical designers in the earlier project stages, detailed site investigation, performing a load test prior to design or confirmation piles prior to construction to confirm design, local experience of the geotechnical consultant, in-house experience and knowledge of project site, and more extensive laboratory testing to determine soil set-up, soil relaxation, and soil consolidation.

Similarly, two other recommendations provided by participants were that the designer should submit two design sections, one assuming dry weather construction and the other assuming wet weather construction, and supply preliminary line and grade information before starting geotechnical exploration.

4.5 Comparison of Rating Between Bridge and Road Pavement Projects

- The research found that the AASHTO Manual contains the most significantly recommended standard design guidelines for conducting geotechnical design for both bridge and road pavements projects. Similarly, the Standard Penetration Test is the highest rated method to conduct subsurface investigation for both bridge and road pavement projects.

- Lack of boring locations and misclassified subgrade were observed to impact cost, schedule, and claims for bridge projects. Contrastingly, for road pavement, misclassified or mischaracterized subgrade and level of groundwater impacted costs, schedules, and claims.
- For both bridge and road projects, geotechnical changes negatively impacted costs, schedule performance, and claims.
- It was noted that the designer should have detailed knowledge about the geotechnical information of the project site. A detailed site investigation should be conducted by a highly-experienced consultant. The development and implementation of minimum standards for subsurface investigation and site characterization were the most recommended mitigation strategies for reducing cost overruns, schedule delays, and number of claims in both bridge and road pavement construction as a result of geotechnical problems.

4.6 Discussion

After a discussion of the previous studies, it is clear that no comparison study was done between bridge and road pavement projects with two different parties (clients and consultants) regarding geotechnical causes of claims, change orders, cost overruns, and schedule delays. To fill this gap in previous research, this study tested ten hypotheses to determine whether the ratings provided by clients and consultants for causes of geotechnical-related problems and their impact on claims, cost overruns, and schedule delays were significantly different in two different types of construction projects: bridge and road pavement projects. The results showed that, in many cases, there was not much difference in opinion between clients and consultants for both projects. However, there were differing opinions among bridge and road pavement projects for only some issues because of differences in the allocated budget for subsurface investigations. The survey participants recommended higher subsurface investigation costs for bridge than road pavement projects. One reason for this may be the direct involvement of the clients throughout the lifespan of the project. However, this may not necessarily be the case for consultants, as they may either be involved in only the design or supervision phases. This might lead to consultants being unfamiliar with the problems that may arise during a project's execution. As a result, the perception of clients and consultants may differ as a natural corollary.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Bridge Projects

Consultants have rated the ASSHTO Manual significantly higher, whereas clients have produced similar ratings for all three manuals for bridge projects. Further analysis showed that clients and consultants rated significantly differently for the FHWA and NHI Manuals, whereas both groups rated the AASHTO Manual similarly. Therefore, the results of group comparison between clients and consultants for use of standard guidelines for design showed that clients significantly preferred the FHWA and NHI Manuals to conduct the geotechnical design of bridges as compared to consultants.

Out of a total of nine methods of subsurface investigation, the top three rated methods were identified and used for group-wise comparison purposes. The results showed that the top three rated methods were: the Standard Penetration Test, the Cone Penetration Test, and the Geophysical Method for bridge projects. The results also showed that consultants and clients were more favorable to the Standard Penetration Test (SPT) for bridge projects. This indicates that, while further dividing into two separate evaluation criteria, there was not much difference in opinion between clients and consultants for bridge projects.

Again, out of a total of nine possible geotechnical-related causes of cost growth for bridge projects, the top three causes were: a lack of sufficient boring locations, misclassified or mischaracterized subgrade, and a level of groundwater table higher than expected. When the top three causes were compared, they did not exhibit a significant difference. The same was true when a comparison was made between clients and consultants.

The top three geotechnical-related causes of schedule growth rated by clients and consultants were: a lack of sufficient boring locations, misclassified or mischaracterized subgrade, and design changes in the superstructure. The top three causes of schedule growth did not exhibit any significant differences for both clients and consultants in bridge projects. Consultants rated these causes of schedule growth significantly higher as compared to clients for bridge projects.

The top three geotechnical-related causes of claims rated by clients and consultants were: a lack of sufficient boring locations, misclassified or mischaracterized subgrade, and a lack of detailed specifications in problematic areas, such as subgrade treatment and piling. The top three causes of claims did not exhibit any significant differences for both clients and consultants in bridge projects. Consultants rated misclassified or mischaracterized subgrade as a cause of claims significantly higher than clients for bridge projects.

Clients have classified no impact due to geotechnical-related causes on cost and schedule growth as the most common, whereas consultants indicated that negative impact was higher in bridge projects. Furthermore, there was a significantly higher number of consultants who responded that geotechnical-related causes had a negative impact on cost and schedule growth than clients for bridge projects.

Both clients and consultants indicated negative impact due to geotechnical-related causes of claims for bridge projects. Furthermore, there was not a significantly different opinion between clients and consultants regarding the impact on claims for bridge projects.

Similarly, the top three recommendations out of eight for reducing cost and schedule growth and claims due to geotechnical-related causes were: designer having detailed knowledge of the project site's geotechnical information, detailed site investigation with a well-experienced consultant, and the development and implementation of minimum standards for subsurface investigation and site characterization. The results showed that these recommendations did not exhibit any significant differences with regards to bridge projects for clients. Consultants, however, have rated the designer having detailed knowledge of the project site's geotechnical information and detailed site investigation with a well-experienced consultant more highly than other recommendations; it is significantly higher for bridge projects. The results also indicate that, while further dividing into two separate evaluation criteria, clients significantly preferred the development and implementation of minimum standards for subsurface investigation and site characterization for reducing cost and schedule growth and claims than consultants for bridge projects.

5.2 Road Pavement Projects

Consultants have rated the ASSHTO Manual significantly higher, while clients have produced similar ratings for all three manuals for road pavement projects. Further analysis showed that clients and consultants rated significantly differently for the FHWA and NHI Manuals, whereas both groups rated the AASHTO Manual similarly. Therefore, the results of group comparison between clients and consultants for the use of standard guidelines for design showed that clients and consultants both rated their preference on these design manuals similarly for road pavement projects.

The results showed that the top three rated methods of subsurface investigations for road pavement projects were: the Standard Penetration Test, the Falling Weight Deflectometer Method, and the Geophysical Method. The results also showed that consultants and clients were more favorable to the Standard Penetration Test (SPT) for road pavement projects. This indicates that, while further dividing into two separate evaluation criteria, clients significantly preferred the Falling Weight Deflectometer Method to conduct subsurface investigations than consultants for road pavement projects

Again, the top three geotechnical-related causes of cost growth for road pavement projects were: misclassified or mischaracterized subgrade, a level of groundwater table higher than expected, and design changes in the road pavement. When the top three causes were compared, they did not exhibit a significant difference. When the comparison was made amongst clients and consultants, consultants rated misclassified or mischaracterized subgrade as a cause of cost growth significantly higher than clients for road pavement projects.

The top three geotechnical-related causes of schedule growth and claims rated by clients and consultants for road pavement projects were: misclassified or mischaracterized subgrade, a level of groundwater table higher than expected, and the prescribed soil treatment method unsuitable for particular site conditions. The top three causes of schedule growth and claims did not exhibit any significant differences for both clients and consultants in road pavement projects. Consultants rated misclassified or mischaracterized subgrade as a cause of schedule growth and claims significantly higher than clients for road pavement projects.

Both clients and consultants indicated negative impact due to geotechnical-related causes on cost and schedule growth and claims for road pavement projects. Furthermore, there was a not significant difference in opinion between clients and consultants regarding the impact on cost and schedule growth. However, there was a significantly higher number of consultants who responded that geotechnical-related causes had a negative impact on claims than clients for road pavement projects.

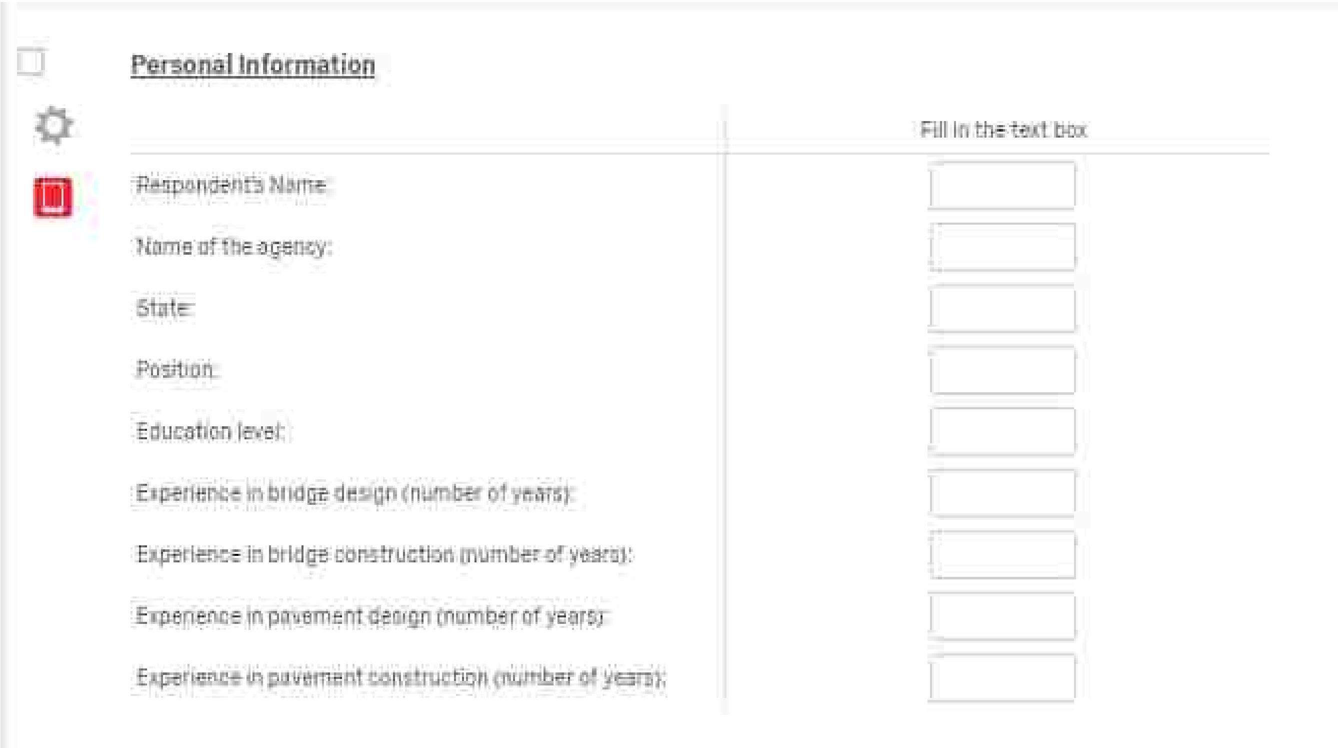
Similarly, the top three recommendations out of eight for reducing cost and schedule growth and claims due to geotechnical-related causes were: designer having detailed knowledge of the project site's geotechnical information, detailed site investigation with a well-experienced consultant, and the development and implementation of minimum standards for subsurface investigation and site characterization. The results showed that these recommendations did not exhibit any significant differences with regards to both bridge projects for clients. Consultants, however, have rated the designer having detailed knowledge of the project site's geotechnical information and a detailed site investigation with a well-experienced consultant more highly than other recommendations; this is significantly higher for bridge projects. The results also indicate that, while further dividing into two separate evaluation criteria, clients significantly preferred the development and implementation of minimum standards for subsurface investigation and site characterization for reducing cost and schedule growth and claims than consultants for bridge projects.

The primary contribution of this study to the existing body of knowledge is the identification of major geotechnical-related causes of cost and schedule growth, change orders, and claims for bridge and road pavement projects. In addition to this, the study also qualitatively quantified the impact of these causes on project performance. The recommendations to reduce the impact of these causes on project performance were also identified.

5.3 Recommendations

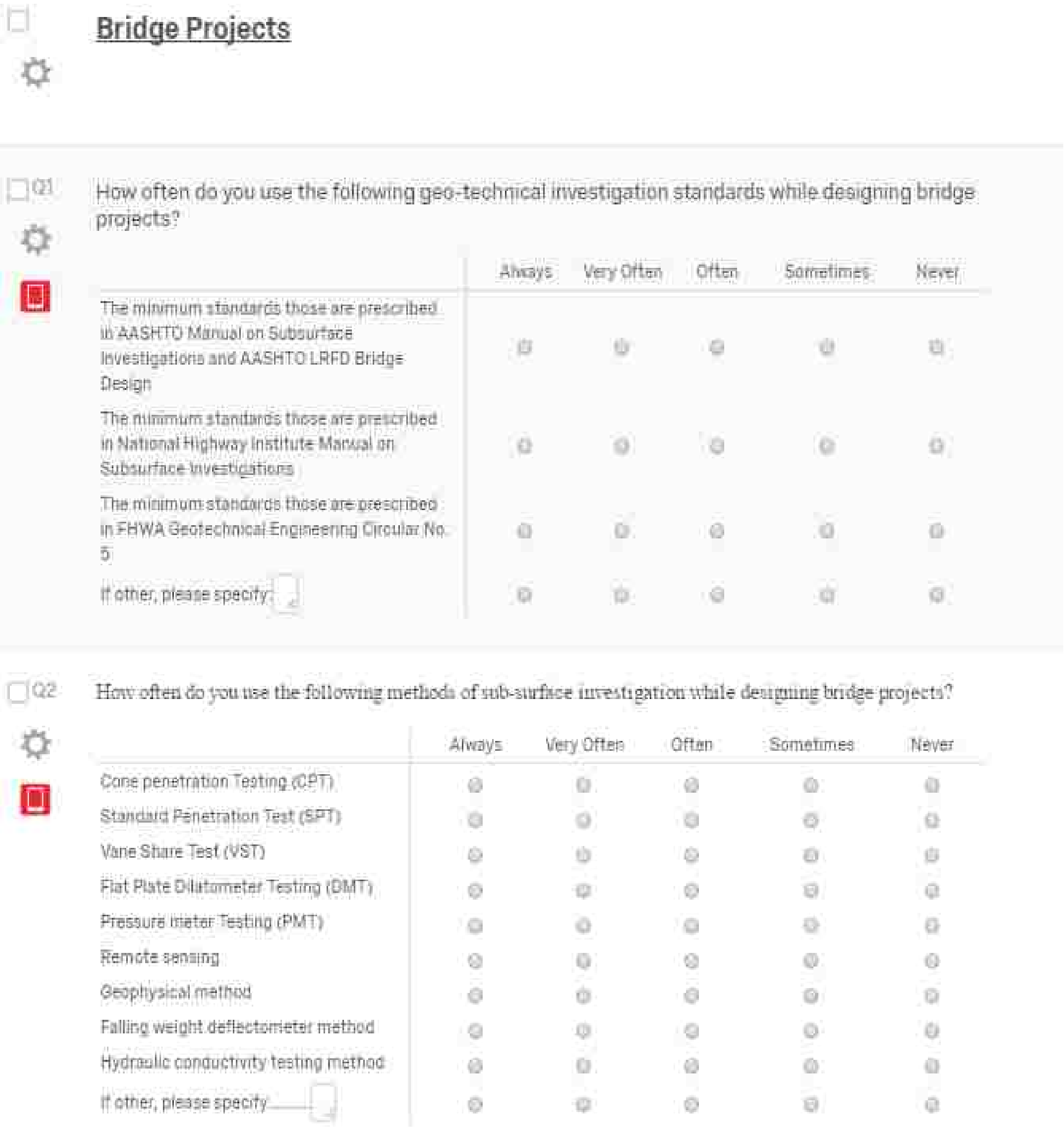
This research presents findings of qualitative information regarding the ranking of geotechnical-related causes of cost and schedule growth, change orders, and claims during the construction of bridge and road pavement projects. Due to the inaccessibility of quantitative data, this study was unable to quantified cost and schedule growth, change orders, and claims due to geotechnical-related causes. Based on this perception study of clients and consultants, it has been determined that geotechnical-related causes had a significant impact on project performance. Therefore, further research should focus on collecting hard project data related to cost and schedule growth, change orders, and claims for bridge and road pavement construction projects due to geotechnical-related causes. Further research, as an extension of this qualitative study, could quantify the amount of cost and schedule growth, change orders, and claims due to various geotechnical-related causes in bridge and road projects. This further study could also identify the correlation between geotechnical-related causes and project performance during the construction phase of bridge and road pavement projects.

APPENDIX A: SURVEY QUESTIONNAIRE



☐ **Personal Information**

	Fill in the text box
Respondent's Name:	
Name of the agency:	
State:	
Position:	
Education level:	
Experience in bridge design (number of years):	
Experience in bridge construction (number of years):	
Experience in pavement design (number of years):	
Experience in pavement construction (number of years):	



☐

Bridge Projects

☐ Q1

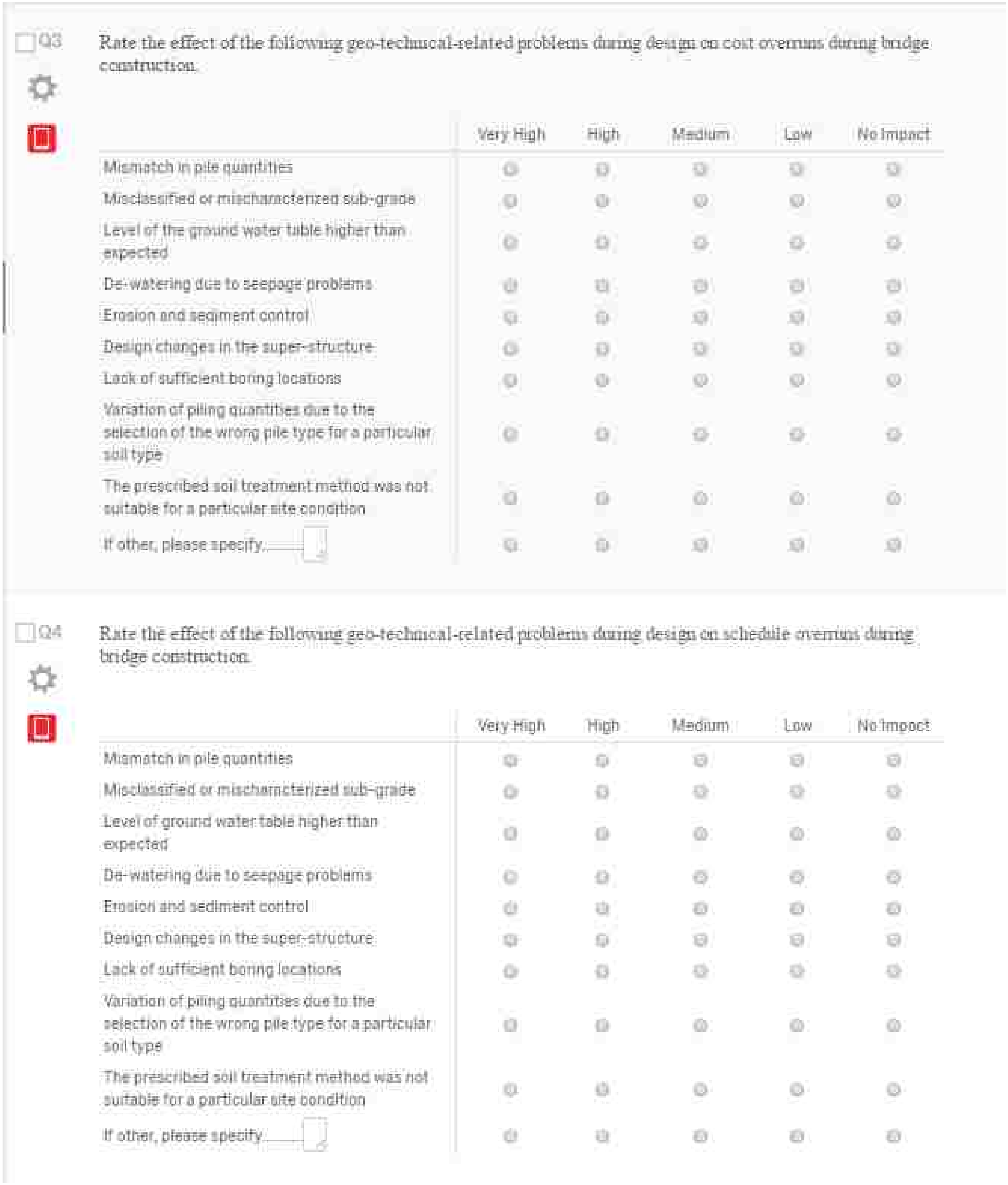
How often do you use the following geo-technical investigation standards while designing bridge projects?

	Always	Very Often	Often	Sometimes	Never
The minimum standards those are prescribed in AASHTO Manual on Subsurface Investigations and AASHTO LRFD Bridge Design	○	○	○	○	○
The minimum standards those are prescribed in National Highway Institute Manual on Subsurface Investigations	○	○	○	○	○
The minimum standards those are prescribed in FHWA Geotechnical Engineering Circular No. 5	○	○	○	○	○
If other, please specify:	○	○	○	○	○

☐ Q2

How often do you use the following methods of sub-surface investigation while designing bridge projects?

	Always	Very Often	Often	Sometimes	Never
Cone penetration Testing (CPT)	○	○	○	○	○
Standard Penetration Test (SPT)	○	○	○	○	○
Vane Share Test (VST)	○	○	○	○	○
Flat Plate Dilatometer Testing (DMT)	○	○	○	○	○
Pressure meter Testing (PMT)	○	○	○	○	○
Remote sensing	○	○	○	○	○
Geophysical method	○	○	○	○	○
Falling weight deflectometer method	○	○	○	○	○
Hydraulic conductivity testing method	○	○	○	○	○
If other, please specify	○	○	○	○	○



☐ Q3

Rate the effect of the following geo-technical-related problems during design on cost overruns during bridge construction.

	Very High	High	Medium	Low	No Impact
Mismatch in pile quantities	○	○	○	○	○
Misclassified or mischaracterized sub-grade	○	○	○	○	○
Level of the ground water table higher than expected	○	○	○	○	○
De-watering due to seepage problems	○	○	○	○	○
Erosion and sediment control	○	○	○	○	○
Design changes in the super-structure	○	○	○	○	○
Lack of sufficient boring locations	○	○	○	○	○
Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	○	○	○	○	○
The prescribed soil treatment method was not suitable for a particular site condition	○	○	○	○	○
If other, please specify........	○	○	○	○	○

☐ Q4

Rate the effect of the following geo-technical-related problems during design on schedule overruns during bridge construction.

	Very High	High	Medium	Low	No Impact
Mismatch in pile quantities	○	○	○	○	○
Misclassified or mischaracterized sub-grade	○	○	○	○	○
Level of ground water table higher than expected	○	○	○	○	○
De-watering due to seepage problems	○	○	○	○	○
Erosion and sediment control	○	○	○	○	○
Design changes in the super-structure	○	○	○	○	○
Lack of sufficient boring locations	○	○	○	○	○
Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	○	○	○	○	○
The prescribed soil treatment method was not suitable for a particular site condition	○	○	○	○	○
If other, please specify........	○	○	○	○	○

Rate the effect of the following geo-technical-related problems during design on bridge construction claims.

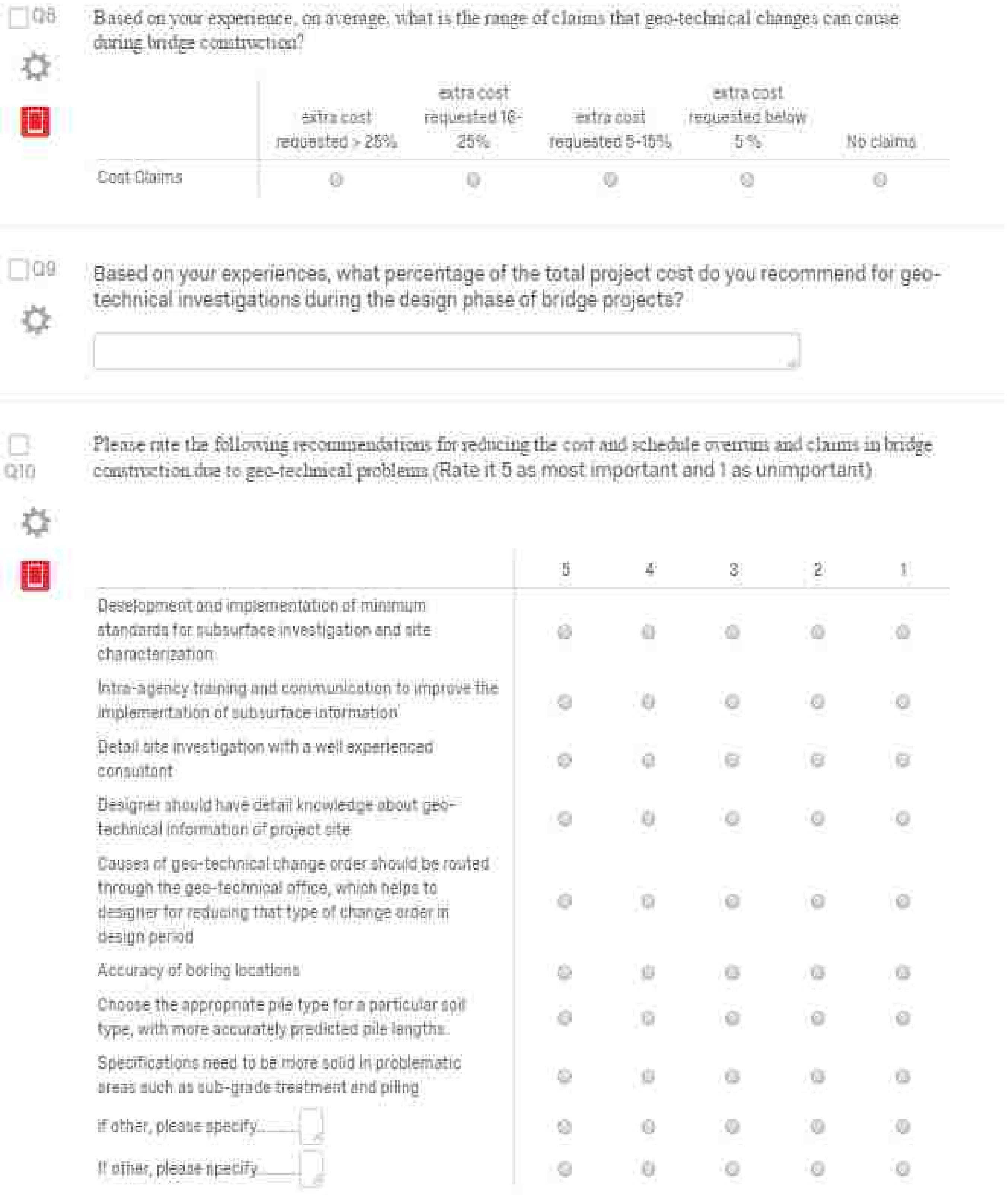
	Very High	High	Medium	Low	No Impact
Mismatch in pile quantities	○	○	○	○	○
Misclassified or mischaracterized sub-grade	○	○	○	○	○
Level of ground water table higher than expected	○	○	○	○	○
De-watering due to seepage problems	○	○	○	○	○
Erosion and sediment control	○	○	○	○	○
Design changes in the super structure	○	○	○	○	○
Lack of sufficient boring locations	○	○	○	○	○
Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	○	○	○	○	○
The prescribed soil treatment method was not suitable for a particular site condition	○	○	○	○	○
Lack of detail specifications in problematic areas, such as sub-grade treatment and piling	○	○	○	○	○
If other, please specify	○	○	○	○	○

Based on your experience, on average, what is the effect of geo-technical changes on the range of cost overruns or being under budget during the construction of bridge projects?

	Overrun budget by > 25%	Overrun budget by 16-25%	Overrun budget by 5-15%	Overrun budget by below 5 %	On budget	Under budget by below 1%	Under budget by 1-5%	Undrer budget by 6-10%	Under budget by > 10%
Cost Performance	○	○	○	○	○	○	○	○	○

Based on your experience, on average, what is effect of geo-technical changes on the range of being behind or ahead of schedule during the construction of bridge projects?

	Behind schedule by > 25%	Behind schedule by 16-25%	Behind schedule by 5-15%	Behind schedule by below 5 %	On schedule	Ahead of schedule by below 1%	Ahead of schedule by 1-5%	Ahead of schedule by 6-10%	Ahead of schedule by > 10%
Schedule Performance	○	○	○	○	○	○	○	○	○



☐ Q8

Based on your experience, on average, what is the range of claims that geo-technical changes can cause during bridge construction?

	extra cost requested > 25%	extra cost requested 16-25%	extra cost requested 5-15%	extra cost requested below 5 %	No claims
Cost Claims	○	○	○	○	○

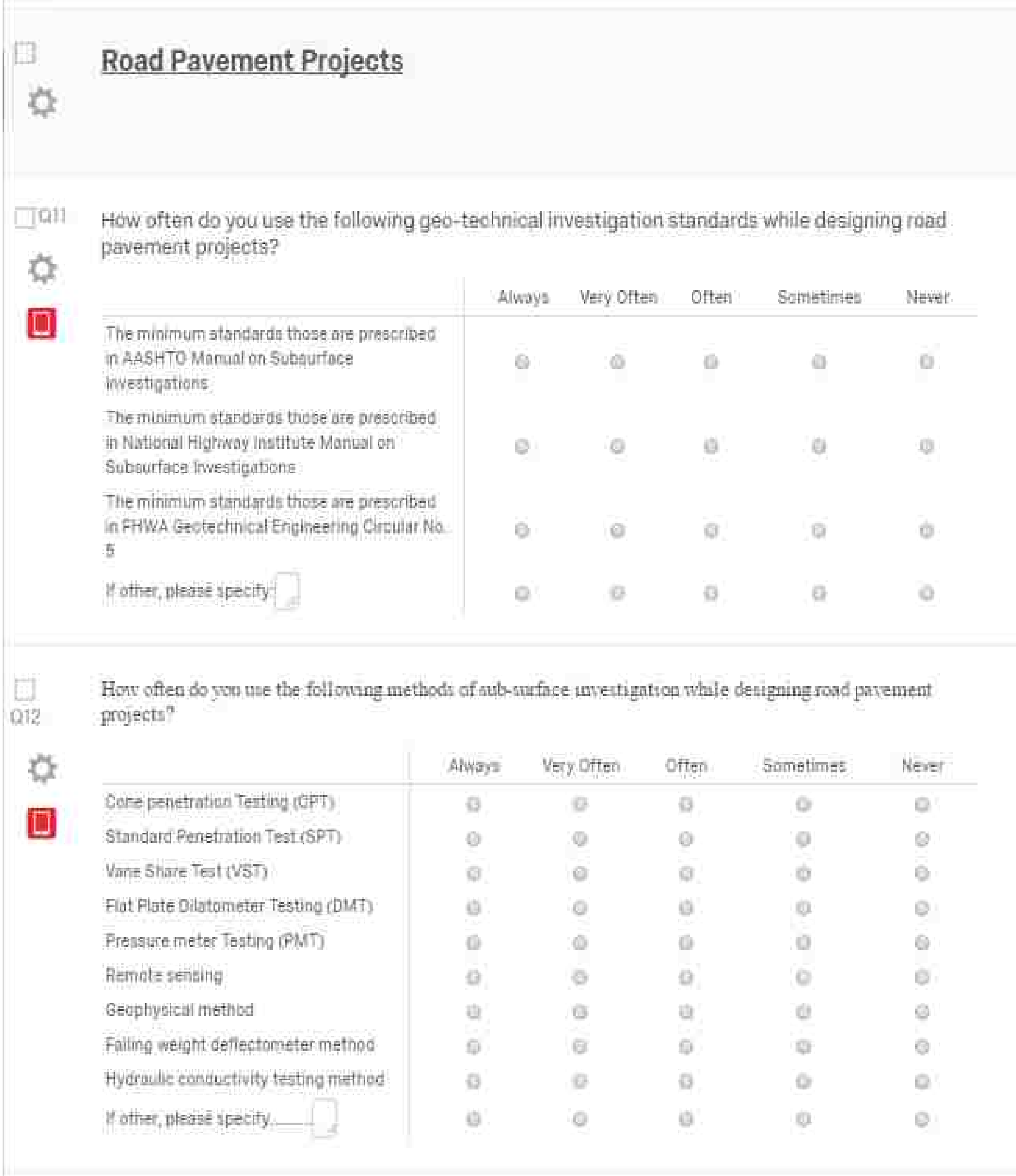
☐ Q9

Based on your experiences, what percentage of the total project cost do you recommend for geo-technical investigations during the design phase of bridge projects?

☐ Q10

Please rate the following recommendations for reducing the cost and schedule overruns and claims in bridge construction due to geo-technical problems (Rate it 5 as most important and 1 as unimportant)

	5	4	3	2	1
Development and implementation of minimum standards for subsurface investigation and site characterization	○	○	○	○	○
Intra-agency training and communication to improve the implementation of subsurface information	○	○	○	○	○
Detail site investigation with a well experienced consultant	○	○	○	○	○
Designer should have detail knowledge about geo-technical information of project site	○	○	○	○	○
Causes of geo-technical change order should be routed through the geo-technical office, which helps to designer for reducing that type of change order in design period	○	○	○	○	○
Accuracy of boring locations	○	○	○	○	○
Choose the appropriate pile type for a particular soil type, with more accurately predicted pile lengths.	○	○	○	○	○
Specifications need to be more solid in problematic areas such as sub-grade treatment and piling	○	○	○	○	○
If other, please specify..........	○	○	○	○	○
If other, please specify..........	○	○	○	○	○



Road Pavement Projects

Q11

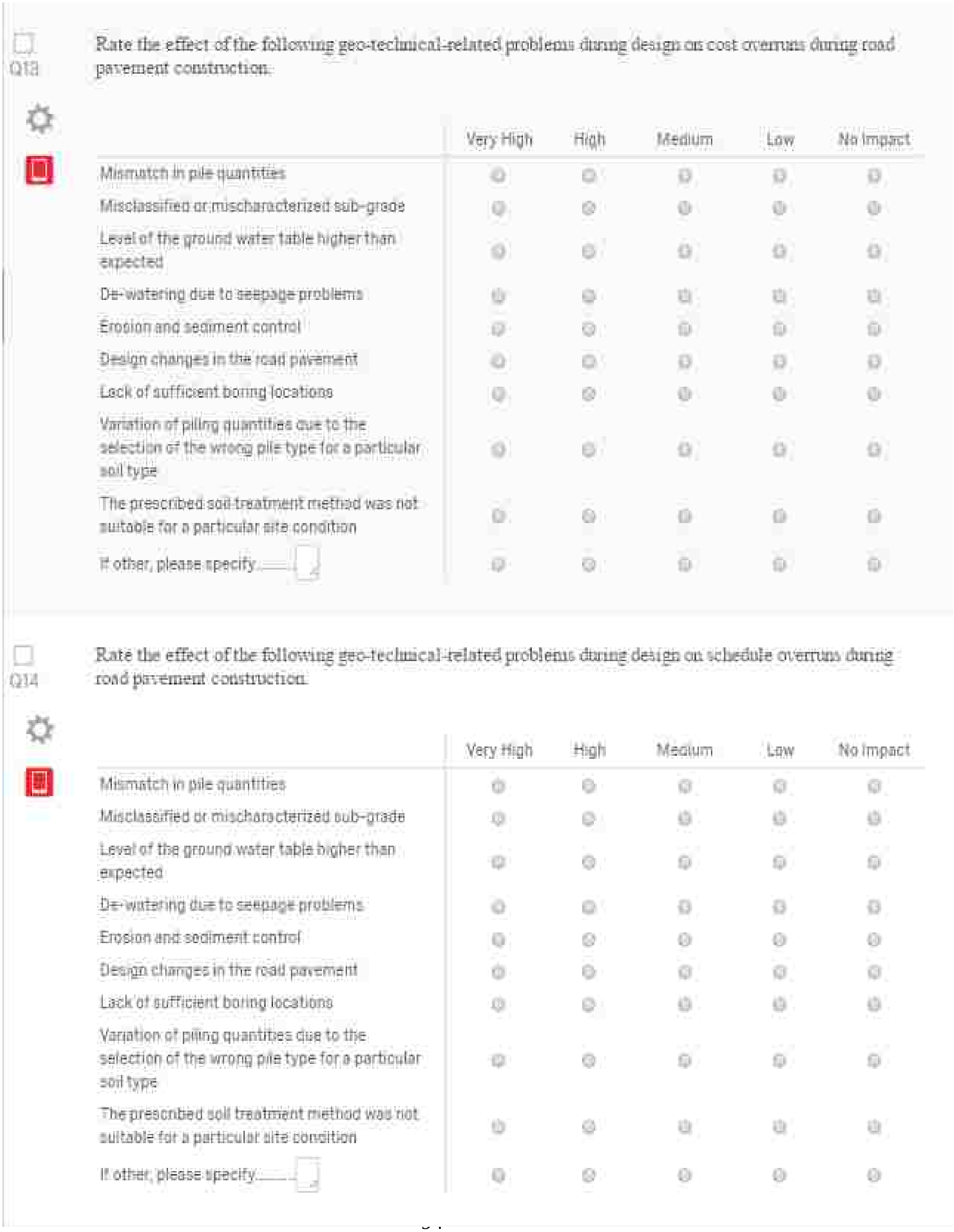
How often do you use the following geo-technical investigation standards while designing road pavement projects?

	Always	Very Often	Often	Sometimes	Never
The minimum standards those are prescribed in AASHTO Manual on Subsurface Investigations	○	○	○	○	○
The minimum standards those are prescribed in National Highway Institute Manual on Subsurface Investigations	○	○	○	○	○
The minimum standards those are prescribed in FHWA Geotechnical Engineering Circular No 5	○	○	○	○	○
If other, please specify ☐	○	○	○	○	○

Q12

How often do you use the following methods of sub-surface investigation while designing road pavement projects?

	Always	Very Often	Often	Sometimes	Never
Cone penetration Testing (CPT)	○	○	○	○	○
Standard Penetration Test (SPT)	○	○	○	○	○
Vane Share Test (VST)	○	○	○	○	○
Flat Plate Dilatometer Testing (DMT)	○	○	○	○	○
Pressure meter Testing (PMT)	○	○	○	○	○
Remote sensing	○	○	○	○	○
Geophysical method	○	○	○	○	○
Falling weight deflectometer method	○	○	○	○	○
Hydraulic conductivity testing method	○	○	○	○	○
If other, please specify......... ☐	○	○	○	○	○



☐
Q13

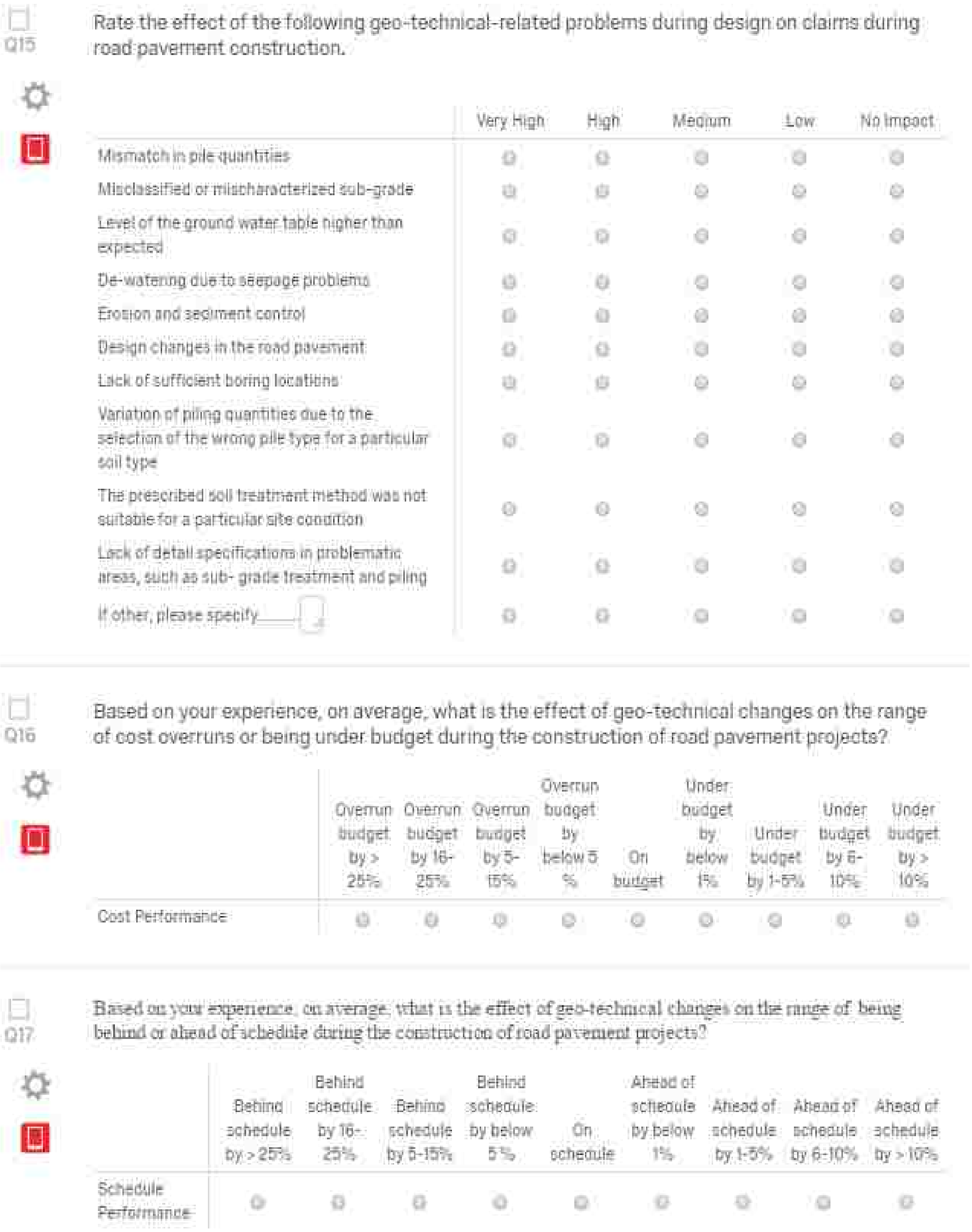
Rate the effect of the following geo-technical-related problems during design on cost overruns during road pavement construction.

	Very High	High	Medium	Low	No Impact
Mismatch in pile quantities	○	○	○	○	○
Misclassified or mischaracterized sub-grade	○	○	○	○	○
Level of the ground water table higher than expected	○	○	○	○	○
De-watering due to seepage problems	○	○	○	○	○
Erosion and sediment control	○	○	○	○	○
Design changes in the road pavement	○	○	○	○	○
Lack of sufficient boring locations	○	○	○	○	○
Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	○	○	○	○	○
The prescribed soil treatment method was not suitable for a particular site condition	○	○	○	○	○
If other, please specify........	○	○	○	○	○

☐
Q14

Rate the effect of the following geo-technical-related problems during design on schedule overruns during road pavement construction.

	Very High	High	Medium	Low	No Impact
Mismatch in pile quantities	○	○	○	○	○
Misclassified or mischaracterized sub-grade	○	○	○	○	○
Level of the ground water table higher than expected	○	○	○	○	○
De-watering due to seepage problems	○	○	○	○	○
Erosion and sediment control	○	○	○	○	○
Design changes in the road pavement	○	○	○	○	○
Lack of sufficient boring locations	○	○	○	○	○
Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	○	○	○	○	○
The prescribed soil treatment method was not suitable for a particular site condition	○	○	○	○	○
If other, please specify........	○	○	○	○	○



☐ Q15

Rate the effect of the following geo-technical-related problems during design on claims during road pavement construction.

	Very High	High	Medium	Low	No Impact
Mismatch in pile quantities	○	○	○	○	○
Misclassified or mischaracterized sub-grade	○	○	○	○	○
Level of the ground water table higher than expected	○	○	○	○	○
De-watering due to seepage problems	○	○	○	○	○
Erosion and sediment control	○	○	○	○	○
Design changes in the road pavement	○	○	○	○	○
Lack of sufficient boring locations	○	○	○	○	○
Variation of piling quantities due to the selection of the wrong pile type for a particular soil type	○	○	○	○	○
The prescribed soil treatment method was not suitable for a particular site condition	○	○	○	○	○
Lack of detail specifications in problematic areas, such as sub- grade treatment and piling	○	○	○	○	○
If other, please specify_____	○	○	○	○	○

☐ Q16

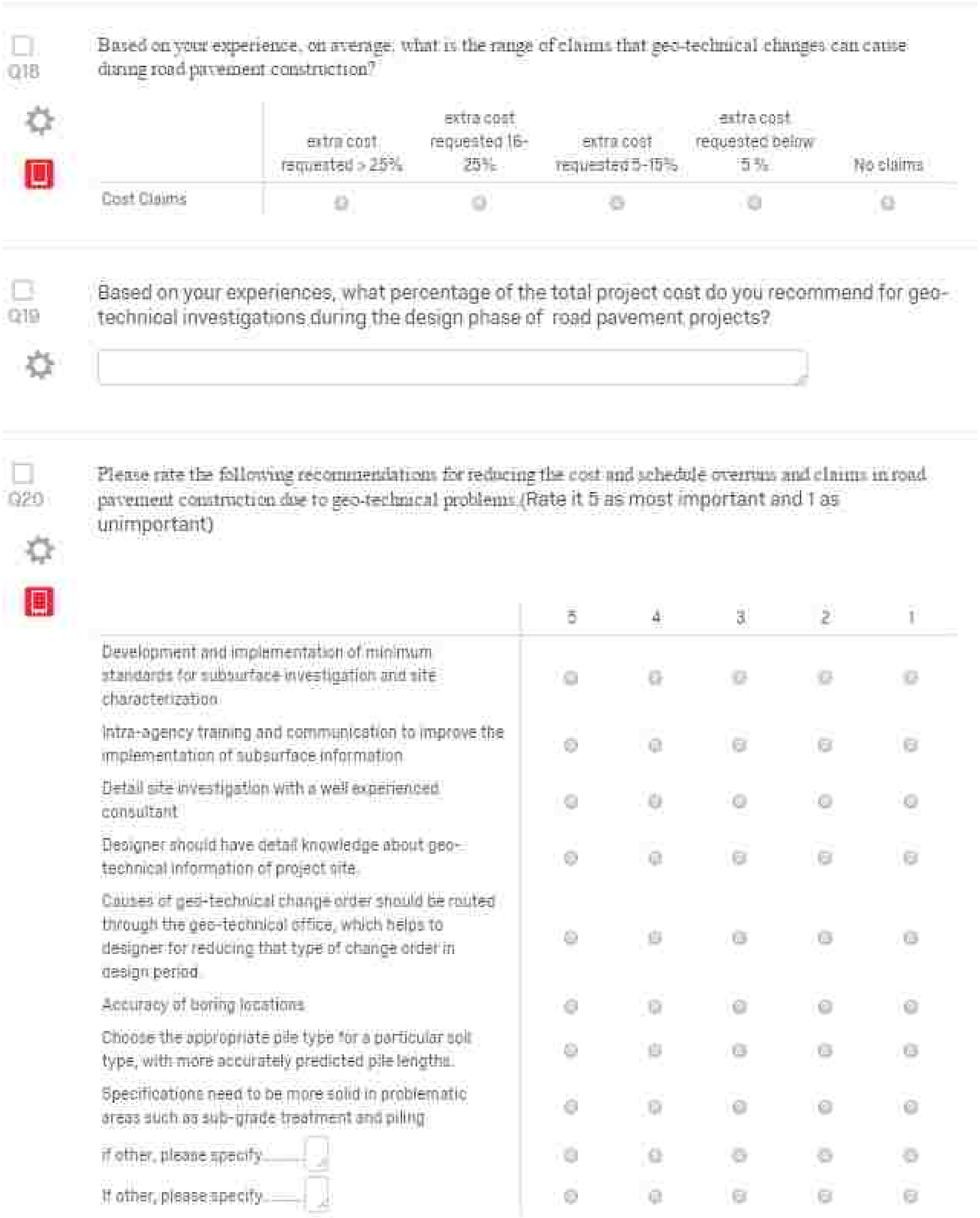
Based on your experience, on average, what is the effect of geo-technical changes on the range of cost overruns or being under budget during the construction of road pavement projects?

	Overrun budget by > 25%	Overrun budget by 16-25%	Overrun budget by 5-15%	Overrun budget by below 5 %	On budget	Under budget by below 1%	Under budget by 1-5%	Under budget by 6-10%	Under budget by > 10%
Cost Performance	○	○	○	○	○	○	○	○	○

☐ Q17

Based on your experience, on average, what is the effect of geo-technical changes on the range of being behind or ahead of schedule during the construction of road pavement projects?

	Behind schedule by > 25%	Behind schedule by 16-25%	Behind schedule by 5-15%	Behind schedule by below 5 %	On schedule	Ahead of schedule by below 1%	Ahead of schedule by 1-5%	Ahead of schedule by 6-10%	Ahead of schedule by > 10%
Schedule Performance	○	○	○	○	○	○	○	○	○



☐ Q18

Based on your experience, on average, what is the range of claims that geo-technical changes can cause during road pavement construction?

	extra cost requested > 25%	extra cost requested 16-25%	extra cost requested 5-15%	extra cost requested below 5 %	No claims
Cost Claims	○	○	○	○	○

☐ Q19

Based on your experiences, what percentage of the total project cost do you recommend for geo-technical investigations during the design phase of road pavement projects?

☐ Q20

Please rate the following recommendations for reducing the cost and schedule overruns and claims in road pavement construction due to geo-technical problems.(Rate it 5 as most important and 1 as unimportant)

	5	4	3	2	1
Development and implementation of minimum standards for subsurface investigation and site characterization	○	○	○	○	○
Intra-agency training and communication to improve the implementation of subsurface information	○	○	○	○	○
Detail site investigation with a well experienced consultant	○	○	○	○	○
Designer should have detail knowledge about geo-technical information of project site.	○	○	○	○	○
Causes of geo-technical change order should be routed through the geo-technical office, which helps to designer for reducing that type of change order in design period.	○	○	○	○	○
Accuracy of boring locations	○	○	○	○	○
Choose the appropriate pile type for a particular soil type, with more accurately predicted pile lengths.	○	○	○	○	○
Specifications need to be more solid in problematic areas such as sub-grade treatment and piling	○	○	○	○	○
If other, please specify........	○	○	○	○	○
If other, please specify........	○	○	○	○	○

APPENDIX B: SOFTWARE REQUIREMENTS

The following software were used for this study:

1) Microsoft Excel
2) Microsoft Word
3) IBM SPSS Statistic (Version 22)

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